

PB 273 051

DEVELOPMENT OF EMERGENCY
ESCAPE SYSTEMS GUIDELINES
FOR UNDERGROUND METAL AND
NONMETAL MINES

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

Bureau of Mines Open File Report 134-77

by

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FINAL REPORT

on

Contract No. J0255017

Development of Emergency Escape Systems Guidelines
for Underground Metal and Nonmetal Mines

May 1976

REPRODUCED BY
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SPRINGFIELD, VA. 22161

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FORWARD

This report was prepared by Foster-Miller Associates, Inc., Waltham, Massachusetts under USBM Contract Number J0255017. The contract was initiated under the Metal and Nonmetal Health and Safety Research Program. It was administered under the technical direction of SMRC with Mr. D. E. Nicholson acting as the Technical Project Officer. Mr. B. G. Horton was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period April 1975 to May 1976. This report was submitted by the authors on 28 May 1976.

SUMMARY AND CONCLUSIONS

This report describes a study to develop a detailed set of guidelines and equipment recommendations to be used as a guide for mine operators, mine inspectors, and equipment manufacturers in implementing the emergency escapeway standards for metal and nonmetal underground mines. It was sponsored by the United States Bureau of Mines.

The first part of this report reviews the historical background of metal and nonmetal mine fires and the development of present and proposed mandatory standards. This is followed by a discussion of the survey of representative mines and how the proposed standard affects these mines. The remainder of the report covers technical discussions of each escapeway component including a comprehensive computer simulation of mine evacuation. Following the technical discussion of each group of escapeway components is a list of the pertinent guidelines.

A study of past mine fires indicates that a serious commitment by operators to the proposed escape standards would be instrumental in saving lives in the future. The most significant event in a recent mine fire, in which no deaths resulted, was the very early discovery of the fire. The evacuation was orderly thanks to careful preparation by the mine personnel. However, the mine was possibly only spared a real disaster because of the discovery of the fire almost at its inception. Installation of automatic fire and smoke warning devices may be the single most important step in preventing future disasters.

The self-rescuer has saved many lives in mine fires. Men have also died while attempting to use them. The reason men died was either because the unit was not working or the miner did not understand how or when to use it. There is no good excuse for either of these conditions occurring. Regular maintenance and inspection should prevent unit failures. Frequent instruction on when and how to use the self-rescuer would prevent confusion and potential fatalities. A means of

detecting and measuring carbon-monoxide should be made available to all miners so that the breathing units will be used when required.

The self-rescuer or improvements thereof such as oxygen breathing units are, and probably always will be, the most important means of saving lives when mine fires contaminate the air. Regardless of what rules have been imposed on a mine, the ventilation controls installed or other safety measures taken, the possibility of smoke and carbon-monoxide being liberated into the mine atmosphere still exists. The provision for personnel breathing apparatus and the training in its use cannot be overemphasized.

The survey of representative mines and M.E.S.A. field offices revealed that the mines will have great difficulty complying with certain sections of the proposed standards. The clause referring to environmental damage to one escapeway not effecting the other escapeway, if strictly enforced, would shut down many mines. Mines with large stoppings have considerable recirculation. Leaks as small as 4 percent of the air flow through the stoppings (most have considerably more) can contain enough carbon-monoxide during a fire to create a lethal mixture in the alternate escapeway. Leak proof large stoppings are not possible in the current state-of-the-art. Enforcement of this clause would be very difficult since equipment to measure small leaks is also beyond the state-of-the-art. Use of effective personnel breathing apparatus is the only sure method of ensuring breathable air during a fire.

The 45 minute time limit for evacuation is easy to meet in some mines while other mines, especially deep mines, may not be able to comply. An alternate and possibly quite reasonable interpretation of this could be: 45 minutes to a fresh air base. (see Section 3.6.1) Most mines could comply with this interpretation without jeopardizing the lives of the miners.

The provision that escapeways must extend to within 1000 feet horizontally and 300 vertically of a working place does not treat each situation equally. The intent of the rule is to provide some maximum allowable condition which ultimately relates to time required to reach a point where there are two separate means of escape. A formula is presented which meets this intent, but allows for all combinations of horizontal and vertical (ascending or descending) distances.

The condition of secondary escapeways was found lacking in some cases. To provide a safe escapeway the secondary route should be maintained in the original mined condition.

Fire retardants for timbered shafts are discussed. There are two types, impregnation of various salt solutions or coating with fire resistant paints. Fire retardants can have a remarkable effect in preventing the spread of a fire. Fire retardants are only effective, however, when complete coverage of the wood is attained. This makes treatment of existing mines only partially beneficial. New mines or new sections of mines of course can be treated during construction with very good results.

Warning systems used to notify miners of an evacuation are not effective in many mines. Stench in the compressed air and/or ventilation air often moves too slowly and becomes diluted. Phone systems are best if they can be made redundant so that at least one set of lines can be expected to be in working order following a fire or other disaster.

Escapeway signs are different in almost every mine. Likewise, hoisting bell signals vary from mine to mine. Standard signs and signals are recommended for the mining industry.

The computer analysis of mine evacuation shows that the mine transportation and haulage system can be very effective in minimizing escape times. Most transportation vehicles only require the addition of oxygen breathing equipment for the operator to drive the vehicles through smoke for the required number of trips to evacuate all the miners.

Storage of fuel underground is a potentially dangerous procedure. With proper valving, surface storage with fuel lines to the working levels is a safer means of distributing fuel oil. Guidelines are provided for both methods.

A computer program was written to simulate a mine evacuation under a large variety of conditions. A specific mine was used for the model presented and the results are compared with a fire drill conducted at this mine. The program analyzes the transient conditions of smoke, miner and hoist movements and predicts escape time and smoke exposure of each miner. The program can be adapted to any mine and is particularly suited for analyzing various escape strategies to determine potential problems and to estimate escape times under drill or fire conditions. The program assumes ventilation flow patterns to be unchanged by the fire. Prediction of ventilation changes under random fire conditions may not be possible.

Emergency hoists are evaluated and a substantial list of suppliers is presented. The hoists discussed are for emergency escape use and should be simple and dependable. The power for the emergency hoist should be independent of all other mine equipment so that only a fire or accident in the immediate vicinity of the hoist could make it inoperative.

Refuge chambers can be used in two ways.

- a) Long term permanent use - to provide a life supporting environment for the time it takes to be reached by rescue teams when escape is blocked due to cave-ins or fire.
- b) Short term temporary use - to provide temporary refuge and a supply of portable breathing units to enable miners to escape through a toxic atmosphere.

Three basic types of chambers can be identified.

Type 1 - Outside air supply (borehole or dual compressed air)

Type 2 - Internal oxygen supply and air purification equipment

Type 3 - No outside air supply, oxygen source, or purification equipment.

All chambers, regardless of how well built and sealed, will leak to some degree. This leakage must be taken into account in the design of the chamber.

Type 1 chambers are the most desirable, since this approach is the simplest way to guarantee a life supporting environment. Due to large distances from the surface which frequently occur in metal/non-metal mines this approach is not always feasible.

Type 2 chambers are a possible alternative. However, the hardware for their implementation (particularly the removal of CO) has not been fully developed and tested, and some additional research and development effort would be required before such a chamber could be specified.⁽¹⁾

Type 3 chambers have limited applicability. It is difficult to conceive of any method which can guarantee a life supporting atmosphere in such a chamber for more than 24 hours. This limitation must be considered in terms of the potential applicability of the chamber.

Therefore, a meaningful refuge chamber requirement promulgated at this time would require each chamber to have either a borehole to the surface or two independent compressed air lines to the surface.

Some areas touched on in this report require further in-depth study and development before implementation could be required. A list of the most important subjects follows:

- 1) The automatic fire and smoke warning systems, when perfected, will largely increase the chances of a safe evacuation. (See reference 14 for current work on this subject.)

- 2) Improved communication for control of evacuation.
A specific scheme might be a low frequency signal generator and a receiver powered by a lamp battery.
- 3) A carbon monoxide filtration system suitable for refuge chamber use.
- 4) Recommended fire resistant treatment and tougher rules requiring the use of fire resistant materials in mines.
- 5) A means of preventing "environmental damage" between escapeways.
- 6) Improved visual inspection method for self-rescuer units.

Positive developments in the above list of topics would undoubtedly contribute toward increased safety of the mines in the future.

Due to the difficulties in complying with all of the proposed standards at this time, especially the "environmental damage" clause and refuge chambers in some mines, it is recommended that efforts be increased to improve self-rescue equipment for escape in contaminated air. As development progresses in the area of ventilation stoppings for escapeways and refuge chambers, enforcement of these standards can occur. The standards as written should not be static, continual upgrading should be undertaken as our knowledge and technology improve.

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1. Introduction

This report is submitted in fulfillment of the requirements of USBM Contract No. J0255017, "Development of Emergency Escape Systems Guidelines for Underground Metal and Nonmetal Mines". Under this contract the history of past mine fires was studied. Representative metal and nonmetal mines were surveyed and escapeways, refuge chambers, life support, and emergency hoist requirements were studied to determine the problems in complying with the proposed regulatory standards and their enforcement by MESA Mine Inspectors. In addition, a computer program was written to evaluate mine evacuation performance. The completed program is included in the appendix.

1.1 Historical Review of Metal and Nonmetal Mine Fires

Early records of mine fires are poorly documented because there was no statutory provision for reporting fires to the Bureau of Mines. The survey of representative mines during the course of this contract indicated that many small fires still go unreported even though they are now required to report all fires. A recent report survey approximately 80 disasters in metal and nonmetal mines.⁽⁶⁾ Table I is a summary of some of these fires. Historically most metal and nonmetal mine fires have been caused by electrical problems. Spontaneous combustion and the use of welding equipment are the other major causes of mine fires⁽¹⁴⁾. Although not documented, many mine personnel agree that 30 percent to 40 percent of underground metal and nonmetal mine fires have their origin from cigarettes and other smoking related materials. The number of fires related to spontaneous combustion is decreasing and equipment fires are on the increase. The reduction of spontaneous combustion fires can be attributed to the use of sandfill in more mines and the increase in equipment fires to the increased use of LHD equipment.

TABLE I - SUMMARY OF MINE FIRE FATALITIES IN U. S.
METAL/NON-METAL MINES*

Date	Fatalities	Name	Location	Description of Disaster
8 June '17	163	Granite	MONT.	Fire (Shaft)
27 Aug. '22	47	Argonaut	CALF.	Fire (Shaft)
24 Nov. '27	7	Magma	ARIZ.	Fire (Shaft)
1 June '59	6	Sherwood	MICH.	Inrush of hot gas and steam
14 Nov. '60	1 (boy)	Pere	ILL.	Fire in storage materials in abandoned mine
27 Aug. '63	18	Cane Creek	UTAH	Gas explosion
8 July '64	1	Climax	COL.	Fire and Explosion
5 Mar. '68	21	Belle Isle	LA.	Fire (Shaft)
20 Jan. '70	2	Star	IDAHO	Fire in vent tube (welding)
2 May '72	91	Sunshine	IDAHO	Fire
25 Aug. '73	2	Lakeshore	ARIZ.	Muck slide and fire
9 May '75	0	Homestake	S. DAK.	Fire - spontaneous combustion

*Taken in part from "Rescue Shelter Analysis for Metal/Nonmetal Mines" Pittsburgh Technical Support Center by Ward, D. C.; Dalzell, R. W.; Nagy, J.; Kloos, E. J.; Myers, C. H. and Harris, E. J.

The introduction of the self-rescuer has been instrumental in saving many lives, however, there have been cases where presumeably good units have not worked or the individual did not know how to use it causing a fatality.

Improvements in warning systems and mandatory evacuation drills have been responsible for saving many lives. The Homestake fire in May, 1975 resulted in complete evacuation without loss of life⁽¹⁶⁾. The successful evacuation was due to some conscientious planning by this mine, the effective use of the phone system, and the good fortune on the early discovery of the fire. Even though no lives were lost, a very serious situation existed and it may have been only luck which prevented loss of life.

A significant amount of time was lost in notification of the danger after the fire was discovered. Evacuation was started 46 minutes after the initial discovery. Fifteen minutes were wasted trying to operate a disconnected fire hydrant. Twenty-two minutes were spent by the men travelling to the nearest phone and there was a nine minute gap between the time the men who discovered the fire called the mine superintendent and the first evacuation calls were made to the mine personnel. Stench was not used for eight more minutes after the evacuation was started.

This delay could have been disasterous if the fire had developed to a greater extent prior to being discovered. It took fully 2 1/2 hours from the time of the initial fire discovery until all were evacuated (not counting two men who did not get notified nor did not smell the stench and were brought out later unharmed).

The referenced MESA report⁽¹⁶⁾ tabulates the times etc., as discussed above, but does not emphasize the seriousness of the delays. The situation had the potential of being one of the country's worst disasters, but because no lives were lost, no issue was made over the lengthy and unnecessary warning delays.

Past history of mine disasters can be summed up in the following quote, from Robert Barrett in MESA Magazine, April 1976.

"Hard-rock mines are reaping the positive effects of the Sunshine disaster - increased safety legislation on their behalf. That disaster was responsible for many mandatory standards as well as increased inspections There is much to learn from the past, for those who do not learn from the past are condemned to relive their mistakes."

1.2 Development of Present and Proposed Mandatory Standards

The accident and disaster record of the metal and nonmetal mines was recognized at the Federal level in 1961 when Congress passed Public Law 87-300. This law authorized and directed the Secretary of the Interior to study health and safety conditions in noncoal mines, the causes and means to prevent injuries and other health hazards. This study by the Secretary of the Interior resulted in a report to Congress with recommendations for legislation pertaining to health and safety in metal and nonmetal mines. Public Law 89-577, The Federal Metal and Nonmetal Mine Safety Act, was passed in 1966 as a result of the report to Congress. This law gave the Secretary of the Interior authority to promulgate health and safety standards "for the purpose of the protection of life, the promotion of health and safety, and the prevention of accidents in "mines for minerals other than coal or lignite. Those standards dealing with conditions or practices which reasonable could be expected to cause death or serious injury are mandatory. Others are advisory standards. The Secretary or his authorized representatives is given authority to inspect any mine subject to the chapter to determine if the regulations are being met. The proposed mandatory and advisory standards were published in their entirety in the Federal Register, Vol. 35, No. 11, Jan 16, 1969. After review and publication in the Federal Register, most of the standards were adopted and became effective July 31, 1970. Additional rules were adopted and published in the Federal Register on Feb. 25, 1970 which became effective Feb. 25 1971.

The following paragraphs review the chronologic steps that take us to the current standards.

On February 25, 1970, the following mandatory standard was promulgated:

57.11-50 Mandatory Every mine shall have two separate properly maintained escapeways to the surface which are so positioned that damage to one shall not lessen the effectiveness of the other, or a method of refuge shall be provided when only one opening to the surface is possible.

This standard left room for debate over what was "possible"; quite obviously, two separate escapeways were not required in all cases, even when the mine was in full production. To solve these problems, a revision was published on June 24, 1970, as proposed rule making:

57.11-50 Mandatory Every mine shall have two separate properly maintained escapeways to the surface which are so positioned that damage to one shall not lessen the effectiveness of the other.

This revision clearly required two independent escapeways in all cases, which in turn prompted a further revision, published on December 17, 1971, as proposed rule making:

57.11-50 Mandatory Every mine shall have two separate properly maintained escapeways to the surface which are so positioned that damage to one shall not lessen the effectiveness of the other. A method of refuge shall be provided while a second opening to the surface is being developed.

In July of 1972, the Federal Metal and Nonmetal Mine Safety Advisory Committee recommended promulgation of this standard (the 12/17/71 revision). However, the recommendation of the Director's Review Panel was not to promulgate the 12/17/71 revision but to retain the standard promulgated 12/24/70. On April 27, 1973, MESA distributed an interpretation of the existing standard, as follows:

"Two separate escapeways to the surface" shall mean that there shall be two entirely independent escape routes including levels, drifts, cross-cuts, raises, and shafts from each working area of a mine to the surface.

Working areas are the places where men are actively engaged in mining work (or work related activities) other than raises, shaft or drift development. A work area may be a group of working places but common to each other.

"Properly maintained" means that all standards for safe travelways shall be adhered to.

"Two escapeways--which are so positioned that damage to one shall not lessen the effectiveness of the other" means that any damage to one escape route shall have no effect on the other route. This will include all possible damage such as fire, explosion, or mechanical failure. If damage by fire would contaminate the other escape route, provision must be made to isolate one route from the other.

"A method of refuge shall be provided when only one opening to the surface is possible" means that a refuge chamber shall be provided until a mine goes into production stage of operation, at which time two separate escapeways shall be required; work toward establishment of a second escapeway shall commence immediately. The production stage is when the mine begins to produce ore other than development ore. A refuge chamber shall also be provided at all new areas within a mine where a second escape is not possible, and shall be permitted as an alternative only until the second escapeway becomes possible and during its construction. Construction of the second escapeway shall commence immediately and shall proceed simultaneously with other development work. As an example, this will apply to such cases as new level development from a shaft after the shaft station has been completed.

Boreholes are acceptable escape routes but hoist and conveyance must be on the property and operational.

To summarize, it is standard 57.11-50, as originally promulgated 12/24/70, together with the application note just quoted, which is the current law on escapeways by which all underground U. S. metal/nonmetal mines must abide.

In December of 1973, MESA drafted a new, more comprehensive revision of 57.11-50, which was subsequently submitted to the Advisory Committee for evaluation. This revision is as follows:

Suggested Revision of Mandatory Standard 57.11-50

57.11-50 (a) Except as provided in subparagraph 8 of this paragraph:

1. Each mine shall have at least two separate and properly maintained escapeways from each working place to the surface which are so positioned that physical or environmental damage to one will not lessen the effectiveness of the other, and which meet the requirements of travelways and man hoisting standards. These escapeways shall reach to within 1000 feet horizontally or 300 feet vertically of each working place.*

2. In mine accessed by vertical or inclined shafts, raises, or winzes, more than 300 feet in vertical extent, hoisting facilities shall be provided in escapeways.**

3. When levels are driven from the shaft, a refuge chamber shall be constructed at the shaft station before development exceeds 300 feet in horizontal distance.

* Subparagraph 1 has been amended by the advisory committee to stipulate that if men cannot reach the surface from a working place in one hour then a refuge chamber must be within 1/2 hour of that working place. For the purposes of this report, the original subparagraph will be used - not this recent ammendment.

** Subparagraph 2 has been approved by the Advisory Committee.

4. Horizontal openings either from the surface or from existing mine openings shall not be advanced more than 1000 feet from a set of escapeways.

5. At least one of the escapeways shall be on intake air and separated from the other escapeway by solid ground, fire doors, bulkheads or ventilation control doors to prevent environmental damage of the escapeway if fire, smoke or combustion gases make the other escapeway impassable.

6. Exit from the mine shall be possible from any working place within 45 minutes when travelling in normal mine air.

7. In mines accessed by vertical or inclined shafts, raises, or winzes, a suitable refuge chamber should be provided at each shaft station. These chambers may be utilized for other purposes providing that material stored in the chamber does not restrict access or reduce the volume of contained respirable air to an unacceptable quantity.

8. The District Manager of the district in which a mine is located may approve exceptions to the requirements of subparagraphs 1 through 7 of this paragraph in mines where fire, inundation, or other entrapment hazards are minimal and only one escape route is available and refuge chambers are provided if the operator can satisfy the District Manager that such escape route and escape facilities will enable miners to escape quickly and safely to the surface in the event of an emergency.

57.11-50 (b) The operator shall, within 90 days from promulgation of this standard, submit to the District Manager for the district in which the mine is located for approval a plan containing descriptions, maps, and diagrams accurately describing and depicting the escapeways and escape facilities from each working place. Such plan shall be updated by the operator as necessary and each revision

shall be submitted to the District Manager for approval. Each escapeway shall be inspected and escape facilities shall be tested frequently by competent persons, and properly maintained by the operator to insure that all persons, including disabled persons are properly protected or safely evacuated in the event of an emergency. The plan shall include the following:

1. An up-to-date mine map at a scale of not less than 1" - 300' showing:
 - a. All mine openings (drifts, raises, shafts, and cross-cuts, etc.), working areas, and all boreholes open to the surface.
 - b. Method of isolation of escape routes.
 - c. Location of refuge chambers and their service lines.
2. Description of the method of mechanical transportation assistance provided in each escape route.
3. Description of hoisting facilities in shafts and raises used as escape routes, including cage capacity and time involved for hoisting complete crew expected to use each facility.
4. Description of total evacuation time of total crew by each escape route.
5. Description of each refuge chamber or area as to location, capacity and service available.
6. Description of testing or inspection methods and frequency for all aspects of the plan.

7. Description of fuel storage areas, type and number of pieces of diesel equipment, type of shaft, and escape route ground control.

It is this set of revisions which Foster-Miller has used as a basis for this report, in both the evaluation of current escapeway conditions and in recommendations of other guidelines. Accordingly, it is necessary to provide an interpretation of several key points in the proposed revisions:

Subparagraph 1: "Environmental damage" includes not only physical damage (roof falls, muck slides) but contamination, such as ventilation, leakage which could permit smoke (or CO) laden air in an intake escapeway to short-circuit to an adjoining return-air escapeway.

It is also assumed that subparagraph 1 shall not apply to development or exploration.

Subparagraph 7: Note that the language of this subparagraph says "should" rather than "shall"; in other words, it is advisory rather than mandatory. The intent of this subparagraph is to say to an operator: "Subparagraph 3 required a refuge chamber at the shaft station while the level was being developed. Therefore, even after the level has been cut through to provide a secondary escapeway, it would be a good idea to leave the refuge chamber intact and maintain it properly.

The remainder of this report deals with these standards, how representative mines currently comply, the problems with meeting the standards, technical analysis of the source of the problems involved, equipment recommendations, and guidelines for compliance with the standards.

2. Survey of Representative Group of Metal and Non-metal Mines

Before proceeding to develop and analyze Emergency Escape System Guidelines, it was necessary to obtain a broad range of information, including both fact and opinion. Although there were many areas to consider, the surveys had three primary goals:

1. To determine the current state of underground escapeway planning and execution in American, metal and non-metal mines.
2. To determine, for a wide range of mining conditions, what difficulties can be encountered in complying with present and proposed escapeway regulatory standards.
3. To determine what improvements could be made and what equipment and technology was available to aid in implementing these improvements.

To accomplish these goals, three major surveys were undertaken:

1. Survey of MESA and State Mining officials, discussed in Section 2.1.
2. Survey of representative U.S. metal and non-metal mines, discussed in Section 2.2.
3. Survey of manufacturers supplying equipment, primarily hoisting, suitable for use in escape systems; the product information which was obtained is discussed in Section 7.

2.1 Survey of MESA and State Mining Officials

Discussion with government mining officials included a broad range of topics, including --

- . discussions of the mines to be visited.
- . impact of current and proposed standards.
- . comments on major areas of concern in escapeway planning, including ventilation, hoisting, communications, refuge shelters, warning systems, and escape time (Sections 3.1.2 through 3.1.7)

2.1.1 Government Offices Contacted

The MESA Inspection Offices, MESA Technical Support and Management Centers, and the State Offices contacted are listed in Appendix F.

2.1.2 Ventilation

Consensus: Ventilation and a complete understanding of the systems are the most important elements in an emergency escape plan. Where primary fans are located underground, remote control for stopping and starting the fans should be located on the surface.

Varied opinion on reversible fans: Some felt primary fans should be reversible and used only when the location of all personnel underground was known and they had been notified the fans were to be reversed. Some with this viewpoint indicated that any mine with reversible fans should have determined the effect of fan reversal (by actual testing) on the ventilation system prior to an emergency.

Others felt that fans should not be reversed under any condition. The basis of this opinion was that the fire could have destroyed some of the ventilation stoppings and therefore it would be impossible to determine the effect in the mine.

Consensus: The requirement for the construction of stoppings and bulkheads that would prevent environmental damage of one escapeway from another was of great concern. In those districts with large room and pillar mines it was the opinion that construction of such a stopping was not within the present state-of-the-art.

2.1.3 Hoisting

Consensus: Secondary hoisting must be provided. Most discussion on this subject related to the need and amount of safety equipment that should be required on an emergency hoist. A majority felt that emergency hoists should comply with the standards of regular hoists, if possible, but in some cases where standard regulations would affect the reliability of the hoist, they should be neglected. The most mentioned areas of deviation from the standards were overtravel for slow hoists, fleet angle for hoists in restricted areas, sheave diameter and the need for guides. Simplicity and reliability were the most important elements.

2.1.4 Communication

Consensus: Communication is especially important in those districts with deep multi-level mines. Where refuge areas cannot be accessed by a borehole from the surface, two independent communication systems are essential.

2.1.5 Refuge Shelters

Varied opinion on the need and use of refuge shelters.

1. Those who did not like the use of refuge shelters felt that escape plans should provide for exit under all conditions. Additionally, there are environmental conditions (i. e., high rock temperatures, excessive water, etc.) which will not allow the construction of a refuge shelter that can provide the needed life support requirements.

2. Those that agreed on the use of refuge shelters felt they should either be connected to the surface by a borehole or contain two separate compressed air sources. The maintenance of life support systems such as food and water were considered to be necessary only in a few cases; for these cases, concern was expressed on how pilferage could be controlled to assure that the necessary supplies would be available when needed.

2.1.6 Emergency Warning System

Consensus: Emergency warning systems that rely on stench are inadequate due to the slow and unpredictable flows in the compressed air and ventilation circuits. Phone lines, blinking lights, or a siren-equipped vehicle travelling to the working places is adequate if these systems will reach even the most remote workers. Long range research might yield better systems, such as radio signals transmitted through the ground or underground openings to all miners.

2.1.7 Escape Time

Consensus: The most important factor in any emergency is getting everyone out of the area of imminent danger within the 45 minute time limit. Once that is accomplished, unnecessary speed in final exit from the mine could create an additional accident hazard.

In some districts, it was felt that some operators would be able to comply with the 45 minute proposed regulation only by abandoning portions of the mine or by developing a new mine. While a new mine development is a large capital investment, it could be a viable economic alternative because these properties are also contending with extremely inefficient operating costs due to poor crew transportation.

2.2 Mine Surveys

Results on the surveys of nine representative mines are included in this report. Each mine survey consisted of three parts:

- Interview with MESA official in the respective mine district.
- Interviews with responsible mine officials.
- On-site visits, both surface and underground.

Data collected during each visit included the following:

- Maps on mine ventilation system.
- Maps on mine electrical system.
- Details on mining plan.
- Location and concentration of people underground for each shift.
- Detailed information on all mine hoists, fans, trips, materials handling systems, environmental and space constraints.
- Personal visit to the most remote site(s) in mine.
- From personal observations, representative travel times.

The on-site surveys were supplemented by a review of two reports covering more than twenty mines including some of the mines visited. The reports were the result of studies by Theodore Barry and Associates under USBM Contract S0241085 and the University of Idaho under USBM Contracts S0220131 and S0230037.

Table IX - XVII in Appendix G contain thumbnail sketches of each mine visited. As agreed at the program's inception, the mines shall remain anonymous, identified only by letter. The following sections contain a brief discussion of each mine; for brevity, most of the information contained in the Tables is not repeated in the text.

Included in the discussion of each mine is an analysis of whether or not each mine complies with the proposed revisions to the standards (Subparagraphs 1 through 7) contained in Chapter 1. To simplify this analysis, the seven standards have been grouped as follows:

- . Subparagraphs 1 and 5: Requirements for dual escape-ways, one on intake, within 1000 feet horizontally and 300 feet vertically of working places. Prohibition of "environmental damage"; i. e., fire in one escapeway contaminating the other.
- . Subparagraph 2: Hoists required in any escapeway shaft deeper than 300 ft.
- . Subparagraphs 3, 4 and 7: Requirements for escapeways and/or refuge chambers during development drift advancement.
- . Subparagraph 6: 45 minute time limit for evacuation.

For a more complete analysis on how each Subparagraph might be applied to the mines as a group, the reader is referred to Chapter 3.

2.2.1 Mine "A"

Mine "A" is a single-level, room-and-pillar copper mine. Depth varies from zero at one end of the mine to over 1000 feet at the other extreme. The underground area encompasses about 20 square miles of area.

Subparagraphs 1 and 5 (Dual escapeway requirements): Mine "A" uses a ventilation and escapeway plan very similar to coal mines, providing an intake and a return-air escapeway from each working place. However, the "intake" air for some working places is the air which has already been used by another section. That is, not every working place is on a separate split of air. Furthermore, some of the return-air escapeways parallel the intake-air escapeways. Because of the inevitable leakage through stoppings, these parallel return-air escapeways could become contaminated by a fire on the intake side. Therefore, a very strict reading of the "environmental damage" clause would negate the acceptability of these return escapeways. In other areas of the mine, the two escapeways led in opposite directions to different portals, and could therefore withstand even the most rigid interpretation of "environmental damage".

From a physical structure point of view, the return air escapeways, although not regular travel routes, are very well maintained and easily travellable by vehicles at moderate speeds.

The escapeways were better marked than any other mine surveyed. Signs are made by fluorescent spray paint on the walls at every intersection. Approximately every fifth intersection, the sign included not only the escapeway symbol but also a legend indicating to which portal the escapeway was leading.

Subparagraph 2 (Hoist in 300-foot-vertical escapeways): This mine complies totally, including the use of an emergency hoist and torpedo capsule in one return air shaft designated as a secondary escapeway.

Subparagraphs 3, 4, and 7 (Escapeway and refuge chamber requirements during development work): Parallel drifts are driven during all advancement work, so that the intake-return dual escapeway system is always maintained. The one exception was several years ago when an experimental piece of equipment was used to drive a single drift through to a new shaft. For this effort, a refuge chamber was constructed. Now that the entry has been cut through, the refuge chamber has been left in place, 90 percent intact.

Subparagraph 6 (45 minute time limit): Fire drills are carried only as far as assembling the work crews in the lunch rooms, so an official time is not available. However, based upon travel times recorded from the most remote working places, it is felt that the entire mine could be evacuated easily in 45 minutes.

2.2.2 Mine "B"

Mine "B" is a deep, multi-level, lead-zinc mine, with the lowest levels approximately 5400 feet below ground. As shown in an elevation view of the mine, (Figure 1) there is a downcast incline (about 45°) at each extreme of the mine. This arrangement provides for two truly independent escapeways in virtually all parts of the mine, as discussed in the following paragraphs:

Subparagraphs 1 and 5 (Dual escapeways): This mine is extremely fortunate in having a main shaft (actually incline) at each end of the mine. In most instances, the men will always have a choice of which shaft to go to; because the inclines are in opposite directions from any working place, the escapeways are truly independent.

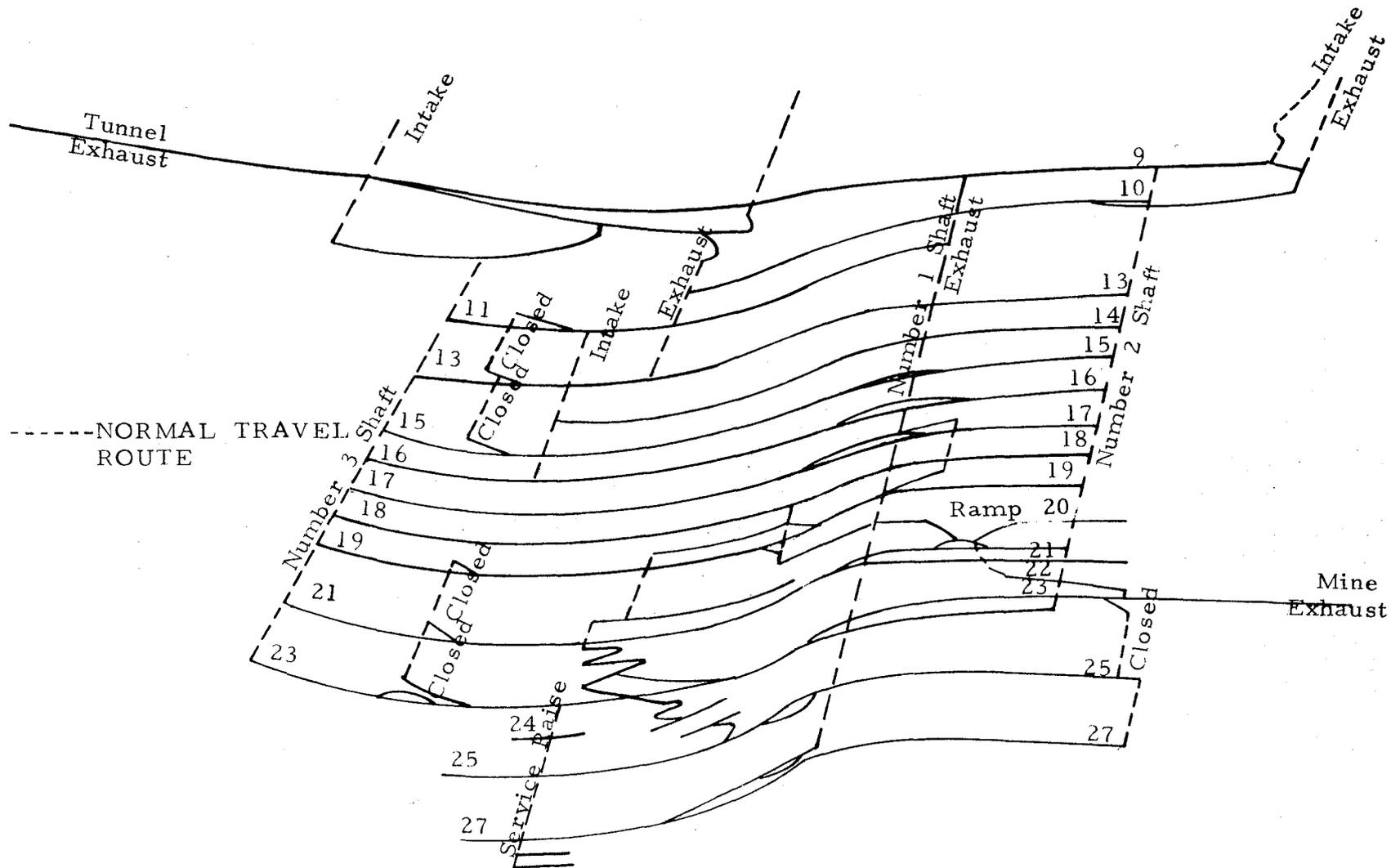


Figure 1 Simplified Elevation View of Mine "B"

Furthermore, the upcast shaft (used for hauling muck) could also be used as an escape center, although it is not included in the present escape plans.

Escapeways are not very well marked. However, escapeway maps are maintained in many locations. These maps are detailed enough to be accurate and yet simple and small enough to be easily understood, in fact, they were the test maps seen on the survey.

Subparagraph 2 (Hoists in 300-foot-vertical escapeways): All of the mine below the main tunnel complies with this standard. To pursue the secondary escapeway instead of taking the horizontal tunnel out of the mine would involve some climbing.

Subparagraphs 3, 4 and 7 (Escapeway and Refuge chamber requirements during development work): Like many of the multi-level mines, this mine's problems of complying with these escapeway standards are not acute when sub-levels are being established. Typically, a ramp is driven up or down from a main level and forms the only means of escape. Alternatively, development may include a blind raise. To comply with the horizontal distance requirement, this mine would have to close some sub-levels or else bore a raise which would make contact with another level.

Subparagraph 6 (45 minute time limit): Fire drill evacuations have been timed in 80 minutes. This includes waiting for the train in the main tunnel and the 12 minute train ride to the outside. It is possible that all men reach the main level in 45 minutes, perhaps by adding capacity to the two main man-hoists (assuming of course that loading/unloading facilities were available to accommodate the added cars). The possibility of equipping and designating a main level as a "fresh air base" is discussed more fully in Section 3.6.

2.2.3 Mine "C"

Mine "C" is a multi-level, lead-zinc mine, with a maximum depth of 7,700 feet. Primary access is along a two mile adit, vertical travel downward is then provided by two separate hoisting systems. This mine was chosen as a model for the computer simulation studies, discussed in Appendices A and B.

Subparagraphs 1 and 5 (Dual escapeway requirements):

This mine can be envisioned as a ladder, the two rails being the shafts and the rungs the underground levels. One shaft is downcast and contains a single hoist. The other escapeway is upcast and consists of two shafts offset on the 4,000 level or at approximately one half the depth of the mine. This arrangement provides for two totally separate escape routes from every level.

Subparagraph 2 (Hoists in 300-foot vertical

escapeways): The two main escape shafts are provided with complete hoisting facilities, with shaft stations on the main levels, 200 feet apart (vertically).

Subparagraphs 3, 4 and 7 (Escapeway and refuge

chamber requirements during development work): This mine currently has a minimal amount of development work.

The sub-levels in this mine have vertical distances of less than 200 feet and horizontal distances less than 1,000 feet.

Subparagraph 6 (45 minute time limit): Fire drills

for this mine have been timed in 43 minutes, which gets all the men to the main level, but does not include the 15 minute train ride to the outside. To get everyone outside in 45 minutes would be essentially impractical at this time. The shaft station on the main level is near the end of the two mile untimbered adit supplying the fresh air to the mine.

Mine "D"

Mine "D" is a medium-depth, multi-level lead-zinc mine, with the deepest levels approximately 2,900 feet below ground. However, this mine is unusual in that the 2,900 level has an adit leading directly to the outside. This arrangement greatly simplified the hoisting problems, especially in an emergency, because there is no area in the mine in which a man would have to travel up to reach the surface (although in many cases travelling up would be the fastest way out).

Subparagraphs 1 and 5 (Dual escapeways): In most areas of this mine, there are two different escape routes. As usual, the question of how "independent" the routes are leads to a discussion of the ventilation system. This mine has a great deal of recirculation; furthermore, the ventilation system is complicated by old workings and stopes which have caved to the surface. It is therefore probable that smoke in one airstream would quickly contaminate the other airstreams. Partially offsetting this disadvantage is the mine layout which has two independent intake air portals at the mine extremities.

Subparagraph 2 (Hoists in 300-foot-vertical escapeways): All of the main vertical shafts have manhoisting equipment installed. In addition, this mine has raises and slopes as high as 800 feet which are provided with hoisting equipment. The major problem for these areas is that there are very few types of hoisting equipment, suitable for use in raises, which are man-rated by the manufacturer.

Subparagraphs 3, 4 and 7 (Escapeway and refuge chamber requirements during development work): All of the active areas within this mine would comply with the proposed standards, with one possible exception. There is one working area accessed by a single drift; a refuge chamber has been constructed at the end of this drift.

Although the areas are not now being actively worked, there are at least seven development drifts which extend several thousand feet past a point of dual escapeways. If work is re-established in these areas, refuge chambers would be required; furthermore, if these areas went into production, dual escapeways would be required - presumably provided by raises between the levels.

Subparagraph 6 (45 minute time limit)

This mine can be evacuated in 45 minutes.

2.2.5 Mine "E"

Mine "E" is a single-level, modified room-and-pillar mine. The depth averages about 1300 feet; the mine is serviced by one main shaft and seven five-foot diameter ventilation shafts, one of which is equipped with an emergency hoist.

Due to the radon problem, Mine "E" has a ventilation system substantially above-average for a hard-rock mine.

Subparagraphs 1 and 5 (Dual escapeway requirements): The current escape plans provide for two separate escapeways, one to the regular hoist and one to an emergency hoist 600 feet away. It is quite possible that a fire could contaminate both shaft stations, in which case the escape plan calls for retreating to one of the ventilation boreholes, which are well-situated at every extremity of the mine. However, these other boreholes are not equipped with hoists, and the plans call for the men to barricade themselves next to the shafts until help arrives.

In addition to the above provisions, several of the other mines in this area are connected, allowing escape through an adjoining mine.

Because of the proximity of the two main escape shafts, the dual escapeways (as they are currently designated) are not truly independent, because a fire near one shaft could contaminate the other. The ventilation boreholes at the mine extremities would provide an excellent secondary escape route, if they were provided with escape hoist facilities. If this were the case, this mine would not only comply with the letter of the proposed regulations; it would be a model of compliance.

Subparagraph 2 (Hoists in 300-foot-vertical escapeways): See the previous paragraphs.

Subparagraphs 3, 4 and 7 (Escapeway and refuge chamber requirements during development work): Development work is accomplished by advancing the room-and-pillar system and/or sinking a ventilation hole ahead of the working areas. There are no single-drift developments more than a thousand feet from dual escapeways.

Subparagraph 6 (45 minute time limit): This mine can easily be evacuated in 45 minutes.

2.2.6 Mine "F"

Mine "F" is essentially a single-level modified room-and-pillar lead-zinc mine, approximately one-thousand feet in depth. Ore-passes lead from the main mining level to a small haulage level. A plan view of this mine can be visualized as star-shaped, with two hoisting shafts near the center of the star, and the tips of the star approximately two thousand feet from the center.

Subparagraphs 1 and 5 (Dual Escapeways):

Single-drift travelways lead to each working place, at the tips of the star-shaped mine. There are no crosscuts and stoppings; ventilation is carried to the places by vent tubing. As such, this mine could not comply with the dual escapeway requirements. To comply with the strict interpretation of the proposed standards, two major efforts would be required:

- . Cut through parallel drifts to some working places
- . Erect air-tight stoppings, with man doors, between some rooms. In some instances, these stoppings would have to be at least 100 feet wide.

Subparagraph 2 (Hoists in 300-foot-vertical escapeways): This mine currently has a hoist in each of the two main shafts, leading to the surface.

Subparagraphs 3, 4 and 7 (Escapeway and refuge chamber requirements during development work): Application of these requirements to Mine "F" would depend primarily upon the exact definition of "development". For the most part, the level of effort required for compliance has already been covered in the discussion of Subparagraphs 1 and 5.

Subparagraph 6: Mine "F" can be easily evacuated within the 45 minute time limit.

2.2.7 Mine "G"

Mine "G" is a deep, multi-level, iron mine, with the lowest levels currently 2500 feet below the surface. The ore body is approximately 2000 feet long, and 400 feet thick, so that this is truly a three dimensional mine. A simplified three-dimensional perspective of this mine is shown in Figure 2.

Subparagraphs 1 and 5 (Dual escapeways): This mine is a classical case of the problems of providing truly independent escapeways, perhaps because it is so typical of a complex, three dimensional mine. As shown in Figure 2, men in the "sample" working place" have two distinct methods of escape: out the intake to Shaft No. 1 or out the return to Shaft No. 2.

However, how separate are these two escapeways relative to contamination of the ventilation system? If a fire breaks out at the "hypothetical fire location," the intake entry could become smoke-filled very rapidly. Furthermore, short circuits along the drift may well fill the return-air drift long before smoke (or stench) has reached the sample working place. (For simplicity, the case of smoke propagation to upper or lower levels through raises and active and worked-out stopes will not be considered at this time). Of course, the crosscuts shown in the figure are not in reality so simply, and may include worked-out areas, faults in the strata, etc.

This mine, like a majority of those surveyed, have provided two entirely separate escapeways, but there is an ever-present danger of a fire in one escapeway contaminating the other.

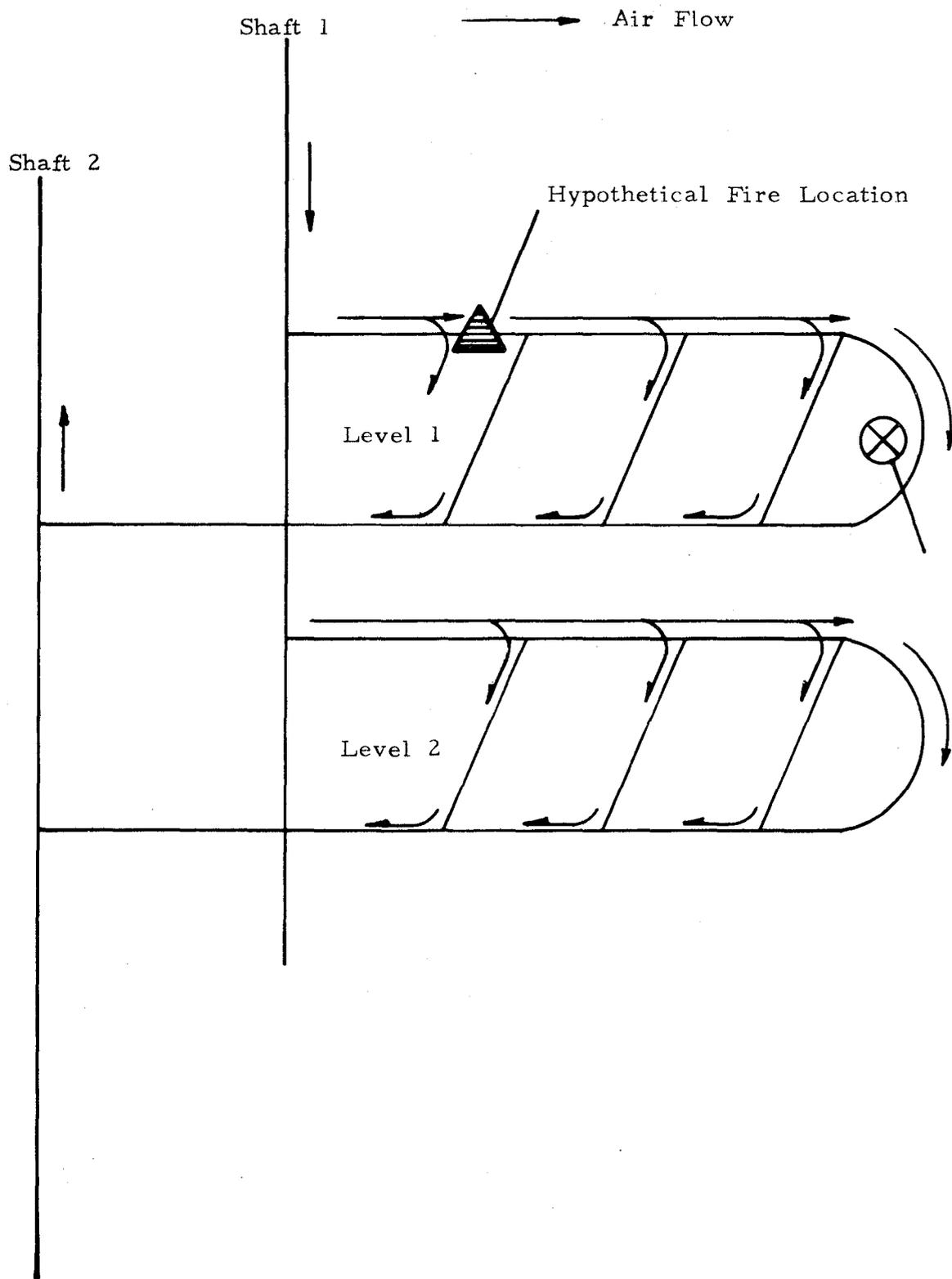


Figure 2 - Simplified 3-Dimensional Perspective of Mine "G"

One possible safeguard is to provide a refuge chamber at the shaft station(s). These chambers would serve a very special function - to provide a livable atmosphere for a short period of time; i. e., long enough for the hoist to evacuate all waiting men. The chamber must provide for a positive-pressure atmosphere to insure that any leakage in the chamber is outward.

Subparagraph 2 (Hoists in 300-foot-vertical escapeways): This mine is in compliance with this standard.

Subparagraphs 3, 4 and 7 (Escapeways during development work): Like the other multi-level mines, Mine "G" would have to change their mining plan when establishing sub-levels. A level-by-level analysis of this mine established that six sub-levels had been driven more than 1000 feet from dual escapeways. It is noteworthy that although the 1000 foot requirement is not now the law, the maximum distance from dual escapeways was 1400 feet. To follow the letter of the proposed standard would require either closing the affected sub-levels or else driving an additional opening.

Subparagraph 6: This mine can be evacuated in less than 45 minutes.

2.2.8 Mine "H"

Mine "H" is a single level room-and-pillar limestone mine. Underground area is approximately four square miles and averages two hundred feet in depth. Ventilation is both natural and forced, by a combination of fans and 45 vent holes to the surface.

Subparagraphs 1 and 5 (Dual Escapeways): The concept of dual, independent, escapeways depends strongly upon the ventilation system. The ventilation system in this mine varies significantly depending upon location, and also with time-because of frequent changes to take advantage of natural ventilation. In addition,

there are no stoppings, ventilation doors, air locks or other ventilation control devices. On the other hand, the huge volume of the mine (drifts and crosscuts 80 feet high and 50 feet wide) means that contaminated air, although free to flow in any direction, will move very slowly.

To comply with the strict interpretation of "environmental damage", this mine would have to install hundreds of air-tight stoppings 80 feet high. Alternatively, ladderways and/or escape hoists could be installed in the vent holes to qualify as secondary escapeways. (careful planning would be required because of the 80-foot roof). Although this latter step would fulfill the letter of the law, it is difficult to foresee an occasion which would make the secondary escapeway safer or more desirable than driving out the primary escapeway.

Subparagraph 2 (Hoists in 300-foot-vertical escapeways): Both of the main exits from the mine are short ramps.

Subparagraphs 3, 4 and 7 (Escapeway and refuge chamber requirements during development work): "Development" work in this mine is essentially just a combination of the standard room-and-pillar mining plan, with additional vent holes drilled as needed. Therefore, escapeway requirements for advancing sections of the mine are really no different than those already presented under the discussion of Subparagraphs 1 and 5.

Subparagraph 6: This mine could be easily evacuated in 45 minutes.

2.2.9 Mine "I"

Mine "I" is a single-level, room-and-pillar salt mine. The salt vein is massive with drifts 30 feet in height. The underground area encompasses about 500 acres.

Subparagraphs 1 and 5 (Dual Escapeway requirements): Mine "I" has its two shafts within 100 feet of each other, one is fresh air the other exhaust. The two air passages are separated by brattice cloth stoppings, 30 feet by 60 feet. There is only one route for the air, that is, not every working place is on a separate split of air. The large size of the stoppings make leakage unavoidable which creates severe recirculation. Therefore, a strict reading of the "environmental damage" clause would cause a violation of the standard.

The travelways both primary and emergency are wide and provide good conditions for vehicle travel at moderate speeds.

The escapeways, although marked, were not particularly easy to read.

Due to the large volume of air in the mine and slow movement of the air (1 mph) contamination due to fire would spread slowly, possibly allowing escape for some miners in uncontaminated air.

For Mine "I" to comply completely to the environmental damage, leak proof bulkheads would be required at all stoppings which separate the fresh and return air passages.

Subparagraph 2 (Hoists in 300-foot-vertical escapeways): This mine complies since it is a one level mine to which it has two shafts with hoisting facilities.

Subparagraphs 3, 4 and 7 (Escapeway and refuge chamber requirements during development work): Parallel drifts are driven during all advancement work, so that the intake-return dual escapeway system is always maintained.

Subparagraph 6 (45 minute exit time): This can easily be met. Truck with a siren is used for warning and all men ride out on the rubber tired vehicles, requiring approximately 15 minutes to reach the hoist.

3. Application of Proposed Revised Standards 57.11-50 to Mines Surveyed

3.1 Subparagraph (a) 1

"Each mine shall have at least two separate and properly maintained escapeways from each working place to the surface which are so positioned that physical or environmental damage to one will not lessen the effectiveness of the other, and which meet the requirements of travelways and man hoisting standards. These escapeways shall reach to within 1000 feet horizontally or 300 feet vertically of each working place."

3.1.1 Discussion

This section will deal with the 1000 and 300 feet distance requirements; Section 3.5 will deal with the "environmental damage" provisions.

During the course of the mine surveys, it became obvious that one mine's 1000 foot distance was nowhere near equal to another's--not in the actual distance but in the time required to traverse that distance. This is true for the 300-foot requirement as well. The most obvious example is that one could traverse down a 300-foot raise much faster than climbing up the same distance.

The temptation is strong to recommend that the distance requirement be changed to travel times instead. However, this approach would unfortunately lead to a lot of subjective evaluations. Having a time requirement for an entire mine evacuation (Subparagraph 6) is one thing; time requirements and the requisite inspection procedures for each working place are quite another.

For whatever its failure to recognize different mine conditions, the distance requirement is straightforward and can be enforced by reference to mine maps alone. However, if the distance requirement, instead of time, is retained, there should definitely be a distinction between vertical travel upward and downward.

A further area of confusion in the distance specifications is as follows - escapeways must extend to within 1000 feet horizontally or 300 vertically. For example, a working place 800 feet horizontally and 800 vertically from any escapeway would appear to comply because it is within 1000 feet horizontally. Furthermore, no hoist would be required because the raise is not part of the escapeway (which starts 800 vertical feet away). If a distance requirement is to be retained, it is recommended that the last sentence of Subparagraph (a) 1 be amended as follows:

These escapeways shall be within one travel unit of each working place. A travel unit, TU, is defined as

$$TU = \frac{H}{1000} + \frac{Vu}{200} + \frac{Vd}{400}$$

where

H = horizontal distance, in feet)	from working
Vu = vertical distance, upward, in feet)	place to
Vd = vertical distance, downward, in feet)	escapeways

3.1.2 Application of Mines Surveyed

Mines "A", "D", "E", "H", and "I" have two escapeways within 1000 feet horizontally and 300 feet vertically of all working places. Mines "B", "C", and "G" have sub-levels, driven off of main levels, which exceed the distance requirements. It is noteworthy that, although these distance requirements are not currently the law, no areas were found which exceeded the limits by

more than 300 or 400 feet. However, to comply with the letter of the proposed law, these three mines must either abandon the relevant sub-levels or else bore a raise through to the nearest main level in order to provide a second means of escape. Mine "F" has several working places accessed by a single drift. To comply, this mine must in some cases drive a second drift up to the work area. In other places, long stoppings across pillared-out areas would have to be constructed to provide two separate escapeways.

3.2 Subparagraph (a) 2

"In mine accessed by vertical or inclined shafts, raises, or winzes, more than 300 feet in vertical extent, hoisting facilities shall be provided in escapeways."

3.2.1 Discussion

This standard is quite straightforward and makes good sense.

3.2.2 Application to Mines Surveyed

All of the mines surveyed presently provide hoisting facilities in at least two vertical escapeways.

3.3 Subparagraph (a) 3

"When levels are driven from the shaft, a refuge chamber shall be constructed at the shaft station before development exceeds 300 feet in horizontal distance."

3.3.1 Discussion

In principle, this standard is desirable, but it appears to conflict slightly with Subparagraph 1. For example, it may be that a small sub-level is driven 500 feet from the shaft and that a secondary escape is possible by traversing that 500 feet and travelling up 100 feet to a main level where another escape route is available. If a refuge chamber is desirable, perhaps the development distance which would mandate the chamber should be made to coincide with the requirements of Subparagraph 1.

Furthermore, if standards are to be promulgated which require refuge chambers, some definitions and guidelines for refuge shelters must be established. A full discussion of this problem is contained in Section 3.8.

3.3.2 Application to Mines Surveyed

At the time the mines were surveyed, there were no 300-foot blind drifts driven off shafts.

3.4 Subparagraph (a) 4

"Horizontal openings either from the surface or from existing mine openings shall not be advanced more than 1000 feet from a set of escapeways."

3.4.1 Discussion

This standard is straightforward and coincides with the provisions of Subparagraph 1.

3.4.2 Application to Mines Surveyed

The problem of sub-levels which extend more than 1000 feet has already been discussed in Section 3.1.2. In addition

to that, Mine "D" has a number of blind development drifts not currently being worked. To comply with (a) 4, parallel drifts would have to be driven, raises bored to connect the drifts (within 1000 feet of the dead ends), or the drifts would have to be sealed off. Several of the other mines have single drifts leading to other mines or old workings. These drifts would have to be sealed or at least "dangered" off.

3.5 Subparagraph (a) 5

"At least one of the escapeways shall be on intake air and separated from the other escapeway by solid ground, fire doors, bulkheads or ventilation control doors to prevent environmental damage of the escapeway if fire, smoke or combustion gases make the other escapeway impassable."

3.5.1 Discussion

This standard is a further delineation of the "environmental damage" provision of Subparagraph (a) 1. As mentioned in Section 1.2, "physical or environmental damage" can be defined to include contamination of the ventilation system. For example, assume an intake escapeway and a return air escapeway are parallel, as shown in Figure 3. If the pressure differential between the two drifts is only 1" water gauge, the leakage rate from the intake to the return is approximately 25 CFM per square inch of leakage area. Stoppings with leakage areas as small as one square inch are rare indeed. Therefore if a fire starts at point A and a man is working at point B, both of his escape routes will rapidly become contaminated.

For a mine to comply with the definition of "environmental damage" as stated above, the mining plan would have to provide a ventilation system similar to either Figure 3 (A) and (B). In Figure 4 (a), the addition of a third drift is ventilated to provide

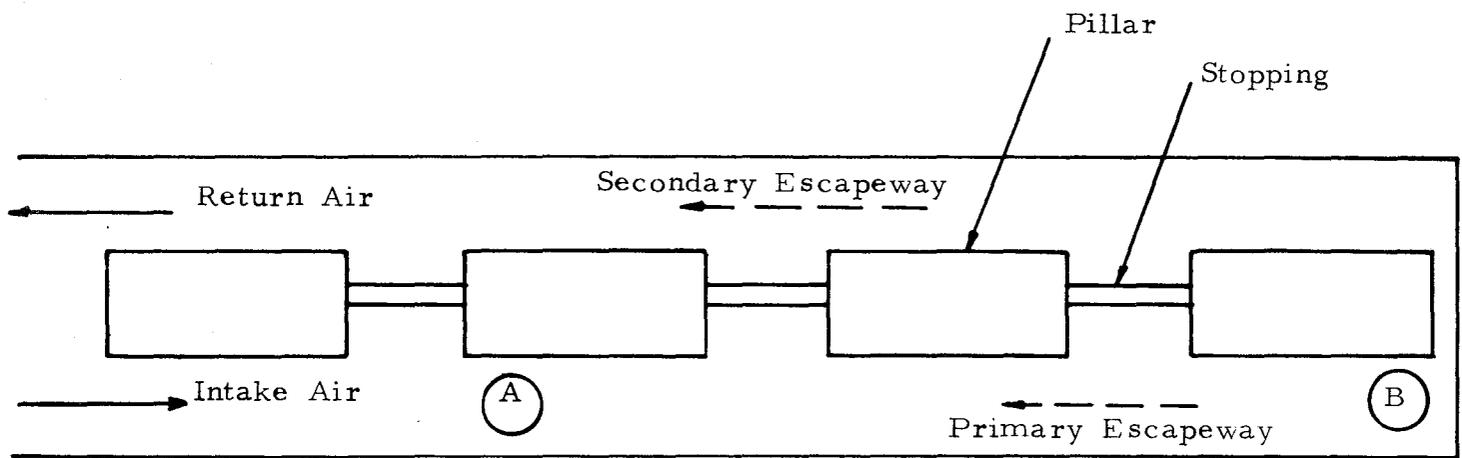
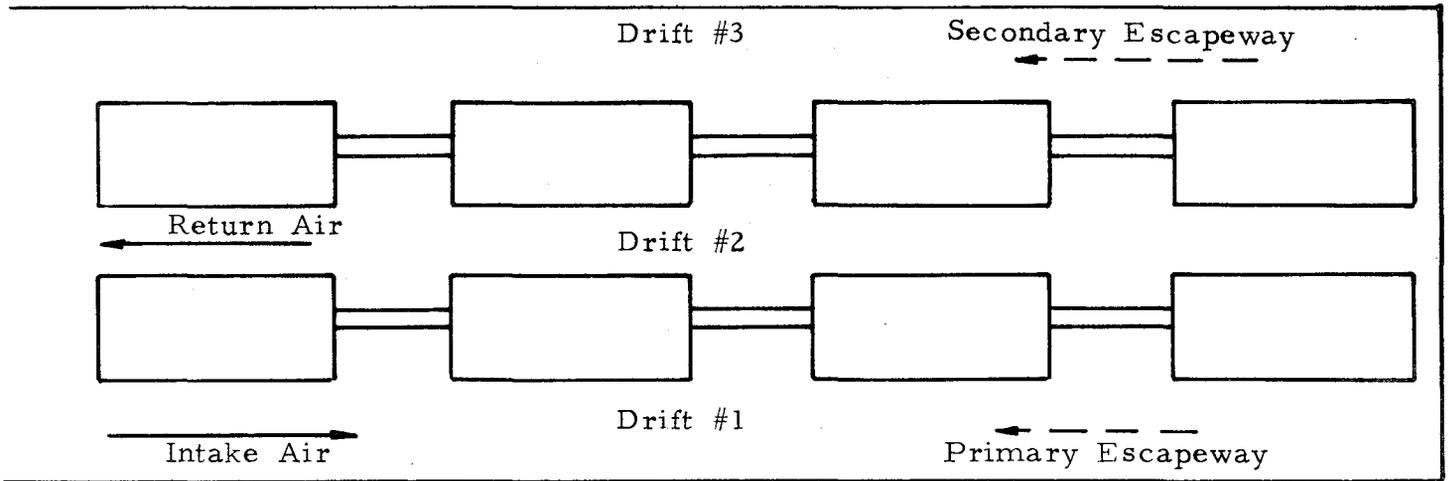
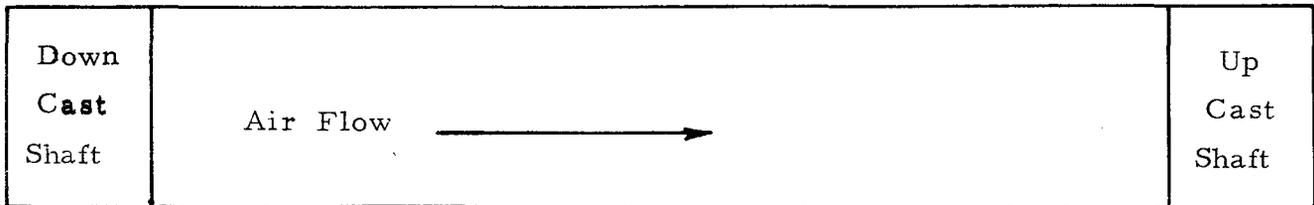


Figure 3 - Simplified Plan View of Typical Mine Drift, Showing Ventilation and Escapeways (all working places within 1000 feet horizontally and 300 feet vertically of escapeways)



(a) 3 Drift Ventilation System



(b) Two-Shaft Mine, with Shafts Located at Opposite Extremes of the Mine

Figure 4 - Simplified Plan View of Mine Layouts
(all working places within 1000 feet horizontally
and 300 feet vertically of main drifts)

a pressure equal to or greater than drift no. 2; this guarantees that there will be no leakage from no. 2 to no. 3. Another alternative is to locate a shaft at each extreme of the mine, as shown in Figure 4 (b). In this instance, men outby the fire area can travel to the downcast shaft; men inby the fire can travel ahead of the contaminated air--there is no risk of starting out in safe air and having to travel through contaminated air to get to the surface, as was the case in Figure 3.

However, if the fire occurs in the main intake shaft or tunnel, all bets are off: the entire mine will eventually become contaminated. The question then becomes whether the men can evacuate by the return-air side before it too becomes contaminated. The only way to guard against this contingency is to provide two totally separated intake air supplies which lead all the way to the surface.

A second contingency which can damage even a very good ventilation system is the thermal effect of a fire. The heat produced and resultant convective currents could change the ventilation dramatically; prediction of the ventilation would be virtually impossible.

3.5.2 Application to Mines Surveyed

The biggest problem in applying subparagraph (a) 5 to any mine is not the ability of the mine to comply but rather the difficulty of enforcing the standard. For example, mines "H" and "I" technically could not comply with the environmental damage provisions. These mines are essentially wide open, with a minimum of "solid ground, fire doors, or ventilation control doors" to isolate one escape route from the other. However, these mines are so massive, and the ventilation air flow is so slow, that it could be argued that one escape route could not be contaminated by the other before the men had been able to escape. For cases like these two mines, how is the standard to be interpreted? Are air velocities required to evaluate the time it takes to pollute both escapeways? If this is the case, what consideration is given to the change in air flows created by the convection currents of a fire.

If Subparagraph (a) 5 is to be enforced literally, mines such as "H" and "I" must provide two physically separated escapeway systems; this would necessitate the construction of many (perhaps a hundred or more) large stoppings, these stoppings would often be so large as 100 feet high and 100 feet wide.

A second problem is applying subparagraph (a) 5 to specific mines is the relative difference between the mines. Again an example taken from the mines surveyed will best illustrate this point. Both mines "F" and "G" would not comply with this standard. In the case of mine "F", single drifts 2000-3000 feet long lead to some working places, ventilated by vent tubing. However, if the single escapeway were contaminated, the men could travel through the contaminated air in a matter of minutes. Mine "G", on the other hand, technically has two separate escapeways. However, bad air on the intake escapeway would rapidly short-circuit to the return escapeway, and men would have to make a trip through contaminated air in either escapeway. In these examples, the mine which appears to be closer to being in compliance (since it does have two escapeways) might actually require men to travel a longer distance through contaminated air than the mine which has but a single escapeway.

Of the other mines, "A", "B", "C" would be mostly in compliance. Mine "D" has some areas with two distinct escapeways and other areas where recirculation and short-circuits would negate the value of the second escapeway. Mine "E" would be in full compliance if hoisting facilities were available at the ventilation boreholes.

3.6 Subparagraph (a) 6

"Exit from the mine shall be possible from any working place within 45 minutes when travelling in normal mine air."

3.6.1 Discussion

This standard is perhaps the key to the entire proposed revision of Section 57.11-50. Regardless of mine size, number of escapeways, or any other factor, all men have to be able to exit the mine in 45 minutes when travelling in normal mine air. The mine's ability to comply can be determined by timing the fire drills which are currently required.

As discussed in the next section, there are many mines in the country which could not comply with this standard. As one would expect, the mines which have the most trouble are the deep, multi-level mines. Even in the biggest mines, the majority of the men can be evacuated in 45 minutes or less, but for some of the men, the time is longer.

A very complete discussion of the travel times involved in evacuating a specific deep multi-level mine is contained in Appendix A of this report. However, for the purposes of this discussion, we can refer to a simplified case, shown in Figure 5. There are six major times involved in getting from a working place to the surface:

- . travel time from working place to main drift
- . travel time along main drift to shaft station
- . waiting time at shaft station
- . travel time of hoist, including loading times at each station and unloading time at the collar
- . waiting time in main tunnel
- . travel time of train out main tunnel

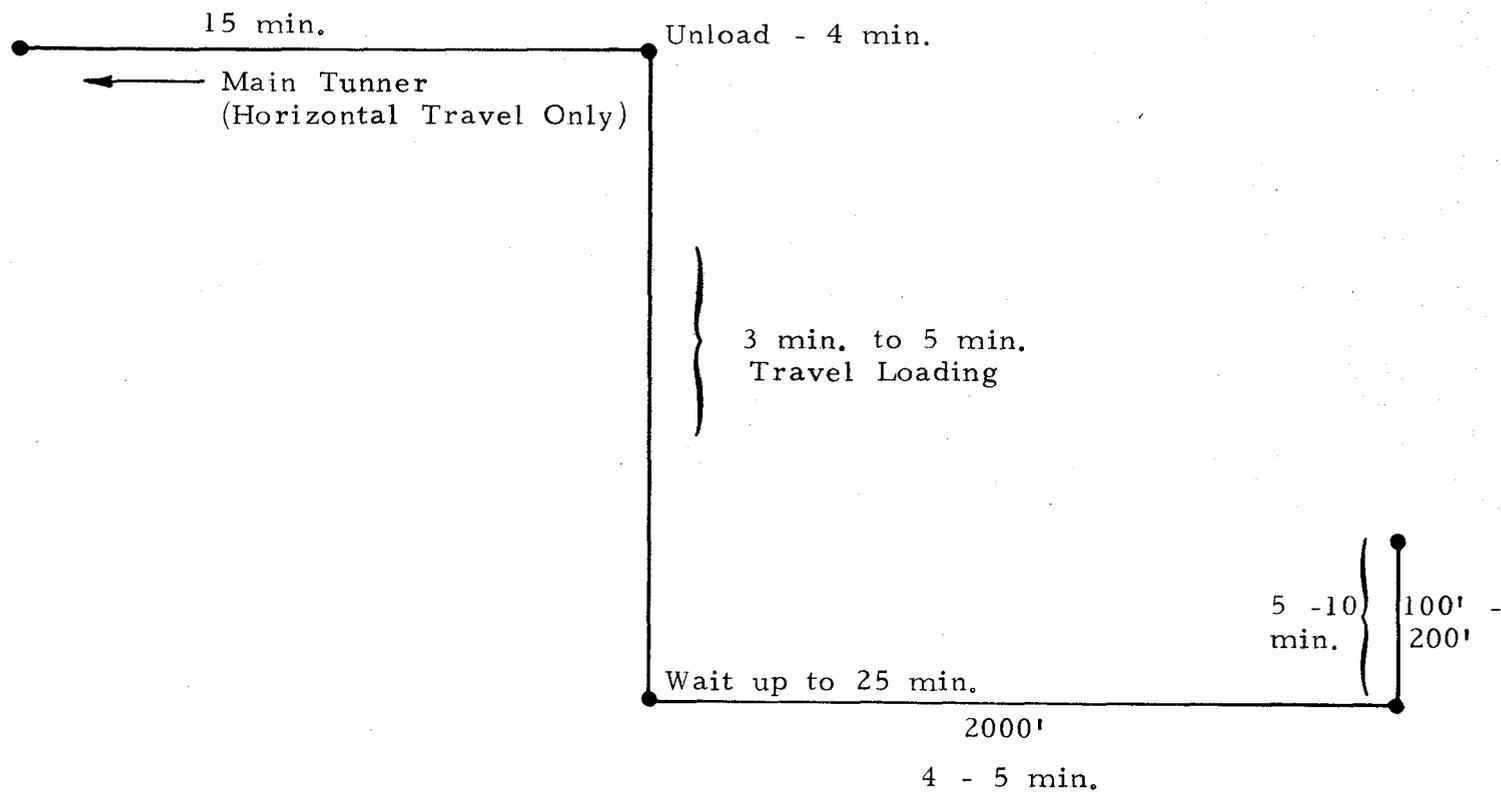


Figure 5 - Simplified View of Travel Times Involved In Mine Evacuation
(Travel And Waiting Times Are Far Worst Cases)

Typical travel distance and travelling and waiting times for the worst case are shown in Figure . It can easily be seen that the waiting time for the hoist is one of the major time-stealers. This wait represents more than just one complete hoisting cycle. For example, if the cage(s) is (are) already full when reaching a given level, men at that level will have to wait through another complete hoisting cycle. Increasing the hoist capacity is therefore a very good way to reduce evacuation time. However, increases in capacity are usually accomplished by stacking more cages. If this is done, then the shaft stations (most specially the collar) must be rebuilt to permit loading/unloading more than one cage simultaneously--otherwise the increased capacity will be largely offset by the added time needed to successively jog each cage into position at a given station.

Another factor which has a major impact on total travel time is the phrase "exit from the mine". This discussion so far has assumed that this phase means exit from underground. However, many of the large multi-level mines can get all of the men to the main tunnel level in 45 minutes. (Main tunnel level is defined as a drift requiring only horizontal travel to reach the outside. This is usually the level at which the main underground shafts have their collar . It is quite possible that some portion of this level could be established as a fresh air base, so that once the men reached that level they would be out of danger. Figure 6 shows three different possibilities for establishing such a fresh air base. A fresh air base would be similar to the concept of a refuge chamber, but would require two positive sources of fresh air, uncontaminated by contact with any other portion of the mine's ventilation or compressed air system. Additionally, a fresh air base would have to be located such that final exit from the mine can be made by horizontal travel only.

If this concept were accepted, then Subparagraph 6 could be amended to read "Exit from the mine or travel to a designated fresh air base....".

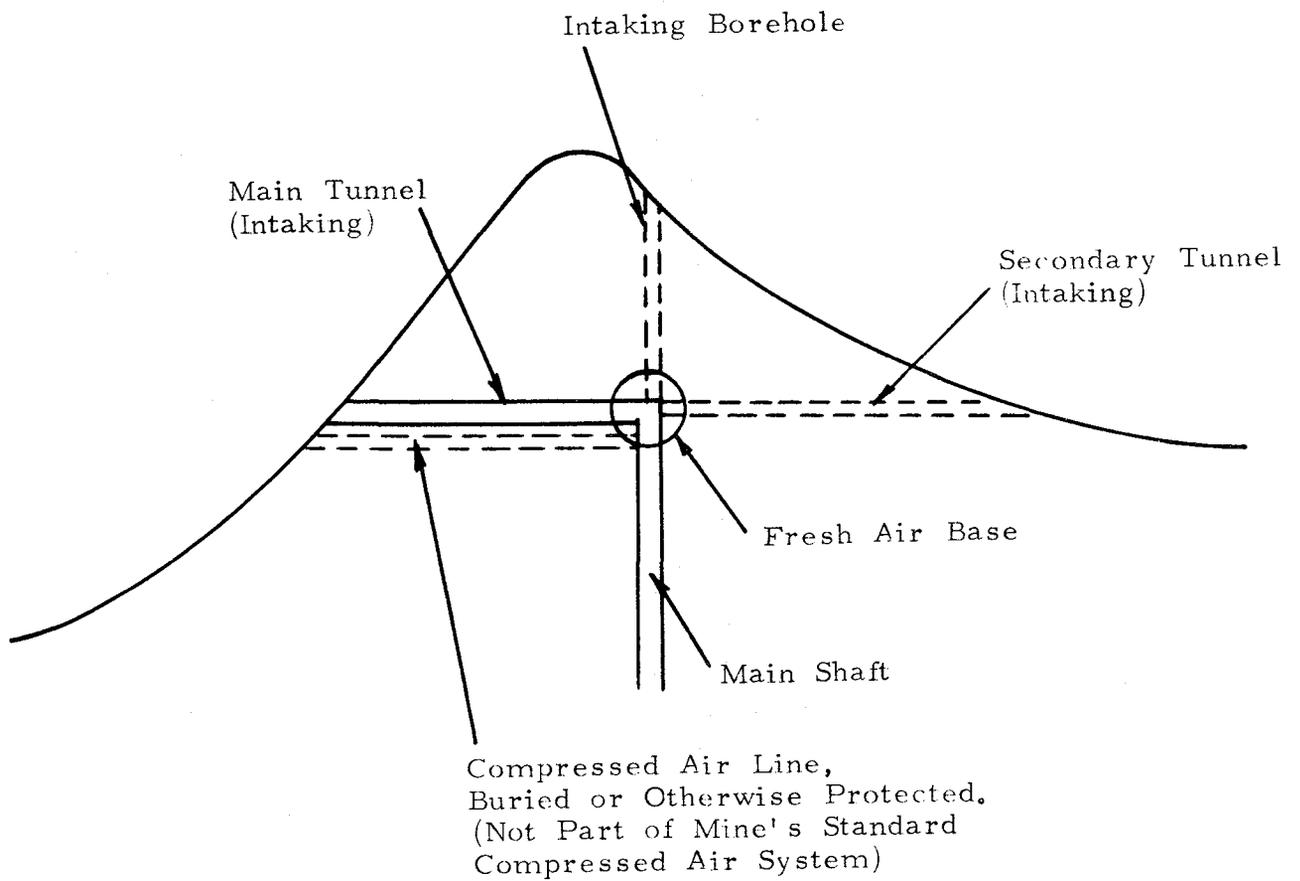


Figure 6 - Cross Section of Mine,
Showing Establishment of Fresh Air Base

3.6.2 Application to Mines Surveyed

Mines "B" and "C" cannot be evacuated in 45 minutes. There are two possibilities to permit compliance with these proposed standards:

1. Close off areas of the mine and limit the number of men underground at any one time.
2. Improve the hoisting facilities to increase hoisting capacity. This might permit the men to reach the main level, but not get out of the mine, in 45 minutes. If this is the case, then fresh air bases could be established on the main level, as discussed in 3.6.1

3.7 Subparagraph (a) 7

"In mines accessed by vertical or inclined shafts, raises or winzes, a suitable refuge chamber should be provided at each shaft station. These chambers may be utilized for other purposes providing that material stored in the chamber does not restrict access or reduce the volume of contained respirable air to an unacceptable quantity."

3.7.1 Discussion

As discussed in Section 1, this subparagraph is interpreted to be a recommendation, rather than a requirement, that any refuge chambers built to comply with Subparagraph 3 should be left in place even after they are no longer required.

3.7.2 Application to Mines Surveyed

Only one of the mines visited had installed a refuge chamber during drift development. Ground shifting and concussions from blasting had necessitated frequent repair; once the drift was cut through to a second shaft, maintenance of the chamber had ceased. It was still 90 percent intact during the mine visit.

4. Guidelines for Implementing the Emergency Escapeway Standards for Metal and Nonmetal Mines

The technical discussion of each escapeway component precedes the specific guidelines for the component. Generally, the technical discussion provides the background and reasoning behind the guidelines.

Section 5 is a discussion of general escapeway requirements, including the escape route, fire retardants, warning systems, ventilation systems, escapeway signs and signals, auxiliary transportation and fuel storage. The discussion is followed by a list of guidelines pertaining to the escapeways.

Section 6 is a summary of the computer simulation of an escapeway system for Mine "C". A complete documentation of the simulation is included in Appendix A and B.

Section 7 covers emergency hoisting requirements and concludes with the guideline, for emergency hoists, their inspection and use.

Section 8 is a discussion of refuge chambers and life support and is concluded with guidelines for the application of this equipment.

5. General Escapeway Requirements

5.1 Escape Routes

Present escapeway regulations state "Every mine shall have two separate properly maintained escapeways to the surface which are so positioned that damage to one shall not lessen the effectiveness of the other, or a method of refuge shall be provided when only one opening to the surface is possible."

"Escape routes shall be:

- a. Inspected at regular intervals and maintained in safe, travelling condition.
- b. Marked with conspicuous and easily read direction signs that clearly indicate the ways of escape."

"Application: "Regular" intervals means at intervals no greater than monthly where conditions are stable and oftener where conditions may change."

"Designated escapeways inclined more than 30° from the horizontal shall be equipped with stairways, ladders, cleated walkways, or emergency hoisting facilities."

As can be noted in present and proposed regulations there must be two separate properly maintained escapeways. In most operations, the escapeways will consist of one route that is the normal travelway used in day to day operations. The second route is usually a return airway through old work areas. Based on this generally accepted practice, we will designate the two types as primary and secondary.

The primary escapeway is defined as the normal route that is used in travelling to and from working places. A secondary escapeway is one which is used for emergency use only. It is possible for a mine to have more than one primary or secondary escapeway.

The primary route is generally on intake air with good vertical and horizontal transportation. Due to constant use the drifts, shafts, raises and winzes are usually observed daily. Therefore, recent falls, slabbing, squeeze and ditch problems are corrected by on-shift utility crews. The resulting maintenance will allow fast and safe exit in a minimum of time.

Secondary routes encompass a wide range of conditions. In most mines, the secondary route is through worked out areas and in most cases, on return air. In deep multi-level mines, the secondary escapeway may be through heavily timbered drifts with a minimum area. In room and pillar operations, the secondary escapeways are usually in the return airways which are larger and in general, better condition than those in vein type mines.

In most mines, maintenance of secondary escapeways is a problem. Equipment and services that were used for original mining are usually removed as mining progresses. In many cases, it is no longer possible to get mechanized equipment in the drifts, or raises. In those areas with high extraction, the escapeways are subjected to squeeze and poor ground conditions, therefore, they are maintained at a minimum size. It is our feeling that more attention must be given to the condition of secondary escapeways.

Present and proposed regulations state that escapeways must be maintained in a safe and travelable condition. Our definition of a safe and travelable escapeway is one that is maintained in its original mined condition. The drifts that were originally driven eight feet wide and nine feet high, should be maintained to that dimension.

For operations that experience very poor ground conditions the drifts should be maintained to a minimum width of four feet and height of five feet inside the supports. Unless the original drift size was less.

Where water is a problem, ditches should be maintained to keep the level below track or road level. In very wide escapeways, consideration should be given to the need for guide ropes that miners could use when travelling in dense smoke.

5.2 Fire Retardants

Many mines have timbered shafts and drifts. These wood lined passages can contribute to the rapid spread of what might have been a localized fire. Many mines are now using diesel powered equipment which create an additional fire hazard. A non-flammable passage becomes a very important means of localizing those fires which may occur.

Some new mines use non-combustible materials such as steel or concrete, however, timber remains the primary material in the majority of mines.⁽¹²⁾ Various treatments are available to reduce the flammability of wood. The treatments fall into two categories, impregnation with salt solutions and surface coatings.

Five retardants work in one or more of the following ways:⁽¹³⁾

- a. The retardant decomposes at a temperature below that of the temperature of wood; it gives off non-flammable gases which inhibits flame propagation on the material surface.
- b. The retardant decomposes and absorbs heat which may extinguish the flame.

- c. The retardant melts at a lower temperature than would ignite the wood, covers the surface with a glaze which seals the material from the air. It also holds any charcoal which acts as an insulator.
- d. The retardant induces a rapid formation of a heavy layer of charcoal, which by excluding air, prevents further combustion.

A list of several types of coatings is given in Appendix D.

Impregnation of the salt solution may be done by soaking at atmospheric pressure or at high pressure. It can only be done prior to installation. Impregnation is a more permanent method of fire resistance since it reaches the inner fibers and cannot be chipped off as can a surface coating.

Surface treatment is the only method possible on existing timbered passages. For this reason it is especially important as a means of providing fire resistance to the older mines which have not had any fire retardant materials used in the wood construction.

Most fire resistant points consist of potassium or sodium silicate with an inert filler such as kaolin or asbestos. Cement coatings, lime wash and calcium sulphate have also been used.

The fire resistant paints may be brushed or sprayed on the surface. The backside of the timber may be coated by spraying through systematically drilled holes. The major problem with coating material surfaces in place is the ability to attain 100 percent coverage. Without complete coverage, a fire would spread, although undoubtedly at a slower rate.

A Russian report⁽¹⁵⁾ indicates good results with a mixture of sodium silicate and asbestos powder. A test fire burned for 1.5 hours with temperature exceeding 1300°F and left the coated wood undamaged.

Salt solutions may be painted or sprayed on, but due to poor penetration, it's fire retardant capabilities will be questionable.

5.3 Warning Systems

An effective system of notifying miners is essential to an effective escape system. The ideal warning system would allow two way communication between the surface and each point within the mine where miners would be located. This, of course, would allow information on the disaster situation to be transmitted so that the proper escape plans may be used. Where possible, mines should be equipped with telephones.

An alternate warning system must be available to backup a phone system. The most common warning system is the use of stench (ethyl mercaptan-freon mixture). Stench is released into the compressed air and/or the ventilation system and ideally spreads throughout the mine. This method, when used only in the ventilation air, moves very slowly and in many cases too slow to be effective. In addition, most metal and non-metal mines have a great amount of recirculation and or dilution that results in the stench being unnoticed by the time it reaches the miners. For those mines that inject the stench into the compressed air line, the travel time is greatly improved. A serious problem with this system is that the miners may not be using compressed air at the time of the emergency and therefore will not receive notification. The computer simulation described in this report shows that many miners are notified by smoke, not the stench. Overall the best method would be the requirement that stench be released in both ventilation and compressed air. Even though the same problems are encountered the overall chances of notification are improved.

One possibility of improving this method of warning would be to locate the dump stations on each individual level and have the dump system activated remotely by the hoistman upon his notification of an emergency. An alternate warning method could be a surface located low frequency signal generator and a receiver powered with a lamp battery that could give both a visual and audio signal. The receiver could be attached to a roof bolt or wedge driven into the rib to pick up the signal. A small receiver could easily be carried by each crew during their shift and recharged in the same manner as the lamp battery. Where the mining plan permits, blinking lights or siren equipped vehicles are desirable alternatives.

An automatic warning system is under development in the U. S. Bureau of Mines Contract H0242016. The goal is to develop and demonstrate a reliable mine shaft fire and smoke control system.⁽¹⁴⁾ Initial tests of the system have proved successful.

5.4 Ventilation Systems

In most mines effective ventilation is a difficult problem in respect to escapeways. Most mines have a large amount of recirculation, e. g. leakage of intake air into exhaust air through stoppings. This problem, which may be relatively minor during normal operation, can become a critical one if a fire occurs. With recirculation, smoke can spread rapidly from the primary to the secondary escapeway. The mines' ability to comply with the rule "environmental damage to one (escapeway) will not lessen the effectiveness of the other" may be difficult in many mines. Typical leakage rates on well constructed new stoppings range from 5 CFM/100 ft² for foam coated to 35500 CFM/100 ft² for brattice cloth at 1" water pressure difference assuming no leakage at the junction of the mine surface and the stopping.⁽⁸⁾ A fire in one escapeway producing 1 percent carbon monoxide will contaminate the other escapeway to a dangerous level if the stopping leakage is only 4 percent. A problem in evaluating a ventilation system for leakage and recirculation is that

of proper instrumentation. Present equipment is adequate to determine volume and flow direction at any one point within a reasonable degree of accuracy. Equipment to measure the amount of leakage within the limits required to determine environmental damage does not exist today. Equipment will be required not only to measure the leakage through stoppings and bulkheads, but also to measure leakage through the strata around the stoppings and into or out of old workings.

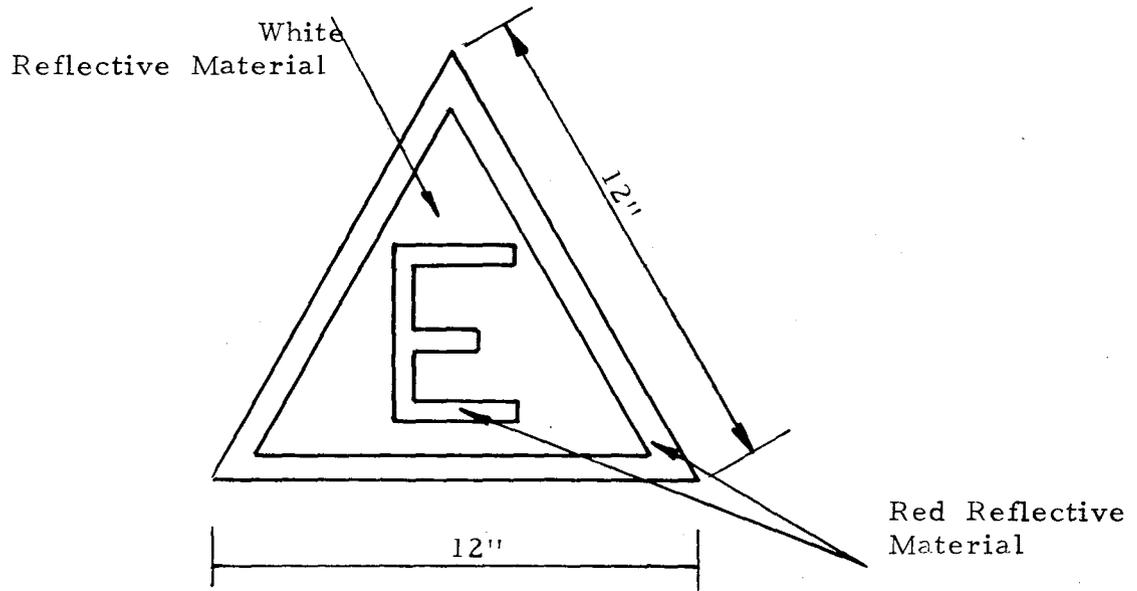
5.5 Escapeway Signs and Signals

The type and size of escapeway signs should be standardized. At present, each individual mine uses escapeway signs which are purchased or made to their own specifications. In some mines they are painted on pillars or timbers and tend to become covered with dust. We feel it is important to standardize the size, shape and color of signs for the entire industry including coal. Such a change would mean that when a miner moved from one mine to another or from one type of mining to another, he would always be familiar with the escapeways.

The signs should have a particular shape to designate primary and secondary escapeways. The shape should be such that a color blind person would not have to rely on colors. In addition to shape, the signs should also have individual colors for primary and secondary routes. Large signs should be placed at all major intersections and stations, smaller reflectors should be placed in primary and secondary escapeways so that one is always in view. Suggested escapeway signs are shown in Figures 7 and 8.

Bell signals used in hoisting operations are not, at the present, consistent throughout the mining industry. A standard signal code should be adopted to avoid serious delays during an emergency caused by personnel not familiar with the particular code of the mine. This subject has been approached before, but due to complex problems in arriving at acceptable signals with all Federal and State agencies, it has always been dropped. This a very important area and an effort should be made for standardization if effective escapeway systems are to be developed.

1. Primary escapeway sign to be placed at major intersections, shaft stations, raises, etc.



2. Secondary escapeway sign to be placed at major intersections, shaft stations, raise, etc.

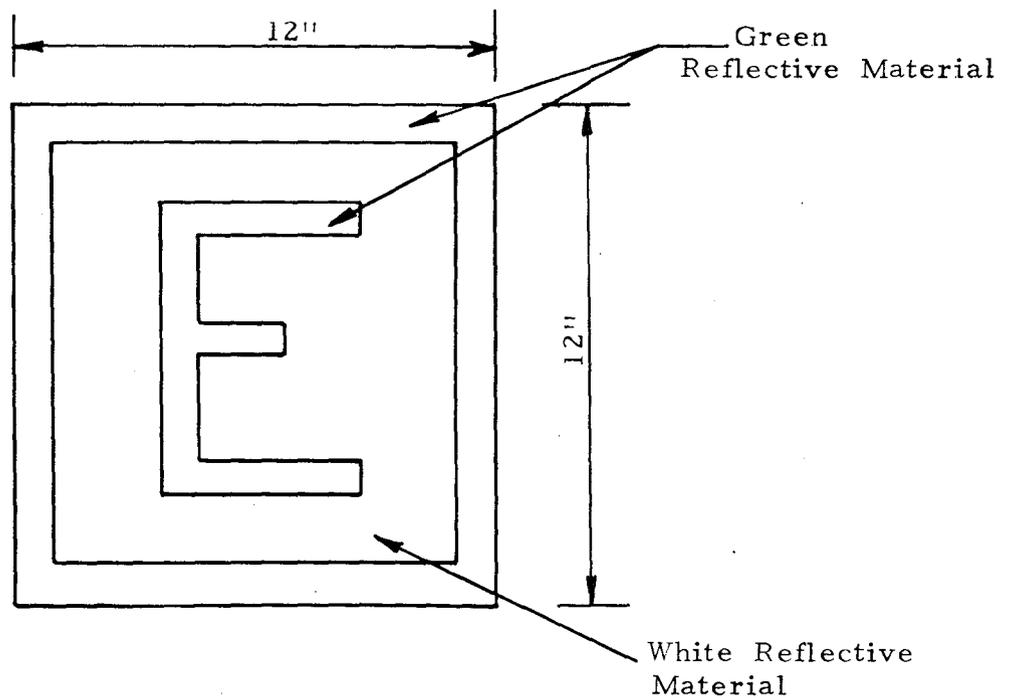
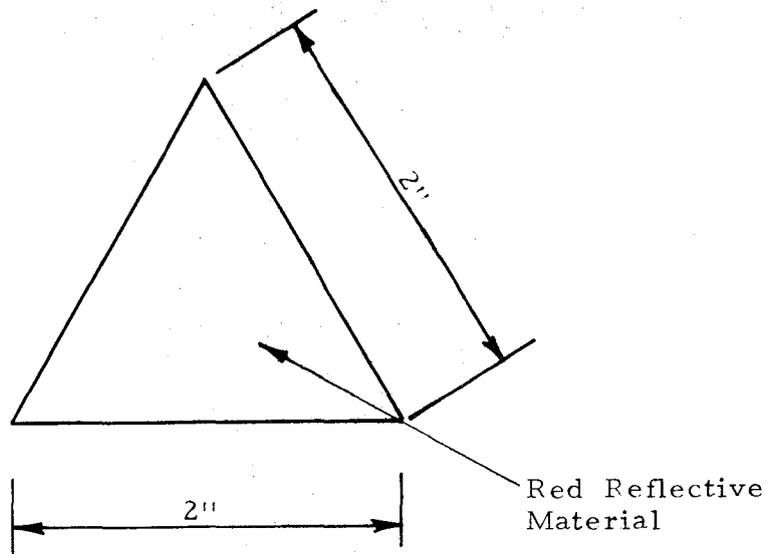


Figure 7 - Escapeway Signs

3. Primary Escapeway Reflectors



4. Secondary Escapeway Reflectors

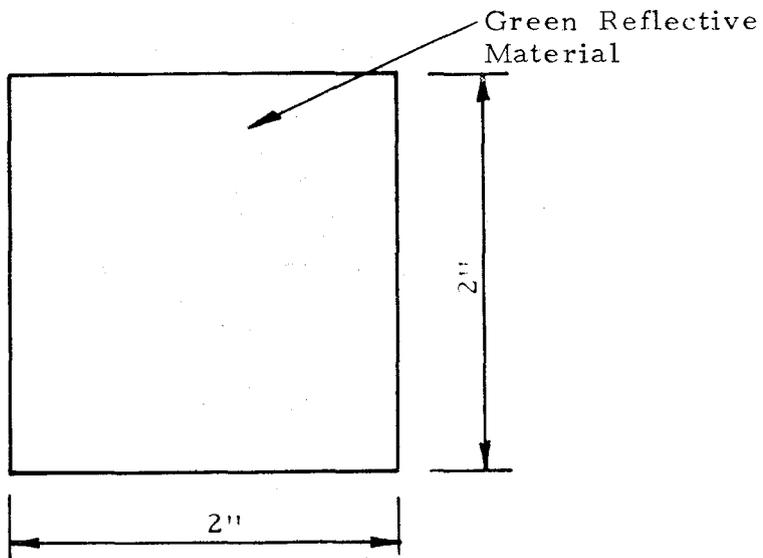


Figure 8 - Escapeway Signs

5.6 Auxiliary Transportation System

Transportation systems in metal and non-metal mines are as varied as the number of mines. Present methods of moving miners include hoisting, rail, rubber tired vehicles and walking.

Rail systems range from slow units operating on 18 gauge track to large high speed units on standard rail. In vein type mines the units are generally small and slow due to the many curves and narrow drifts. These units are usually battery powered. In large operations, such as block cave mines, it is possible to drive large straight drifts. This allows the use of large high speed units. These units are either powered by diesel, electric trolley or battery-trolley combination.

If the rail system is to be used as part of the emergency evacuation system, self-contained breathing apparatus should be provided for the operator. The system could be similar to those now required for underground hoist operators, but limited to two hours. This would be extremely important to operators on production levels who would be required to make several trips in smoke. If the operator had only his self-rescuer, it could create enough discomfort that he may not be able to make all the required trips.

The use of rubber tired transportation during an emergency has some advantages and disadvantages when compared to rail. It has the advantage of not being restricted to one travelway. In many mines this would allow several routes to the working places to pick up men and additional ways to exit. This flexibility also creates a disadvantage. Unlike the locomotive operator travelling in heavy smoke who does not need good vision to follow the rail, the rubber tired operator needs to see where he is going at all times or slow down. Again, as in the case of the locomotive, the rubber tired vehicles should be equipped with self-contained breathing units.

Other possible methods of emergency transportation which should be considered are conveyor belts, rope tows and man lift belts.

Many mines use conveyor belts for the transportation of ore. These systems in many cases would only require minor modifications such as a shut down bar at the point of discharge. This type of bar would stop the conveyor if a person failed to get off at the correct location. A simple restart switch could be located at the same point. The use of this system would require that all employees be trained in the proper methods of getting on and off a moving belt. In many mines this would provide the fast and safe method of exit.

The second method would be the use of a conventional rope tow or chain tram similar to those used at ski areas. They would be useful on ramps or inclines and would not require a straight drift.

The computer simulation of a mine evacuation included in this report shows that auxiliary transportation can be very effective in substantially reducing the time of evacuation. All mines should consider adapting their current transportation systems to be used as emergency escape facilities.

5.7 Fuel Storage

Fuel storage in underground mines entails greater risks than surface storage of fuel. The contents of a typical 500 gallon fuel tank, if burned, could create over 100,000 cubic feet of carbon monoxide and carbon dioxide, enough to contaminate the escapeways of most mines. Therefore, if fuel must be stored underground, extreme care must be taken to prevent spillage and fire.

In many situations a fuel line from the surface would provide a less hazardous means of delivering fuel to vehicles underground. Surface storage of fuel with lines to the required levels would

limit the amount of fuel in the mine to the capacity of the vehicle fuel tanks. A pipeline from the surface without pressure limiting devices could develop very high pressures, in excess of 3000 psi, at the filler nozzle. Therefore, a safe fuel line must have pressure regulation and flow limiting devices which will prevent high pressure fuel delivery and accidental spillage.

The refueling area in a mine should be located in a safe area out of the main stream of traffic. Figures 9, 10 and 11 show recommended ways of providing safe ventilated refueling areas for in mine fuel tanks and lines from the surface.

5.8 Escapeways - Guidelines

1. Except in situations where ground conditions will not allow, escapeways should be at least 6 feet high (excluding necessary roof support) and the travelway in such escapeway should be maintained at a width of at least 4 feet.
2. All escapeways shall be well drained or provided with walk boards.
3. In shafts, raises, winzes, or inclines, landing openings will be large enough to pass a litter.
4. Equipment for transporting men up ramps will be available within the length of time required to assure escape within the 45 minute time limit.
5. Inspection of escapeways by a qualified person shall be made every 14 days.
6. A record of escapeway conditions shall be maintained at the mine office.

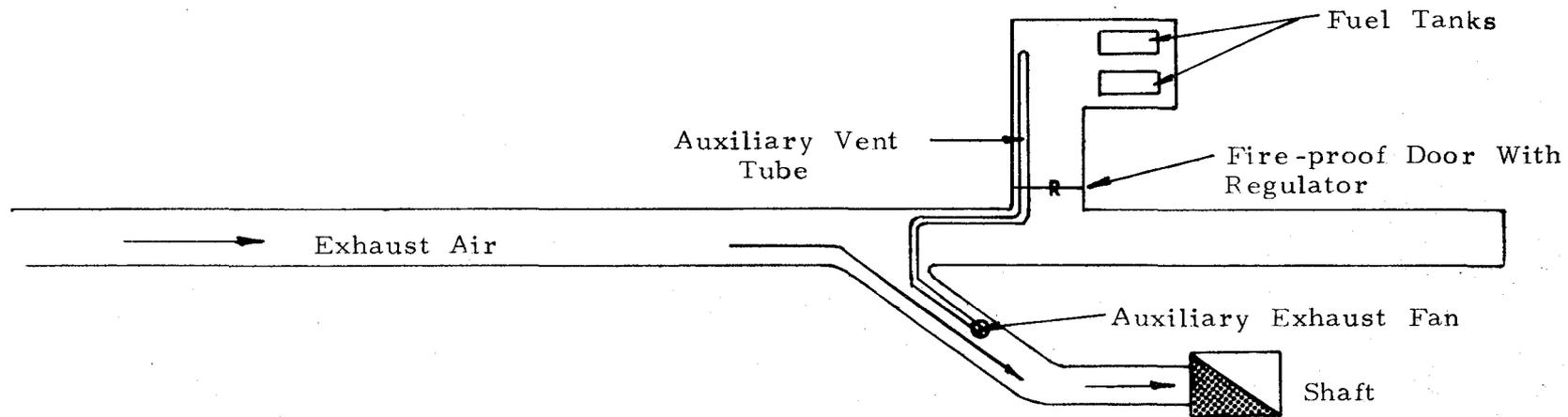


Figure 9 ----- Fuel Storage Area

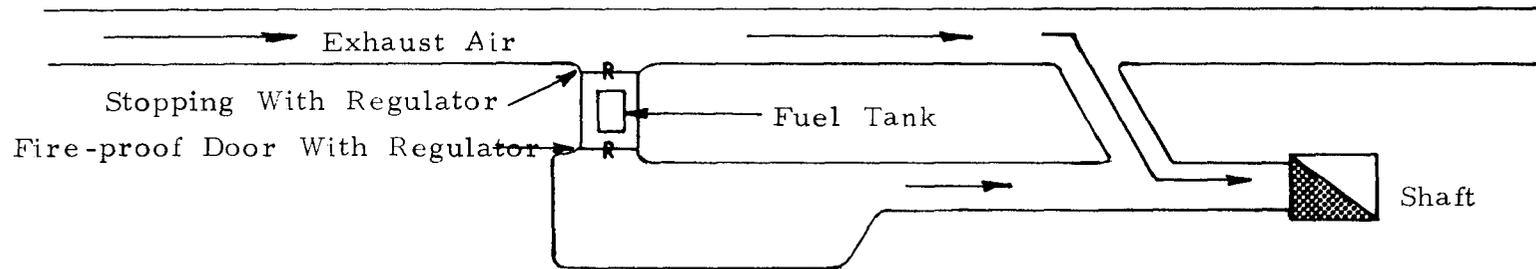


Figure 10 - Fuel Storage Areas

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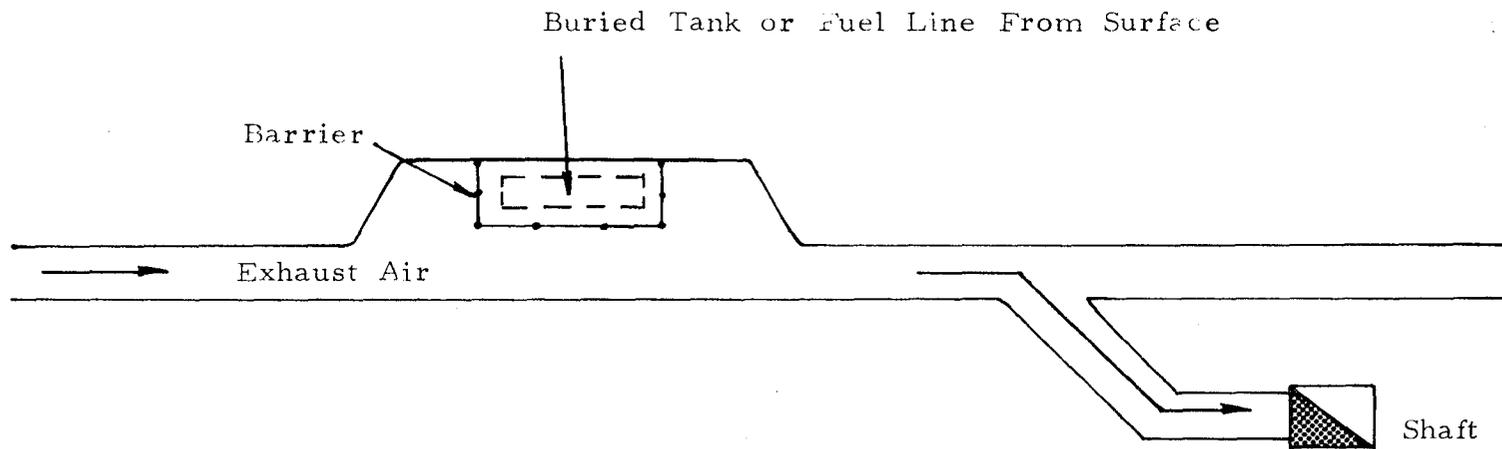


Figure 11 - Fuel Storage Areas

7. Escapeway signs shall be provided and maintained at all intersections and every 500 feet in long drifts.
8. At least 4 square inches of reflective material must be included with each escapeway sign.
9. All escapeway reflectors shall be 4 ft. above the floor and perpendicular to the wall.
10. All escapeway maps and plans shall show primary and secondary escapeways.
11. Emergency escape maps ("you are here" type) shall be posted to all major intersections, hoist locations, and shaft stations.
12. Evacuation warning systems shall be capable of notifying all personnel in time to allow escape in 45 minutes.
13. Normal position of air doors shall not be changed without instructions from the person in charge of the emergency evacuation.
14. Refuge chambers shall be provided at a distance of no more than 1000 ft. horizontally or 300 ft. vertically from development and exploration areas.
15. All vehicles used for mine emergency escape shall be equipped with a two hour self-contained breathing unit.
16. Fuel tanks may rest on foundations on the ground, or in mines not subject to squeezing ground, may be buried.

17. Fuel tanks not buried shall be located in a cross-cut or recess where vehicles travelling in the haulage-way cannot collide with them. Such a cross-cut or recess shall be ventilated by a separate split of air to a return or by auxiliary ventilation to a return. Air volumes should not be large, approximately 20 CFM⁽⁴⁾ per man working in the fuel storage area. Such a cross-cut or recess shall also be equipped with metal doors between the tank and haulageway, which shall remain closed except during fueling operations.
18. Buried tanks shall be located in a cross-cut or recess, or the area above them protected by a beam or barrier, so that vehicles cannot drive over them. If located in a cross-cut or recess, such a cross-cut or recess shall be ventilated as in (17) above, except that doors shall not be required.
19. No tank shall be located in an intake airway.
20. Stoppings and regulators used in ventilating fuel storage areas shall be of fireproof construction.
21. The fuel tank should not be located less than 100 feet to intake air shafts, magazines, hoppers where welding is done, or electrical switching gear.
22. The distance between any two flammable or combustible liquid storage tanks shall not be less than 5 feet.

23. Excessive amounts of fuel shall not be stored underground, the amount should be limited to a one week supply. Hoisting of fuel should be done during a single non-production shift each week, when the number of personnel in the mine is at a minimum.
24. Spillage shall be controlled by a non-flammable absorbent material which shall be periodically collected and disposed of outside the mine.
25. Fuel oil storage tanks shall be constructed of steel and designated as atmospheric tanks, i. e. designed to operate at pressures not greater than .5 psi gage.
26. Tanks shall be welded, riveted and caulked, brazed, bolted, or constructed by a combination of these methods. Filler metal used in brazing shall be nonferrous metal or an alloy having a melting point above 1000°F and below that of the metal joined.
27. Tanks shall be designed according to:
 - a. Underwriters' Laboratories, Inc., Subjects No. 142, Standard for steel aboveground Tanks for Flammable and Combustible Liquids, 1968, or
 - b. American Petroleum Institute Standards No. 12A, Specification for Oil Storage Tanks with Riveted Shells, Seventh Edition, Sept. 1951, or,
 - c. API Standards, No. 650, Welded Steel Tanks for Oil Storage, Fifth Edition, July 1973.

28. Venting for tanks:

- a. Atmospheric storage tanks shall be adequately vented to prevent the development of vacuum or pressure sufficient to distort the roof of a cone roof tank or exceeding the design pressure in the case of other atmospheric tanks, as a result of filling or emptying, and atmospheric temperature changes.
- b. Normal vents shall be sized either in accordance with: (1) the American Petroleum Institute Standard 2000 (1968), Venting Atmospheric and Low-Pressure Storage Tanks; or (2) other accepted standards; or (3) shall be at least as large as the filling or withdrawal connection, whichever is larger but in no case less than 1 1/4 inch nominal inside diameter.

29. Tank openings other than vents:

- a. Connections for all tank openings shall be vaportight and liquid-tight.
- b. Each connection to an aboveground tank through which liquid can normally flow shall be provided with an internal or an external valve located as close as practical to the shell of the tank. Such valves, when external, and their connections to the tank shall be of steel except when the chemical characteristics of the liquid stored are incompatible with steel. When materials other than steel are necessary, they shall be suitable for the pressures, structural stresses, and temperatures involved, including fire exposures.

- c. Each connection below the liquid level through which liquid does not normally flow shall be provided with a liquid-tight closure. This may be a valve, plug, or blind, or a combination of these.
 - d. Openings for gaging shall be provided with a vaportight cap or cover.
30. Supports, foundations, and anchorage for all tank locations.
31. Buried tanks:
- a. Tanks shall be lowered into the excavation with care to prevent puncturing, shall be backfilled with fine material tamped in layers to prevent settling, and shall have at least one foot of cover.
 - b. When the vertical length of the fill and vent pipes is such that when filled with liquid the static head imposed upon the bottom of the tank exceeds 10 psi, the tank and related piping shall be tested hydrostatically to a pressure equal to the static head thus imposed.
 - a. General: Tank supports shall be installed on firm foundations. Tank supports shall be of concrete, masonry, or protected steel. Single wood timber supports (not cribbing) laid horizontally may be used for outside above-ground tanks if not more than 12 inches high at their lowest point.

- b. Fire Resistance: Steel supports or exposed piling shall be protected by materials having a fire resistance rating of not less than 2 hours, except that steel saddles need not be protected if less than 12 inches high at their lowest point. Water spray protection or its equivalent may be used in lieu of fire-resistant materials to protect supports.
 - c. Load Distribution: Every tank shall be so supported as to prevent the excessive concentration of loads on the supporting portion of the shell.
 - d. Foundations: Tanks shall rest on the ground or on foundations made of concrete, masonry, piling, or steel. Tank foundations shall be designed to minimize the possibility of uneven settling of the tank and to minimize corrosion in any part of the tank resting on the foundation.
 - e. There should be voice communication between personnel at the in-mine tank and personnel at the surface tank when the in-mine tank is being filled.
 - f. Wherever possible, the filler pipe should be located in a separate utility borehole rather than in a shaft that is used for the hoisting of personnel.
32. Lines from surface storage tanks used for direct filling of vehicle tanks must have flow and pressure limiting devices which insure a maximum delivery pressure no greater than 10 feet level.

6. Computer Simulation of Mine Evacuation

Analysis of mine evacuation involves manipulating a large number of interacting variables, such as mine passages, hoist movements, miner position etc., which makes the problem very difficult to solve without use of a digital computer. Therefore, under this contract, a computer program is written to simulate evacuation of a mine under different configurations. The simulation input variables include characteristics of the mine, expressed in the form of a network of passages, properties of hoists and hoisting strategies, initial miner positions, ventilation and compressed air velocities, stench warning system and self-rescuer capabilities. The simulation can be carried out for cases in which there is no fire, i. e., fire drill simulation, or for cases in which there is a fire at any arbitrary location. The fire is assumed to generate gases which impede movement of miners in the gaseous region. However, the thermal effect of the fire on ventilation or on the miners is not considered. The simulation output includes the evacuation time for each miner, movement of the hoists, propagation of smoke through the mine passages and smoke exposure time of the miners.

Details of the mine evacuation program are summarized in Appendices A and B. Appendix A describes structure of the program and its capabilities. The flexibility of the program and its suggested uses are demonstrated by a number of illustrative examples. Appendix B is a user's manual for the program which includes instructions for program use and explanation of the logic employed in the program. A computer listing and printout of a typical output are also included in the Appendix B.

The ten illustrative examples summarized in Section A.4 (Appendix A) provide proof of validity of the program and help make certain inferences about mine evacuation. The first example, which is simulation of an actual mine fire drill conducted in a mine, has predicted evacuation time within 5 percent of the actual evacuation time in the fire drill, demonstrating thereby, the ability of the program to make accurate predictions.

The illustrative simulations have indicated that increasing hoisting speed and cage capacity and decreasing loading and unloading times result in a significant reduction in evacuation time. The cage capacity can easily be increased by additional man cages or levels to the existing configuration.

In certain cases, the program has predicted that the smoke notifies some miners before the stench warning system can.

The illustrative simulations also include cases where the hoisting strategy has been altered. If hoisting priority is given to miners on the fire level, total evacuation time increases, but the miners in the greatest danger are evacuated to a safe level sooner. If the simulations are to be carried out for a mine with downcast shafts on the main hoist, such alternate strategies will result in a reduction of smoke exposure.

Importance of providing miners with a secondary escape route in case the main escape route is found to be blocked, is demonstrated by two of the cases considered. These cases indicate that it may be possible to save a large number of miners by such a route, even though it is downstream of the fire.

In some cases it may be advantageous not to use the clutched hoist in a double drum configuration. If the miners are dispersed on different levels, as in the cases considered, the clutched hoist is used only for one or two trips before it has to be declutched.

These cases point out the applicability of the program to analyze a large number of situations. The tremendous flexibility built into this program allows evacuation of a mine to be simulated for any variation of ventilation, hoist speeds and capacities, stench warning systems, self-rescuer capacities, travelling rates, miner instructions, etc. By careful use of this program, a realistic assessment of an emergency evacuation can be made and the fire escape procedures may be optimized.

7. Hoisting Systems

Hoists used solely for emergency escape use should above all, be simple and dependable. The hoist systems' motive power should be independent of all other mine equipment so that only an emergency in the immediate vicinity of the hoist will render it inoperative. The hoist should receive the same high level of inspection as is normal with any other man hoisting system. It should be operated at regular intervals, and must include sufficient safety devices to ensure safe operation when hoisting men. Of equal importance, however, safety devices must be included to safeguard the hoist system from inadvertent damage due to inspection, maintenance or operator error. In an emergency situation the hoist operator will be under considerable stress and the system must be simple and foolproof to operate.

Under normal circumstances the hoist will only be operated during the regular inspection cycle. Because of this very low operational use rate, certain requirements, normally associated with man hoisting, can be relaxed. In particular the wire rope installation requirements, in terms of drum and sheave diameter and fleet angles, can be reduced provided that rope inspection during the system life is maintained at a high level.

The following section includes recommended guidelines for emergency hoist system design, installation, operation, maintenance and inspection. A summary of available hoisting equipment and components is included in Appendix C.

Emergency Hoist Guidelines

All hoists designated as part of a mine emergency escape system shall meet the requirements of the Emergency Hoist Guidelines. Where these hoists are also utilized for hoisting other than emergency hoisting, the requirements of Title 30, Code of

Federal Regulation, Chapter I, Part 57, also apply. In areas of conflicting requirements, the Federal Code shall take precedence.

The following Emergency Hoist Guidelines are based on 30 CFR Part 57.19.

Emergency Hoist Guidelines

1. 57.19-1 applies.
2. 57.19-2 applies.
3. Rope shall not be used to connect driving mechanisms to emergency hoists. Belt, gear or roller chain drives are acceptable. Drive selection shall be in accordance with source manufacturers recommendations.
4. All hoists shall be equipped with two independent braking systems. Each braking system shall have a rated capacity of at least 150 percent of the maximum load. At least one brake shall be installed on the winch drum. The winch drum brake shall be spring or gravity set, and operated by the emergency stop control, the overspeed and the over and undertravel sensors.
5. 57.19.5 applies.
6. Hoists shall be provided with devices that automatically apply the brakes in the event of power failure.

7. All emergency escape hoists shall be provided with devices to prevent overtravel and undertravel. When utilized in shafts exceeding 100 ft. in depth, such hoists shall also be provided with overspeed devices. Overspeed sensing devices shall be directly driven off the hoist drum.
8. 57.19.8 applies.
9. The hoist operator shall have an accurate and reliable indicator which shows the cage position at all loading and unloading stations. The accuracy of the indicator shall be sufficient to ensure safe loading and unloading of the cage. The indicator may be a linear or rotary pointer device, a digital readout or identifying marks on the wire rope.
10. 57.19.10 to 13 inclusive apply.
11. All hoists powered directly or indirectly by internal combustion engines shall have the coolant or lubricating oil maintained to at least 60 °F. Where heaters are required they shall be permanently installed. "Dip-stick" heaters are not permitted. Batteries, where required, shall be equipped with trickle chargers and capable of three 30 second engine cranking tests (at 1 minute intervals) without stalling the starter motor.
12. All hoists, using a fuel powered engine, shall be provided with a fuel tank. The quantity of fuel stored shall be adequate for 1 hour of continuous operation with the cage fully loaded. The mine

operator shall determine the fuel consumption/ lifting cycle from an average of five continuous cycles with a fully loaded cage. The calculation and tank size estimate should be submitted to the District Manager (MESA) for approval. Fuel tanks shall be equipped with a measuring stick or gauge which indicates the fuel quantity stored (accuracy shall be \pm 5 percent). Tanks shall be equipped with a glass bowl (or equivalent) in which water or sediment will collect and be discharged. A drain petcock shall be provided. Tank access points shall be fitted with highly visible seals which when broken will highlight the fact that fuel has been removed from the tank. Above ground fuel tanks shall not be located in direct sunlight. Tank installation shall conform to the requirements specified in Paragraph 5.8.

13. Each emergency escape hoist shall be powered from a power source that is independent of both the power source, and the power source routing, that supplies the other emergency escape hoist that services that level.

14. All electric hoists provided with auxiliary power shall be provided with two circuit breaker combination type starters (NEMA Part ICS-2-327A) with interlocks, or an automatic transfer switch (NEMA Part ICS-2-447). All electrical connections for the auxiliary power supply shall be clearly labeled.

15. When any junction with the main mine power distribution is made, suitable circuit protection shall be provided for the branch going inby the emergency escape hoist branch. This protective equipment shall prevent loss of power to the mine power circuit serving the emergency hoist.
16. Suitable overvoltage protection shall be provided to prevent sufficient damage to the operating system to render it inoperative. This protection shall be located within reach of the hoist operator so that it can be reset by the operator.
17. An undervoltage relay shall be provided to prevent the hoist from starting unexpectedly if the operating controls are left in the operating position after a power failure. This relay may be set at the minimum value required to raise the hoist.
18. Alternating current electric motors shall be provided with open phase or phase failure and reverse phase protection to prevent the possibility of motor reversal.
19. Adequate ground protection shall be provided for each conductor, pair of conductors, (or more) from the hoist to the nearest outby circuit protection. The ground wire shall be equal to half the size of the largest conductor and shall be monitored continuously. The ground monitor wire shall be at least equal to a No. 8 AWG wire or larger where used.

20. To increase the operational potential of the system in the event of dire emergency, manual overrides should be provided for overload protection, under-voltage protection, ground monitoring protection, overtravel, undertravel and overspeed. This manual override should consist of positive action required by the operator such as breaking a glass window (similar to those used in fire alarms) and pulling a lever down. One window should be provided for each function. In essence the protective devices ensure that the hoist is protected from damage during the regular maintenance and inspection cycles, thus maximizing its effective availability.
21. When power from more than one major branch circuit or source is readily available for 12 months or more, facilities for connecting each circuit or source, including isolating switches, shall be provided so that a maximum number of power sources are available for the hoist.
22. The United States of America Standards Institute specification cited in "Wire Ropes for Mines", M11.1-1960, or the latest revision thereof, should be used in the selection, installation and maintenance of wire ropes used for hoisting. Where the M11.1-1960 requirements conflict with the Emergency Hoist Guidelines, the latter shall apply.
23. 57.19-21 to -27 inclusive apply.
24. 57.19-35 applies.

25. Head frames should be high enough to ensure that the clearance between the bottom of the sheave or drum and the uppermost part of the rope connection to the cage exceeds 3 ft. The cage position for this requirement is the position at which the cage stops when an empty cage is driven at maximum speed into the overtravel limit sensor.
26. Fleet angles between the headsheave and the drum shall be such that the rope winds consistently on the hoist drum. The angle shall be such that rope wear is not excessive when the system is operated at a duty cycle specified in 46.
27. The minimum diameters of headsheaves and hoist drums should conform to the minimum requirements specified by the wire rope manufacturer. Rope duty cycle should be based on the operational inspection cycle specified in 46.
28. 57.19-40 applies.
29. All cages operating in shafts where the angle of inclination to the horizontal is in excess of 45° shall have a $1/8$ in. thick steel bonnet. Cages shall be designed to accommodate a 120 lb/ft^2 live floor loading. Cages in inclined shafts shall be designed to accommodate a 50 lb/ft^2 internal side loading. Vertically operating cages shall be designed to accommodate an internal loading of 50 lb/ft of side horizontal perimeter.
30. Cages unsupported by guides shall be fully enclosed with a door that can be operated from inside and outside the cage. Free-hanging cages should have

all top and bottom edges tapered or bevelled for a minimum of 6 in, of vertical height to prevent hangups on the shaft wall.

31. Cages shall be of sufficient size to accommodate a loaded litter or stretcher.
32. When a manually operated emergency hoist is installed, a minimum of one trained operator must be available to operate the hoist within 5 minutes of the emergency escape initiation. The hoistman must be available on the same level as the hoist at all times that men are protected by the emergency escape hoist.
33. 59.19-56 to -63 inclusive apply.
34. Provided the cage is empty it is permissible to lower the cage using only the hoist brakes.
35. 59.19-67 to -76 apply.
36. 59.19-81 applies.
37. Two communication systems shall be installed within easy reach of the hoist operator and at least one system shall be in reach of those in the cage. The operating code and directions for its use shall be posted at the hoist control, at all stations, and within the cage. Any sound signals shall be audible to the hoist operator during the hoisting operation.
38. Simple step-by-step directions for operating the hoist shall be posted at the hoist.

39. An eight hour supply of bottled air shall be available for the hoist operator at the hoist station. This air supply should include a 2 hour portable air supply.
40. 57.19-100 applies.
41. The shaft designated as the Emergency Escape Shaft shall be free of all obstructions except those explicitly permitted in these guidelines.
42. Any shaft not sealed from ground water shall be maintained free of any ice buildup which could prejudice the operation of the hoist.
43. 59.19-120 to 128 inclusive apply.
44. Where internal combustion engines are used they shall be started on operating days and run until they reach normal operating temperature.
45. A qualified person shall inspect the hoist on operating days to ensure that all equipment is in proper working order.
46. Each hoist shall be operated for one complete lifting cycle every 7 days. Every 28 days the cage shall be loaded to capacity (live or dead weight) when the lifting cycle is performed.
47. All fluid levels shall be inspected and maintained every day.

8. Refuge Chambers

8.1 Refuge Chambers - Technical Discussion

8.1.1 Introduction

As a part of the overall escape system, refuge chambers can provide a last resort when existing escapeways are blocked. These chambers are intended to provide both protection from toxic gases and a life supporting environment for a period of time before external rescue or further escape efforts can be carried out.

Escapeways may be blocked physically (due to cave-ins, etc), by fire, or by the presence of a toxic or oxygen deficient atmosphere. In the first two cases, the trapped miners would most likely await external rescue efforts, and hence the design of the chamber will have to consider the time durations that such efforts may take. It is also possible, in the second case, for fire fighting and fire protective equipment to be stored in the chamber so that miners may attempt their own escape. In the third case, it should be recognized that a compact, beltmounted 1-hour self-contained breathing apparatus has been developed⁽⁹⁾, and that other, less compact equipment is available for up to 4 hours of self-contained breathing supply. If such equipment were stored in the chambers, then miners could escape by travelling from chamber to chamber, taking temporary refuge in each before proceeding to the next.

8.1.2 Background

The concept of "barricading" has long been recommended for those emergencies where miners are trapped inby a fire. Barricading, which is the construction of a makeshift shelter in a crosscut or deadend, protects the entrapped miners from toxic gases and enables them to conserve a supply of air. In this manner, they can survive two or three days--hopefully enough time for them to be reached by rescue teams. In the past, many lives have been saved with this technique.

A modern outgrowth of the barricading concept is the establishment of pre-existing chambers. These chambers would be situated at critical locations throughout the mine, such that they would provide readily accessible refuge for entrapped miners during an emergency. The concept of an emergency shelter can be implemented by sealing off a section of a drift with bulkheads, each fitted with a door. Only one bulkhead would be needed at a dead end. The shelter, which is the space between the bulkheads, could be equipped with emergency provisions capable of sustaining a number of men for several days. The bulkheads themselves would serve to prevent the contamination of the supply of fresh air within shelter by toxic gases on the outside.

There are some important questions which must be addressed before the emergency shelter concept can be practically implemented. These can be summarized as follows:

1. Placement - where shall the shelters be located, and how many are required?
2. Equipment - what supplies and equipment shall be provided in an emergency shelter to maximize the chances of survival of entrapped miners.
3. Refuge Chamber Design - what kind of chamber structure would most efficiently satisfy the sealing requirements.

The problem of placement must consider the basic emergency escape plan of the mine. Shelters can be placed near each working place, at shaft stations, or at intermediate locations. It is important that the shelters be placed not only where they will be accessible during an emergency, but also where miners are likely to be when they realize that they must seek refuge in a shelter.

Based on these considerations, MESA has proposed regulations which would require refuge chambers at the following locations:

1. At all shaft stations, before development of the level has exceeded 300' horizontally.
2. In areas which are greater than 1000' horizontally and 300' vertically from two independent escapeways.

Because of the large variation in mining methods within the category of metal and non-metal mines, methods for satisfying requirement (2) will have to be designed to suit the particular mining situation⁽⁶⁾. Consideration must be given to the fact that miners may travel good distance from their working place before the decision is made to take refuge in a chamber⁽⁷⁾.

The equipment associated with a shelter has received considerable attention in a recent U. S. Bureau of Mines program carried out by the Westinghouse Corporation⁽¹⁾. This program included the development of a completely self-contained explosion-proof chamber for coal mine applications. All life support provisions, including air purification, food and communication equipment were developed with the chamber. In the subsequent paragraphs of this section we shall review the general life support requirements for chambers in metal/non-metal mines, and various methods of implementing these requirements.

The construction of rescue chamber bulkheads for metal and non-metal mines is considerably simpler than for coal mines due to the absence of gas and the associated explosion hazard. The primary requirements will be resistance to static pressure levels, and a minimization of leakage. The configuration of the chamber as a whole will depend on chamber location and life support equipment.

The following sections will deal in greater detail with the questions of chamber configuration and construction, life support requirements, and potential life support systems.

8.1.3 Rescue Chamber Configuration and Construction

8.1.3.1 Chamber Types

The type of refuge chamber design depends upon the conditions in the mine at the required location. The ideal chamber would have a borehole to the surface through which air, water and food could be passed to the trapped miners. A slight positive pressure could be maintained to ensure no leakage of contaminated air into the chamber. The second best design would have a dual source of compressed air to the chamber. If conditions prevent boreholes or air lines to the chamber there are other options. A chamber can be made large enough to hold a volume of air sufficient to keep miners alive for considerable periods of time without any other atmospheric conditioning equipment. If a large chamber is impossible or if the mine is hot, atmospheric conditioning equipment will be necessary to sustain life.

This section on refuge chambers treats three basic variations of refuge chamber designs:

1. Chamber with outside air source (minimum volume).
2. Chamber with self-sustained atmospheric conditioning equipment (moderate volume).
3. Chamber with no air source and no atmospheric conditioning equipment (maximum volume).

The type of chamber selected for a particular application will depend on the type of mine and the location of the chamber within that mine. For example, it would be wise to consider a chamber with a borehole at shallow depths, but it would not be practical to consider a borehole (or compressed air) at chamber locations remote from the surface. Other variables, such as surface power supply, available space, and alternative usages of the chamber must be considered in the ultimate selection of chamber type. If a tail drift is used as a shaft station refuge chamber for example, then it will likely be used for storage as well, and hence the bulkhead must be designed for the frequent passage of material handling equipment. Also, it is unlikely that a tail drift will provide a large volume chamber. On the other hand, it may be possible to have dual power supplies and compressed air lines at such a location.

8.1.3.2 Leakage

The question of leakage concerns the contamination of the chamber by external toxic gas (primarily CO). Pressure differentials across the bulkheads resulting from changes in atmospheric pressure or other sources will cause leakage into and out of the chamber to occur. Unless the chamber is internally pressurized from an external source (Type 1), it is not possible to completely prevent such leakage. Even in sophisticated structures such as aircraft, a positive air flow is required to maintain pressure differentials. The completely enclosed chamber designed by Westinghouse exhibited a leakage rate of 8 cfm at 26" of water pressure differential⁽¹⁾. A bulkhead sealed against the rough rock surfaces will undoubtedly experience greater leakage. For example, tests of a 900 cu. ft. chamber formed by sealing a crosscut with a urethane foam ventilation stopping leaked at a linear rate of 5 cfm per inch of water pressure differential⁽⁸⁾. Leaks through the strata will also contribute to the larger leakage rates.

In any event, rescue chamber design must consider the leakage possibility. For Type (1) chambers, the outside air source will have to supply sufficient air to insure that leakage is out of the chamber (Figure 12). The blower or compressor must be capable of developing a measurable positive pressure inside of the chamber within its flow capabilities. It is anticipated that this requirement will be well within the capacities of conventional air supplies for a reasonably sealed chamber.

For Type (2) chambers we can consider three possibilities (Figure 13). The first type is one in which an external pressure differential is vented directly into the CO scrubber system, (see Figure 13a). This venting would short circuit all other leakage paths, and thus a pressure balance would be maintained inside and outside the chamber. In order to make this venting effective, the leakage rate for a given pressure differential through the chamber must be negligible compared to the flow rate through the scrubber. This can be determined by comparing the pressure flow characteristic of the scrubbing system with that of the chamber itself.

If the above requirement can not be met, an alternative is to maintain a positive pressure within the chamber by drawing in air from the outside using a fan (see Figure 13b). The air flow rate must be within the capacity of the scrubbing equipment. The chamber must be sufficiently sealed so that a positive pressure will be developed at that flow rate.

The third option is simply to continuously purify the contaminated air as it develops due to chamber leakage (Figure 13c). In terms of leakage rates vs scrubbing capacity, this approach is equally feasible as the two mentioned above. The only difference here is that a circulation must be maintained within the chamber so that the air is uniformly purified.

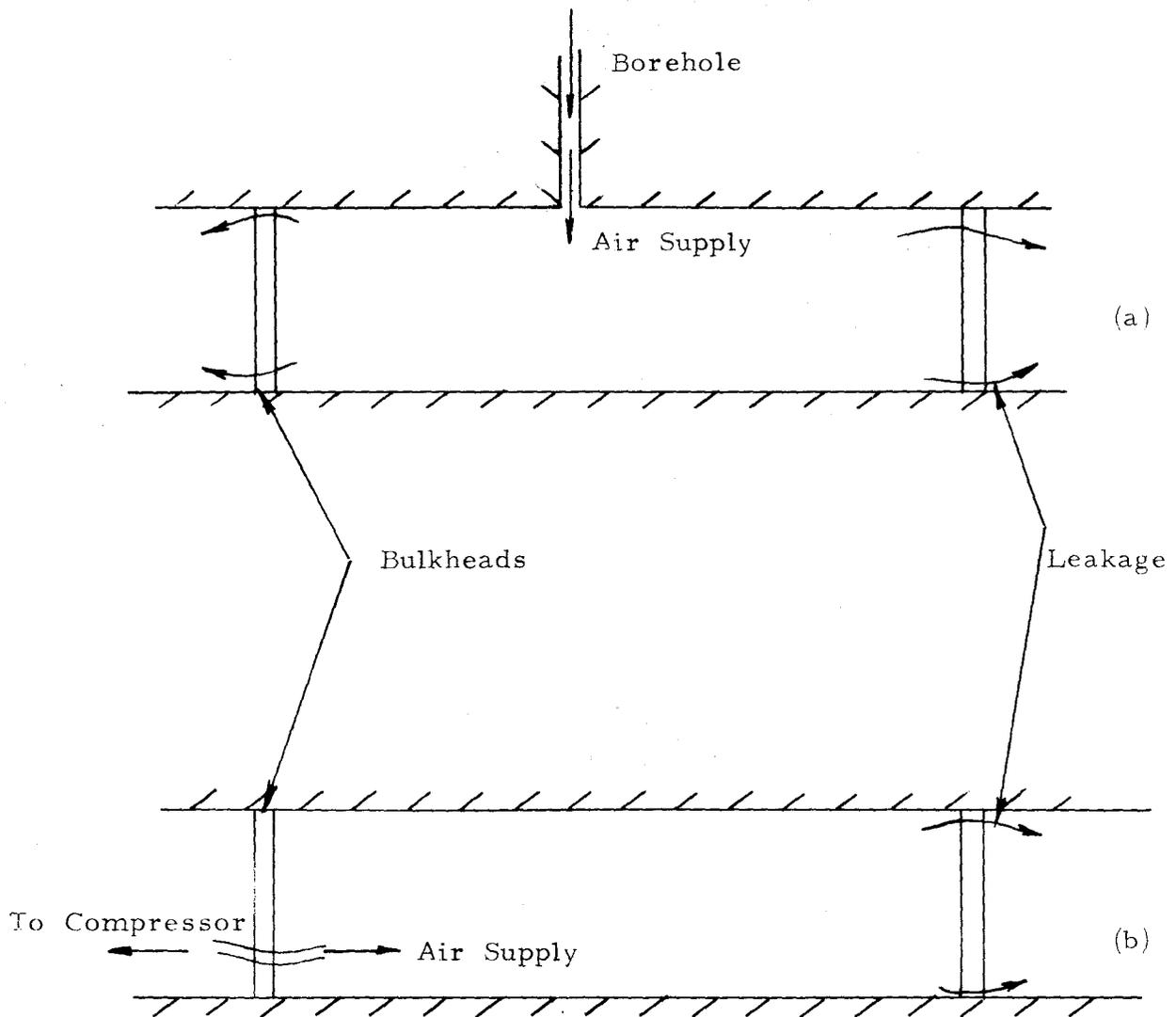


Figure 12 - Type (1) Chambers - Leakage Considerations
 (a) External Air Supply Through A Borehole
 (b) External Air Supply Through Composite Air Lines (Dual Supply)

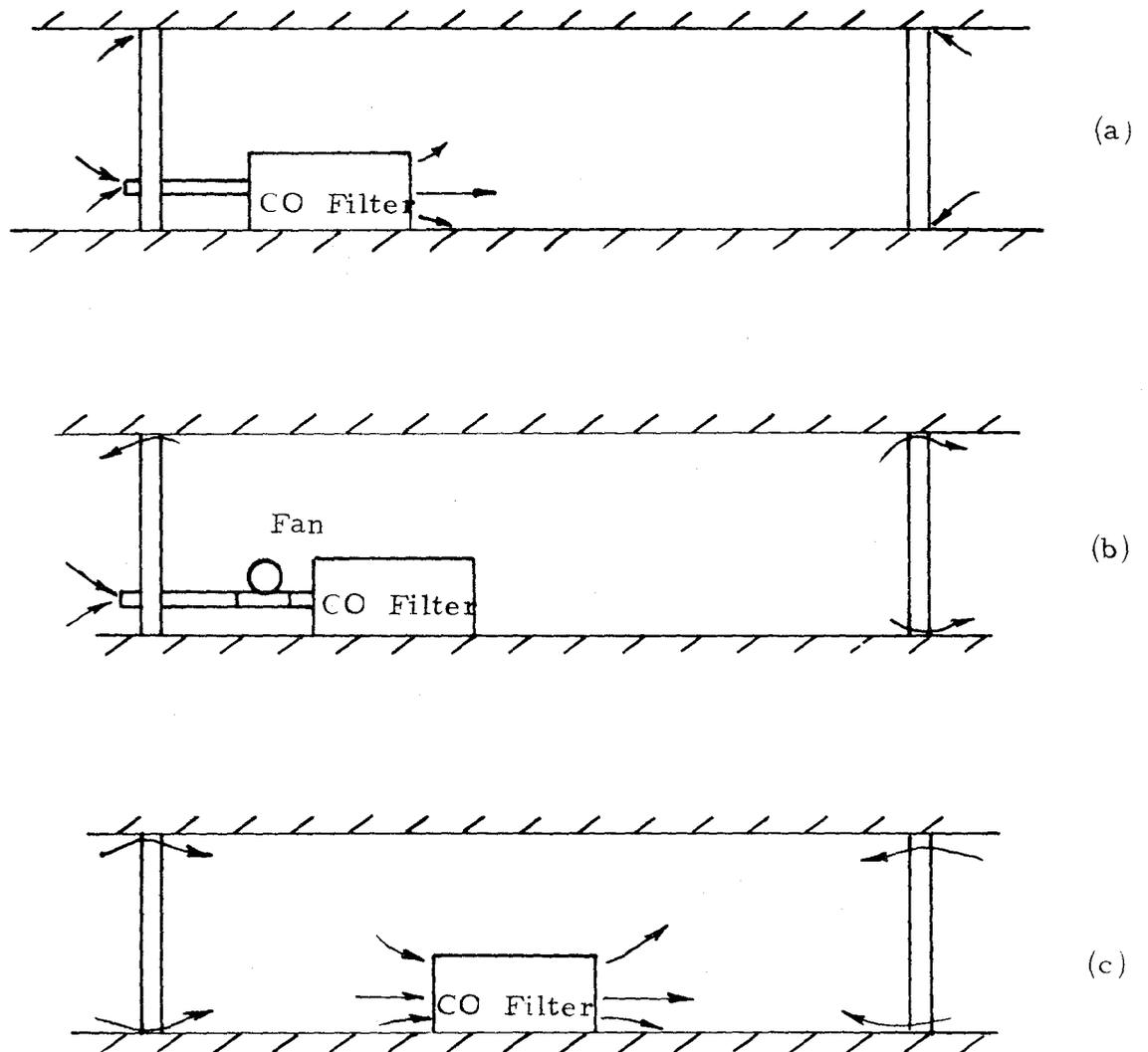


Figure 13 -Type (2) Chambers - Leakage Considerations

- (a) Passive venting through scrubbing unit - external leakage minimized.
- (b) Positive venting with fan. Leakage out of the chamber guaranteed.
- (c) Internal filtration. Overall CO level due to leakage is stabilized.

For Type (3) chambers, leakage will gradually contaminate the chamber air until CO concentrations will become intolerable. The tolerable leakage rate will depend on the chamber volume, the CO levels in the nearby atmosphere, and the total time of entombment. This figure can be on the order of small fractions of a cfm.* The maximum leakage into the chamber will be associated with the equalization of pressure inside and outside the chamber. This can be on the order of 1 to 2 cfm.* The sealing of the chamber provides a time delay on the leakage into the chamber due to an external pressure rise. This is illustrated in Figure 14.** The extent of the time delay can be estimated from the parameter $V/14.7A$, where V is the chamber volume, A is the chamber leakage coefficient, and 14.7 is the nominal atmosphere pressure. For chamber volumes ranging from 10,000 to 70,000 cu. ft., and for the range of leakage data available, this time delay can range from 7 minutes to 10 hours.

One solution to this leakage problem is shown in Figure 15. If there is a pressure increase outside of the bulkhead, the duct will short circuit any leakage that may have otherwise occurred through and around the bulkhead. The gas flow in the duct expands the bladder, and this expansion equalizes the pressure inside and outside the chamber. This eliminates the possibility of further leakage. The fan shown in the figure can be used to guarantee a slight positive pressure inside the chamber. In this latter configuration, one must consider the possibility of leakage in the duct and bladder connections.

8.1.3.3 Chamber Construction

The principal structural element of a chamber is the bulkhead. The bulkhead should be designed and built with the following criteria in mind.

* See Section 8.1.5

** See Appendix E for the supporting analysis

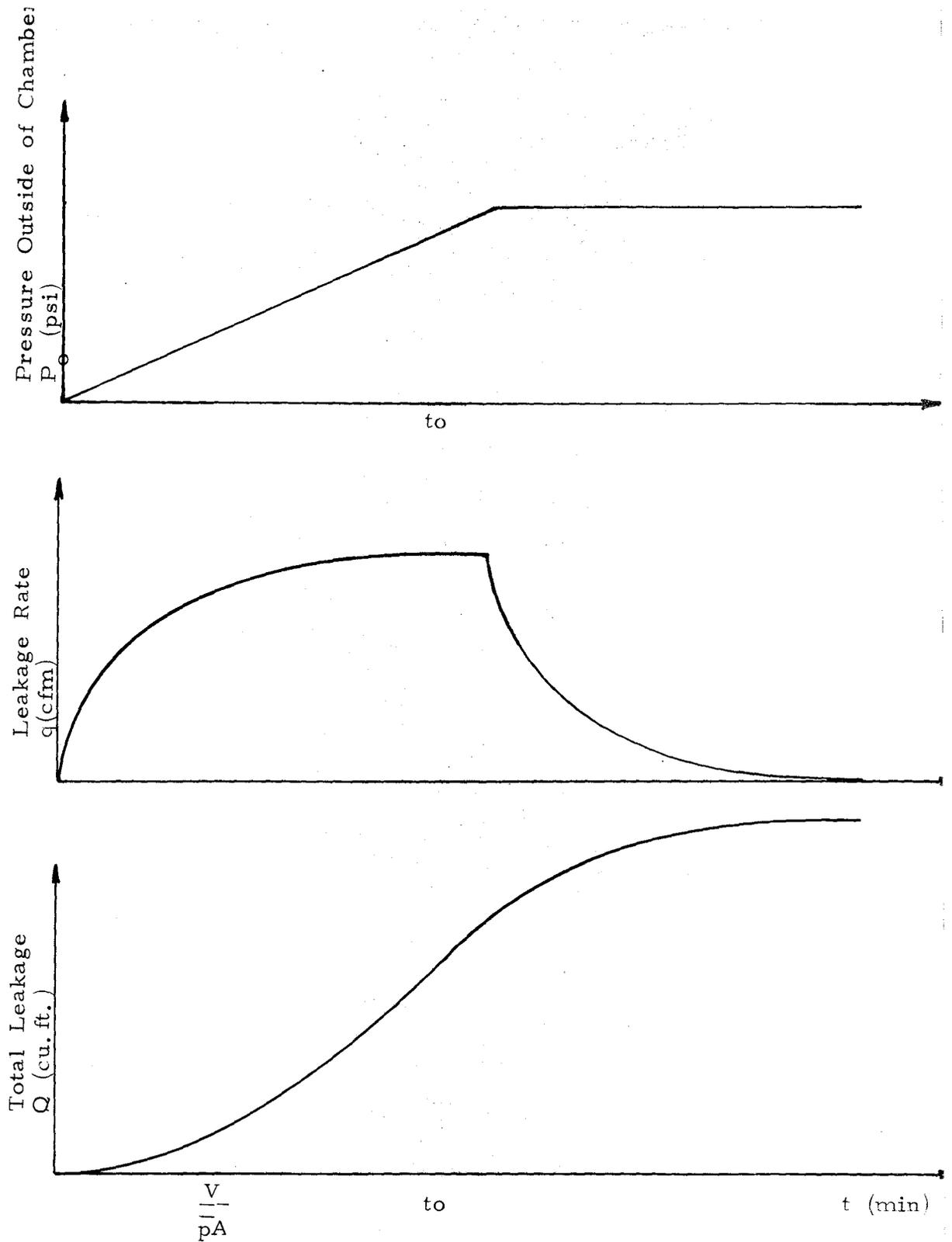


Figure 14 -Leakage Characteristics Of A Rescue Chamber Subjected To A Uniform Rise In Barometric Pressure

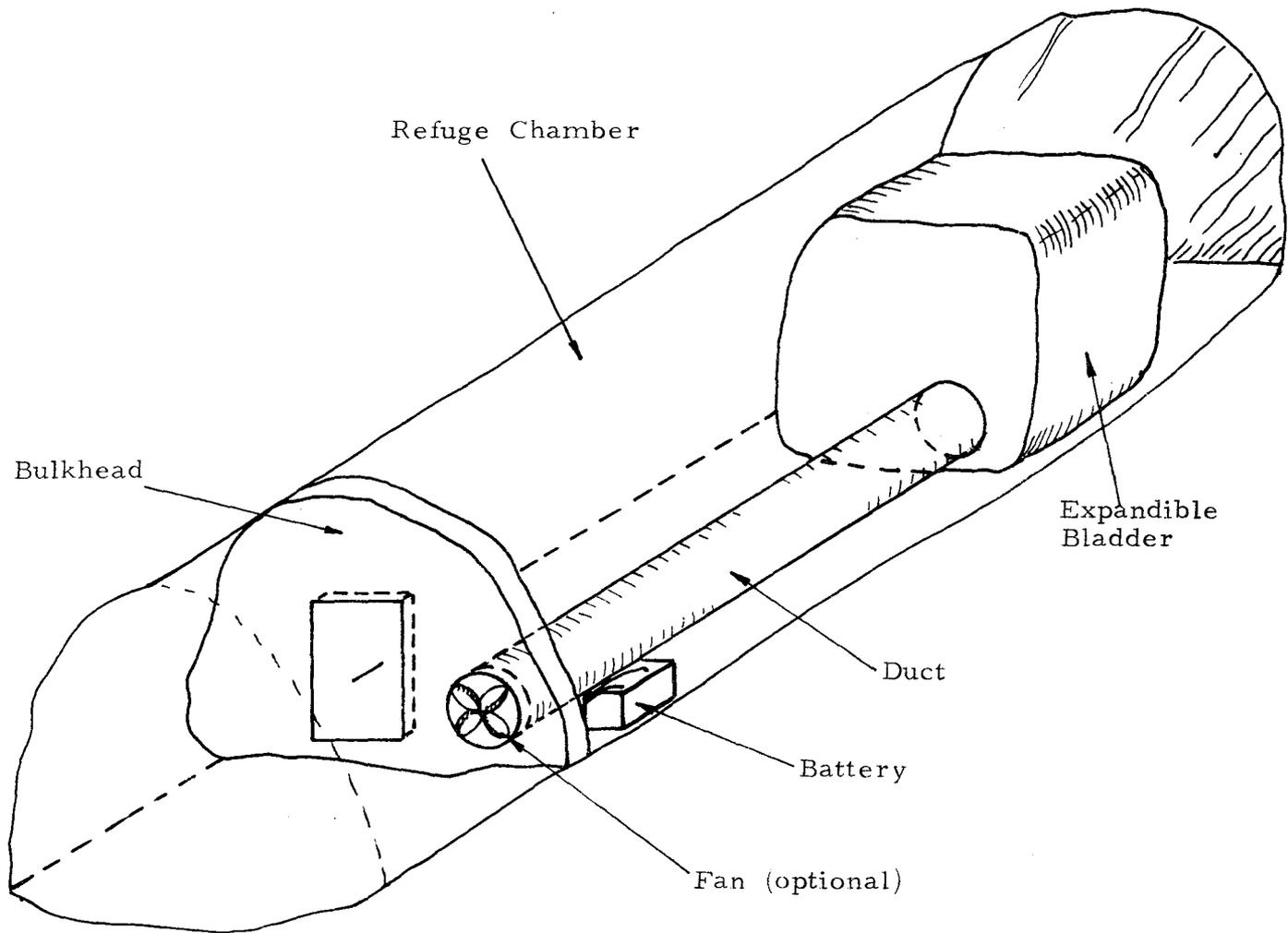


Figure 15 - Rescue Chamber with Bladder

1. Capable of withstanding the static pressure drop associated with natural pressures as well as fan pressures. These can be measured by erecting a temporary stopping and measuring the pressure differential with a manometer or altimeter⁽⁴⁾. In the absence of such a measurement, a maximum pressure differential of 1.5 psi is reasonable to assume. This figure covers the maximum expected barometric change as well as maximum expected fan pressures.
2. Best possible air seal.
3. Access appropriate to chamber function. If the chamber is used as a storage area, access doors must be large enough to accomodate the passage of material handling equipment, and must be sturdy enough to resist damage to mechanical functions or to sealing functions due to such usage. Where this is not the case, simple hatch-type man doors should be sufficient.

Although items 1 and 3 introduce a certain amount of variability into the bulkhead design, the requirements suggest that they be constructed along the lines of a permanent stopping.

Suggested materials include prefabricated sheet metal sections, masonry, poured concrete, or gunite. Previous investigations of such stoppings is available for reference^(7,8). Difficulties in meeting pressure requirements may be encountered in mines where drifts or entries are extremely high (15' +). In these cases it is possible to pile loose material on the floor, and build the bulkhead above the material pile. It will be necessary, then to seal the loose material pile, either by grouting or covering with impermeable sheeting.

Sealing of the bulkhead, particularly between the bulkhead and the rock, should be carried out with a seal which is flexible, and can resist slight ground movements. Urethane foam has such properties, and has been demonstrated to be one of the most versatile sealants for stoppings. Although it has come under criticism due to its flammability, judicious use of foam in the critical sealing areas should not pose a fire hazard. Other inorganic sealants are also available on the market, and these may also perform adequately.

Because of the sealing requirement, bulkheads should have steel doors. These will not warp, and are less likely to be damaged during handling and normal use. The type and size of door, and whether it is manual or mechanically operated, will depend on the shelter application. Mechanically operated doors should be easily operable manually if there is a loss of power.

8.1.4 Chamber Ambient Conditions - Human Requirements

To specify the chamber ambient conditions, certain information on human respiration must be considered. Table II indicates the air and oxygen consumption of persons under different degrees of activity. It should be immediately apparent that the activity must be restricted in a shelter to preserve vital air supplies in a shelter which does not have an external air source.

TABLE II
OXYGEN AND AIR INHALATION RATES IN HUMAN BREATHING*

<u>Activity</u>	<u>At Rest</u>	<u>Moderate</u>	<u>Very Vigorous</u>
Respiratory Rate per minute	12-18	30	40
Air Inhaled per respiration in ³	23-43	90-120	150
Air Inhaled ft ³ /day day (ft ³ /min.)	335 (.23)	2,625 (1.82)	5,000 (3.47)
Oxygen Consumed: ft ³ /day	14.4	100.8	144
ft ³ /min	0.01	0.07	0.10
Respiration Quotient	.75	.9	1.0

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

In normal air, (21 percent oxygen, 79 percent nitrogen), human exhalation contains approximately 16 percent oxygen (CO_2), 79 percent nitrogen (N_2) and 5 percent carbon dioxide (CO_2). The amount of CO_2 generated is a function of the activity level. The actual amount of CO_2 expelled is determined by multiplying the O_2 consumed by the Respiration quotient found in Table II.

In order to determine the ventilation criteria the ambient limits which humans can endure must be established. The conditions which can be expected to occur in the use of an emergency shelter are:

1. Low oxygen level
2. High carbon dioxide content
3. High temperature and humidity
4. Presence of carbon monoxide
5. Other toxic gases

Changes in O_2 and CO_2 levels will result due to human breathing in a confined space. Table III indicates the effects observed⁽²⁾ in an oxygen deficient atmosphere. These conditions will vary in different individuals. Table IV indicates the effects of carbon dioxide on humans.

The temperature/humidity which humans can endure for long periods without ill effects is about 84°F and 100 percent humidity. These values were considered safe by Westinghouse in their Coal Mine Rescue and Survival System report⁽¹⁾.

TABLE III
EFFECTS OF OXYGEN DEFICIENT ATMOSPHERE*

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

* U. S. B. M. Miners Circular No. 33 (1954) p. 2

TABLE IV
EFFECTS OF CO₂ LEVELS ON HUMANS*

<u>Carbon Dioxide</u> <u>Content Percent By Volume</u>	<u>Effect on Humans</u>
0.5	MAC-no effect in 8 hours**
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 U.S. Bureau of Mines

In addition to the atmospheric requirements of the chamber as a closed unit, consideration must be given to the potential pollution of the chamber environment due to the leakage of toxic gases from outside of the chamber. This will be the case when an independent source of positive air pressure can not be supplied within the chamber (chamber types 2 and 3).

The most serious, and most likely pollutant in the mine atmosphere during a fire will be carbon monoxide (CO). The concentration will vary with the type of fire, with time, and with other ambient conditions. Some data along these lines has been generated for timber logging fires⁽¹⁰⁾. The gas analysis of a number of different fires of different intensity and duration indicated a maximum CO concentration downstream of the fire of 0.96 percent. In addition to CO, a maximum of 6.9 percent of CO₂ was also produced. Since these values are for fuel rich fires, the concentrations given can be assumed as conservative estimates for the atmosphere outside of the chamber.

Table V shows the effects of various levels of carbon monoxide on humans⁽³⁾. As can be seen, chamber-air purification requirements must be such that the concentration of CO in the chamber due to leakage does not exceed something less than 0.01 percent.

8.1.5 Chamber Atmospheric Requirements

As discussed in the previous section, atmospheric needs are generated due to depletion of oxygen and generation of CO₂ due to respiration, and due to leakage of CO and CO₂. Specifications for atmospheric control based on the above needs are discussed below in terms of the 3 basic types of chambers.

TABLE V
EFFECTS OF CO LEVELS ON HUMANS*

<u>Carbon Monoxide Concentration</u> <u>Percent By Volume</u>	<u>Effect on Humans</u>
0.01	MAC-no effect in 8 hours
0.02	Headaches in 2-3 hours
0.04	Headaches and nausea in 1-2 hours
0.08	Headaches and nausea in 45 minutes and collapse in 2 hours
0.16	Headaches and nausea in 20 minutes and possible death in 2 hours
0.32	Headaches and dizziness in 5-10 minutes and possible death in 30 minutes
0.64	Headaches and dizziness in 1-2 minutes and possible death in 10-15 minutes

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

8.1.5.1 Type 1 Chamber - Independent Air Supply

An independent source of air supply is the most desirable method for atmospheric control. The O₂ supply/CO₂ removal requirements discussed in the previous section can be translated to an air flow rate of approximately 3 cfm per man. This volume of air (3 cfm) flow will maintain the CO₂ level below the .5 percent by volume shown in Table 8-III if the chamber occupants are at rest. A 20 man chamber, for example, would require 60 cfm. If CO filtration equipment is not present, such small rates will be secondary to the requirement that leakage be out of the chamber, rather than into the chamber.

An independent source of air supply is most effectively and reliably achieved by a borehole to the surface. A small blower at the surface should have no problem supplying the required volume of air. In addition, the borehole may be used to supply food, water and communication. At greater depths, where it is impractical or impossible to reach the chamber with a borehole, compressed air may be used. Two completely independent compressed air sources from the surface should be supplied. If this is not possible, then the chamber should contain an air purification system as a backup (see Section 8.1.5.2).

The required volume of such a chamber is minimized by the fact that air sources are external. One can estimate a volume need by assuming that there will be a 4 hour delay in the startup of the air supply system. Assuming 15 men, and using the figure of 500 cu. ft/m n/day (computed from the data of Section 8.1.4), one computes $15 \times 500 \times 4/24 = 1250$ cu. ft. This is an extremely small volume, and space considerations for comfort would prevail.

8.1.5.2 Type 2 Chamber - Air Purification System

In situations where it is not possible to provide an independent supply of air, it is possible to provide air purification equipment which is capable of supplying oxygen and reducing carbon dioxide and carbon monoxide to acceptable limits. A rescue chamber air purification system of this type was designed and partially tested with satisfaction by Westinghouse⁽¹⁾. Similar systems and components have been designed for the space program, for submarines and small manned submersibles, for fallout shelters, and for pollution control.

Requirements for the air purification system can be obtained from the data of Section 8.1.4. Considering the "at rest" figures of Table 8-I, at least 14.4 cu. ft. of oxygen must be provided per man per day. In addition, the resulting CO₂ level due to the expiration of 10.8 cu. ft./man/day and leakage from the outside must be kept below 1.0 percent. Also, CO levels due to leakage must be kept below .01 percent. These requirements are discussed separately below.

a. Oxygen Supply

Practical sources for oxygen supply are bottled O₂ and chlorate candles. The volume of oxygen required by one man in a day (14.4 cu. ft.) can be bottled at 2200 psi in a volume of $\frac{14.7}{2200} \times 14.4 = 0.10$ cu. ft. A standard cylinder (6 5/8" x 43") equals 0.86 cu. ft. Therefore, support for 15 men for 10 days requires $\frac{15 \times 10 \times 0.10}{0.86} = 18$ bottles.

Chlorate candles have been used as an oxygen supply for submarines, and were specified in the Westinghouse system. Based on the Westinghouse figures, approximately 61 candles would be required for 150 man days of life support.

b. CO₂ Removal

CO₂ can be removed from the air by passing it through a dessicant. A special unit was designed by Westinghouse using baralyme. This unit had the capacity for removing 312 cu. ft. of CO₂ per day, which is more than enough to handle 15 men. The air flow was forced by a hand crank blower.

Another method for CO₂ removal involves bubbling the air through MEA (monoethantamine) After absorbing the CO₂, the MEA is circulated into a vaporizer which boils it off and discharges the CO₂. The MEA is continuously recycled. This method is used on submarines.

CO₂ scrubbers are available commercially for diving and submersible applications. These use Sodazorb,* and are capable of removing 2 liters/minute (96 cu. ft/day). This capacity is somewhat less than required. In addition, the filtration canisters are small, and would require frequent replacement. These limitations are simply due to the market being served. The units could easily be scaled up to meet refuge chamber requirements.

c. CO Removal

CO can be removed with a flow through filtration using hopcalite, the same material used in standard self rescuers. Hopcalite loses its effectiveness at normal temperatures in the presence of moisture. Hence, the air to be filtered must either be heated and then cooled, or it must be dehumidified.

CO removal requirements can be determined from expected leakage rates into the chamber and expected CO concentrations in the leakage gas. For calculation purposes, we shall use the following notation:

* Trade name

V = chamber volume (cu. ft.)

q = leakage flow rate (cfm)

X = CO concentration

t = time (min.)

\dot{p} = external pressure rise rate (psi/min)

Neglecting the damping effect of the chamber seal,* the leakage rate into the chamber will be approximately,

$$q = \frac{\dot{p}}{14.7} V \text{ cfm}$$

The flow of CO into the chamber will be

$$Xq = \frac{\dot{p}}{14.7} VX \text{ cfm}$$

Using representative numbers

$$X = .01$$

$$\dot{p} = .1 \text{ psi/hr} = .0017 \text{ psi/min}$$

$$V = 10,000 \text{ cu. ft.}$$

$$Xq = \frac{.0017 \times 10,000 \times .01}{14.7} = .0113 \text{ cfm}$$

* See Appendix E

Equipment with such capabilities has been designed on a prototype basis^(1,11) but testing has been limited. Such equipment is not commercially available. Further development effort would be required before such equipment could be specified for a refuge chamber.

8.1.5.3 Type 3 Chamber - Use of Available Air Volume

If there is no air purification system, and there is no external air source, then the chamber must supply sufficient volume for O₂ requirements and minimum CO₂ contamination. This figure is approximately 500 cubic feet/man/day, so 150 man days would require 75,000 cu. ft, or a drift 100 ft² x 750 ft. long.

The contamination of the chamber due to leakage of CO can be computed from the discussion in Section 7.1.3.2 and the analysis in Appendix E. The criteria for the CO level to be less than .01 percent can be stated as

$$\frac{QX}{V} \leq .01$$

where

Q = total leakage (cu. ft.)

X = percent CO outside of chamber

V = chamber volume (cu. ft.)

A representative calculation will be made with the following assumptions

Pressure rise of 1 psi in 24 hours

Chamber volume - 75,000 cu. ft.

1 percent CO

Referring to Equation (E.7)

$$Q = \frac{\dot{p}V}{\bar{p}} \left[t - \frac{V}{\bar{p}A} \left(1 - e^{-\frac{\bar{p}A}{V} t} \right) \right] \quad (\text{E. 7})$$

$$\dot{p} = \frac{1}{24 \times 60} = 6.95 \times 10^{-4} \text{ psi/min}$$

$$\bar{p} = 14.7 \text{ psi}$$

$$A = 100 \text{ cfm/psi}^{(8)}$$

$$t = 24 \times 60 = 1440 \text{ minutes}$$

Substituting into Equation (E. 7),

$$Q = 4925 \text{ cu. ft.}$$

and therefore,

$$\frac{QX}{V} = \frac{4925}{75000} = .07$$

Evidently the survival time in this chamber under the above conditions is much less than 24 hours.

The expandible bladder discussed in the previous section will equalize pressure and minimize leakage. Assuming, however, that a 0.1" of water differential exists, using the stopping leakage rates determined in reference (8) (5 cfm at 1" of water), and an outside CO concentration of 1 percent, the CO percent increase per day will be

$$\frac{0.1 \times 5.0 \times 60 \times 24 \times 1 \text{ percent}}{75,000} = .0096 \text{ percent CO/day}$$

In other words, the CO limit will be reached in 1 day.

8.1.6 Cooling of Refuge Chambers in Hot Mines

High temperatures may be encountered in some areas of deep mines requiring some form of cooling in a refuge

chamber. Some areas where refuge chambers would be required may have rock temperatures of 120°F. Prolonged exposure to this condition would be fatal. The maximum condition humans can endure for long periods of time is reported by Westinghouse Electric Corp.⁽¹⁾ to be 84°F and 100 percent humidity.

Mechanical refrigeration is probably the most effective and available means of cooling a refuge chamber. The size unit required depends on several factors. The major factor is the heat flow from the mine rock. An accurate calculation of the cooling requirements is difficult because the heat flow varies with time. Figure 16 shows this heat flow decay with time for an arbitrary refuge chamber 1,000 ft. long with a 10 ft. x 12 ft. cross-section for assumed conditions of 120°F rock and cooling to 84°F within the refuge chamber. A 10 HP cooling unit with a six to eight ton refrigeration capacity would be required to maintain temperatures at a maximum limit. Each specific refuge chamber would require engineering analyses to determine the cooling requirements. The above conditions are maximum conditions. It is possible that the mine would have less than 100 percent humidity and higher design temperatures could then be used safely. The cooling equipment could be installed in conjunction with other air cleaning equipment or separate if cleaning equipment is not used. In either case, no air leakage can be allowed between the contaminated mine air and the chamber.

8.1.7 Power Sources

There may be several options on providing power for the refrigeration unit. Ideally, electric power should be available. To insure that it would be available in an emergency, two separate routings for the cable should be provided. Air lines may be available which could provide power enough to operate an air motor to drive the cooling unit. If this air was from an uncontaminated source such as the surface, it could also be used as a fresh air source for the chamber. This power source also must be redundant to insure that

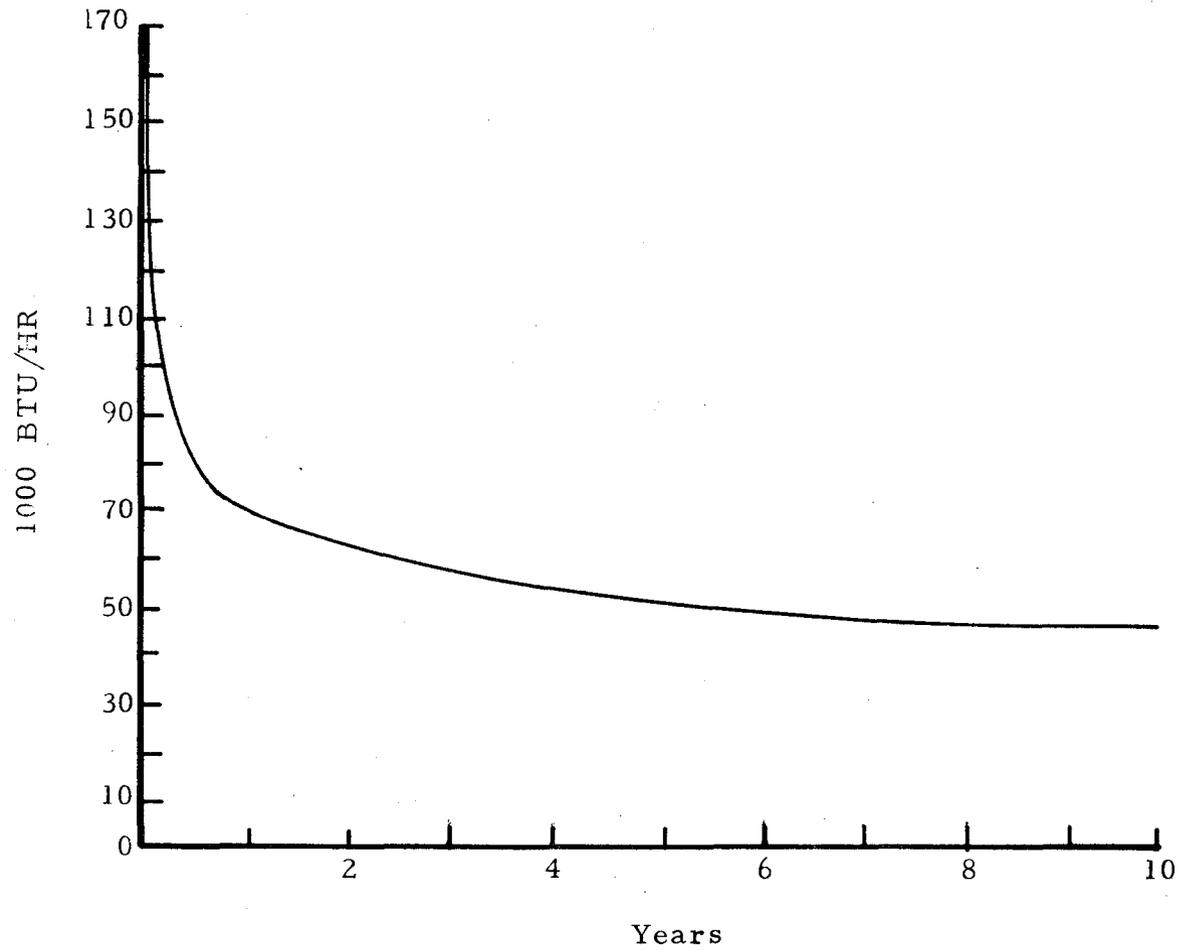


Figure 16 - Heat Load In Chamber Vs. Time Since Opening

at least one is operating during an emergency. Another source of power for the refuge chamber could be a small one or two cylinder diesel engine. A unit of 10 HP would be sufficient for most applications. There are many small diesel power units on the market such as: Kohler, Onan, Slavia, Deutz, Honda, Wisconsin-Hartz, etc. A small diesel is the most efficient method of providing remote power available on the market. Most of these units could be provided with a hand starting system which would eliminate a need for a battery and its associated maintenance.

8.1.8 Other Life Support Considerations

The previous sections have discussed equipment and facilities for providing the atmospheric conditioning in a refuge chamber necessary for life support. Other materials and facilities for an acceptable refuge chamber are food, water, first aid materials, blankets, bunks, toilet facilities, and communication equipment.

Drinking water must be supplied in quantities of at least 2 quarts per day per man. The best system for storage of water is in 5 gallon plastic containers⁽¹⁾. The Westinghouse report (reference 1) suggest one teaspoon chlorox per container to assure long storage life.

Food requirements are generally agreed upon by all references to be 1740 calories per day per man. In the Westinghouse report referred to in this section the military ration (MIL-F-43231),

Food Packet, Survival, General Purpose) was chosen as the best choice. In hot mines consideration will have to be given for a possible limited storage life.

Specifications of the refuge chamber should include first aid equipment to treat wounds, bunks and blankets. Regardless of the provisions for fresh air, unless possibly a borehole to the surface is provided, physical activity must be kept to a minimum to conserve oxygen. Therefore, the trapped miners should spend most of the time on the bunks.

A toilet which uses disposable plastic bags such as supplied for camping should be provided.

Communication with the surface is very important. Information can be supplied to the surface to identify and number the miners trapped and their condition and location. The rescue teams can keep the trapped miners informed on the progress of the rescue efforts. The telephone can be a very important means of providing the encouragement the miners most certainly will need. Ideally the phone system should be a redundant one (lines taking separate routes to the chamber).

To assure that the equipment provided in a refuge shelter will be available a means of enclosing and locking should be provided. One possible scheme could be to store all food, water, first aid and all other critical equipment behind a glassed in enclosure which would require breaking for access by the miners. The glass would also make the periodic visual inspections convenient.

8.2 Refuge Chamber - Guidelines

1. All refuge chambers shall provide per man day expected to use the chamber;

- a. 1740 calories food (MIL-F-43231)
or equivalent.
 - b. 2 quarts water.
2. All refuge chambers shall provide an atmosphere with the following limits CO₂ max percent-1.5; CO max percent-0.01; O₂ min percent-19.
 3. Refuge chambers in hot mines will provide an assured means of cooling to 84°F/100 percent humidity maximum condition for the length of time necessary to affect an escape.
 4. All refuge chambers shall have dual communication systems to a safe area or the surface.
 5. All refuge chambers located on escapeways to which persons may have access in an emergency shall be inspected daily. The inspection shall ensure that all life support equipment and supplies are in working order and available.
 6. All refuge chambers shall have a permanent bulkhead.
 7. All refuge chambers shall have escapeway maps and instructions posted.
 8. All escapeway maps and instructions shall have the latest date of revision.
 9. All refuge chambers shall have sufficient first aid supplies, bunks, blankets, and sanitary facilities for the maximum number of persons expected to use the chamber.

10. Refuge chamber shall be supplied with portable breathing units which will enable individual miners to travel through a toxic atmosphere as far as

a. the next refuge chamber in the direction of escape,

or b. the nearest dual escapeway, whichever is closer.

APPENDIX A

MINE EVACUATION SIMULATION PROGRAM

A.1 Introduction

A computer program has been developed to simulate evacuation of a mine in case of fire. In the following, the capabilities, operations and structure of the program are described with illustrative examples to demonstrate usefulness of using the program. A detailed description of the program with sufficient information to make use of the program appears in Appendix B.

A.2 The Need for a Computer Program

The computer program has been developed in conjunction with the rest of the project to evaluate evacuation capabilities of the mines and develop guidelines for the escape systems.

There are several problems associated with predicting evacuation performance of a mine.

First, the mine has many interconnected passages, shafts, hoists and a number of miners in varying positions. To be able to predict evacuation time requires processing a hugh amount of data. A simplistic approach of determining the miner farthest from the exit and calculating evacuation time for him knowing his walking speeds and hoisting times is not realistic, since the waiting time for the hoist is neglected.

The second problem is being able to repeat the calculations for a number of configurations. It may be possible to spend enough time to hand calculate the evacuation parameters for a single mine for a single configuration, but to evaluate capabilities of the evacuation

system, a large number of possible configurations, e.g., miner positions, fire position, etc., have to be considered. Such a largely repetitive task is best handled by a computer program.

Finally, as mentioned in Section A.4, it is envisioned that in the future such a program may provide a real time option evaluating capability in the event there is a real fire in the mine. Clearly no program can replace the experience the mine supervisors may have in determining the best way to evacuate a mine in such an event, but a program which can compare different options quickly, can be a valuable tool in making the decisions.

Therefore, a computer program has been developed, which at this stage can help evaluate evacuation capabilities of the mine, assist in making specific recommendations to improve evacuation and demonstrate usefulness of the recommended improvements. Although care has been taken to introduce a large number of parameters which may be considered in evacuation of a mine, the program is not, and can not be, all encompassing. Also, the program involves predicting behavior of the miners, regarding their travelling speeds, the directions they will take and the way they will be hoisted. In a real situation such predictions may not entirely be true, since human beings are prone to exhibit apparently unexpected behavior, particularly under stress.

A.3 Program Description

The computer program developed to simulate events in the case of fire in the mine is described in this section. The description is divided into three parts:

1. Program Capabilities: This part summarizes what inputs can be changed, what outputs can be obtained and demonstrates program flexibility through suggested uses.

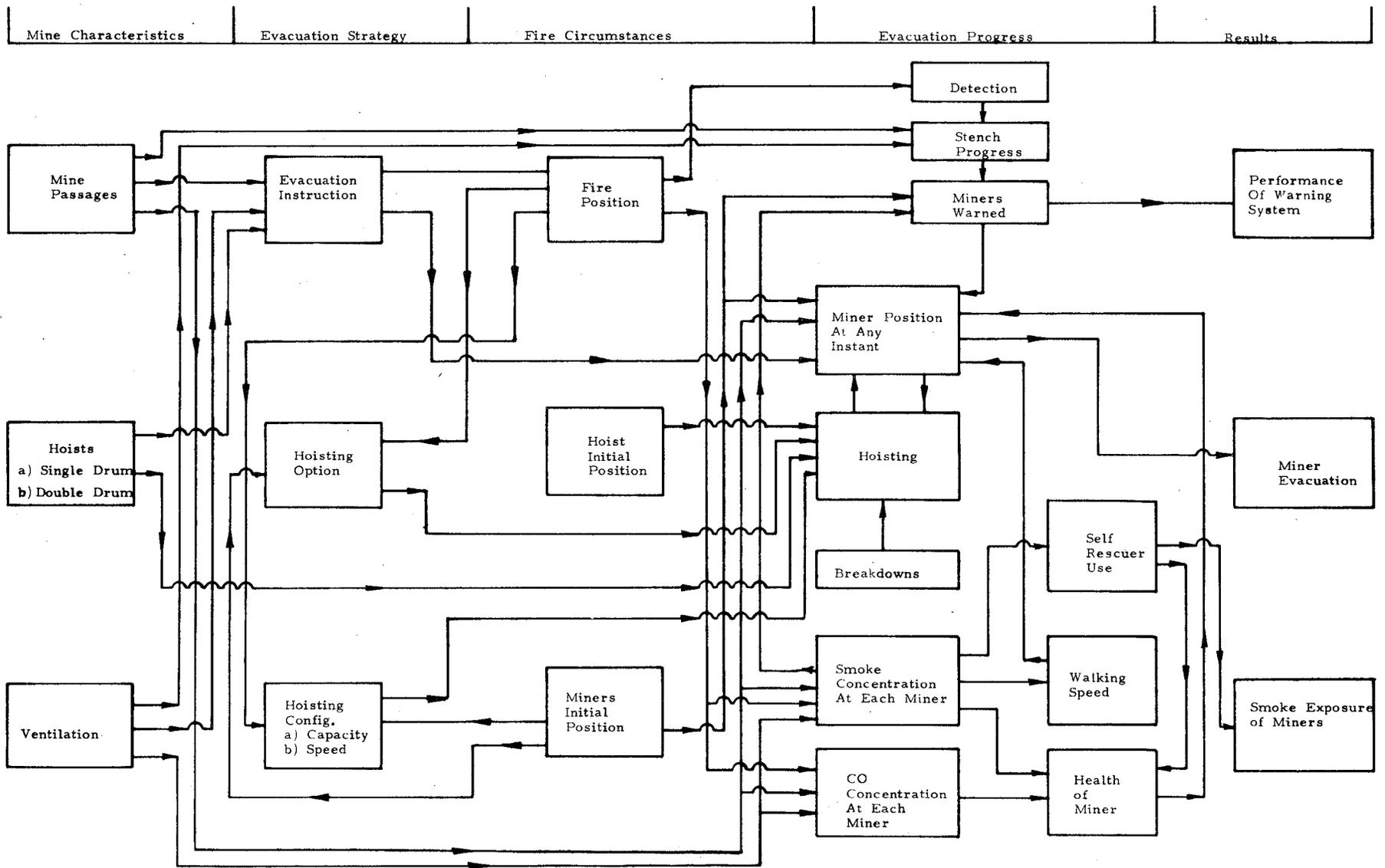


Figure 17 - Mine Fire Simulation Program: Principle of Operation

2. Principle of Operation: This subsection describes what will happen in case of a fire; as assumed by the program. It serves as a bridge between the computer program and real life, by translating the logic used in the program to the assumptions in a real situation.

3. Structure of Program: The main program, the various subroutines and their interconnections are described by this part. A flow chart is used for explaining the basic structure of the program.

The description of the program is only an overview of the main features of the program. A detailed explanation of the data cards, subroutine logic, program nomenclature, etc., can be found in the User's Manual in Appendix B.

A. 3.1 Program Capabilities

The computer program can be used to study the emergency escape system of a mine. It has a flexibility to include practically any mine configuration with any passage network and a variety of hoisting capabilities. The evacuation time for the mine is predicted for the users' selected positions of the miners and any arbitrary location of the fire. The program predicts the manner in which the smoke spreads in the mine and it also includes a simulations of a stench warning system and the use of self rescuers to provide improved realism.

A. 3.1.1 Variable Parameters

The parameters which can easily be changed in the program are summarized in Table VI. As demonstrated by this Table, the program is capable of simulating a vast number of different cases just by simple data card changes. In addition to these changes, even complex parameters, such as an alternate hoisting

TABLE VI

VARIABLE PROGRAM PARAMETERS

Mine Characteristics:

Branches

i. e. Passages
Shafts
Stopes
Raises

Miner speed in each branch.
Ventilation air velocity in each branch.
Compressed air velocity in each branch.

Hoisting:

Hoisting Options

Location
Capacity
Stops
Speed
Operational status
Delay time for changes
Loading, unloading times
Initial positions
Breakdowns

Miners:

Number
Initial position
Evacuation instructions
Initial delay time

Fire:

Location

Stench Warning System:

Dump Location
Delay in activation

Self-Rescuer:

Time limit

option, can be included with relatively little programming, since the program has a modular structure. The program structure, described later in Section A.3.3, consists of a number of subroutines, each with a specific function. Therefore in most cases a programming change can be accomplished by just introducing a new subroutine, or modifying an existing subroutine, with the rest of the program left intact.

A.3.1.2 Program Output

The program output consists of three parts:

a. A chart of chronological events. This includes the following:

1. Time for a branch to be filled with smoke.
2. Time for a branch to be filled with stench.
3. Time of notification for each miner and how notified.
4. Time for a miner to be evacuated and position at which evacuated.
5. Time and position of death of a miner.
6. Clutching and declutching of double drum hoist and the reason for declutching.
7. Hoisting results. How many miners hoisted by which hoist at what time.

b. A summary of the results. This includes:

1. Number of miners in the mine.
2. Number of miners evacuated.
3. Number of miners lost.
4. Evacuation time for the last miner.
5. Delay in stench activation.
6. Delay in notifying the last miner after the stench has been activated.
7. Number of miners notified by stench.
8. Number of miners notified by smoke.
9. Number of miners exposed to smoke.
10. Average smoke exposure, taken over the total number of miners in the mine.
11. Average smoke exposure, taken over the number of miners exposed to smoke.
12. Maximum individual smoke exposure.
13. Man minutes of smoke exposure.

c. Plots: The following plots are generated.

1. A plot of miners evacuated vs. time.

2. Plots of hoist position vs. time, including the levels at which the hoist stops.

The program output also can be changed to include more (or less) parameters by locating the required parameters in the program and inserting (or deleting) the output statements.

A. 3. 1. 3 Suggested Application

The program can be used in many different manners for studying the emergency escape system of a mine. A suggested manner of utilizing the program is summarized in the following steps:

Steps

- a. Study Miner Evacuation for the Existing Configuration and Strategy:

Obtain all data of the mine, e.g.:

Mine passages

Hoist data

Ventilation

Miner position

Stench system

Hoist man's instructions

Miner's instructions, etc.

Then simulate key cases to evaluate the evacuation strategy and the mine configuration, e.g.:

1. How long does it take for the miners to be evacuated (evacuation time) of the notification is instantaneous.

2. Time taken for the stench to reach the miners.
3. Smoke propagation patterns.

b. Identify Problem Areas:

From studying the mine data and results of the simulations carried out in Step a, the problem areas and "bottle necks" in the mine can be identified.

Probable problem areas may be:

Bad warning system,
Bad ventilation strategy,
Hoisting strategy wrong,
Instructions to miners inappropriate,
Insufficient hoisting capacity,
Insufficient escapeways.

c. Suggest Strategy Change and/or Configuration Change:

Once the problem area has been identified, various options can be evaluated using the computer program, e.g.:

1. What happens if the hoisting strategy is changed. i.e., clutched hoist used or not. Three cages used or not.
2. Increase size of cage or speed.
3. More hoists.
4. More passages.

5. Different ventilation scheme.
6. Different stench scheme.
7. Different miner instructions.
8. Different hoisting options.

Suggestions can be made based on this study.

- d. Demonstrate Improvement Due to the Suggested Changes by Comparing Simulation Results with Those for the Original Scheme:

Various possible scenarios can be simulated for both the original evacuation scheme and the suggested scheme, e.g. :

1. Various miner locations.
2. Various fire positions.
3. Breakdowns of the hoists.

A. 3.2 Principle of Operation

The approach selected for representing a mine in the computer program is similar to a network approach used in electrical engineering. The mine is divided into a network of branches, with each branch representing a mine passage, drift, stope, raise, shaft, winze, etc. Wherever two or more branches intersect, in any plane, a node is said to exist. The advantage of using such a network approach, instead of, say, an approach using three dimensional

coordinates, is that the exact geometry of each branch in the mines does not have to be known for an accurate representation.

The dynamic part of the simulation considers four interacting components:

- a. Stench
- b. Smoke (carbon monoxide)
- c. Miners
- d. Hoists.

The simulation algorithm essentially consists of determining motion of each component along the mine branches, taking into account the constraints imposed by the mine characteristics and the components interactions.

- a. Stench

The simulation sets the time to zero when the fire has been detected, or the hoistman is notified of the fire drill, if there is no fire. The stench is dumped at a pre-set point in the compressed air, after a certain time delay, and it travels in the compressed air duct in each branch, at the speed of the air in the duct. The miners who are not hooked directly to the compressed air may still get the benefits of an early stench warning due to, say, leakages in the air duct. In branches where the compressed air is not available, the stench may travel in the normal ventilation air. In any case, the user is allowed to select the stench dumping position, initial delay and the stench velocity and direction in each branch.

During the stench propagation along a branch, if a node is encountered, the stench propagates in the branches where the compressed air assists the propagation.

A miner is considered notified after the first time he encounters stench.

b. Smoke and Carbon Monoxide

Although, presumably, the smoke and the CO may propagate separately in a real fire, in the simulation they have been assumed to travel together. The smoke (and CO) start moving from the fire position in the direction of ventilation air and whenever a node is encountered, the smoke propagates in the branches where the ventilation assists the propagation. No consideration is given to possible ventilation flow reversals due to the fire or caving.

Whenever a miner is in a smoke filled region, he uses his self-rescuer and his walking speed reduces to half, due to lack of visibility. The miner is considered dead if the time limit on the self-rescuer is reached.

Since no thermal effects of the fire are considered, the miners are allowed to pass through the point of origin of the fire.

c. Miners

The miners stay in their assigned initial position till they receive notification by either stench or smoke. After receiving the notification, they start moving in the direction recommended by the evacuation scheme.

When a miner encounters a node, he starts traveling on a branch which he has been instructed to select and when he reaches a shaft station, he waits to be picked up by the hoist. The miner is considered evacuated if he reaches a node so designated.

As mentioned earlier, the miners use their self-rescuers whenever they are in a smoke filled region. A miner is considered lost if his usage of the rescuer exceeds his time limit.

If he dies, while waiting for a hoist, he is left at that station, and if he dies while in the cage, he is left at the top level.

It is also possible to instruct the miners to use a secondary route in case the main escape route is blocked. They can be instructed to try to escape via the main escape route only for a certain length of time. If they are then convinced that the escape via the main route is not possible, they try to escape using a secondary route.

The general rules governing evacuation of the miners do not apply to the hoistman. The program allows for one internal hoistman who stays at his post till one of the following happens:

1. There is no call for hoisting at all. In a case where the miners are using an alternate route, the hoistman waits for a certain length of time and then departs.
2. There is no call for hoisting, for a certain length of time, after the last load of miners. In that case the hoistman presumes his duties to be over and departs.
3. The hoist breaks down irreversibly, in which case the hoistman departs immediately.

It is also assumed that the hoistman does not use his self-rescuer until he leaves his hoist position, having used bottled air while he was at his station.

d. Hoists

The program allows for one double drum hoist, where both the hoists are used, and eight single drum hoist (or the

double drum hoists for which the clutched hoist is not used). The hoisting of the miners is carried out according to one of the three options:

1. Option No. 1

According to Option No. 1, the hoist starts moving down when a miner reaches one of the stations served by the hoist. If, however, a miner on one of the levels below the above miner reaches the shaft station, the hoist changes its destination so that it reaches the lowest level where a miner is waiting. The hoist waits for a time, proportional to the number of miners being picked up, and then moves to the next higher level where the miners are waiting, if additional room is available. Finally, the hoist reaches the main level, discharges the miners and waits for the miners to reach the shaft stations again.

2. Option No. 2

In hoisting Option No. 2, the hoist is directed to a priority level, e.g. the level where the smoke originates, if any miners are waiting at that level for the hoist. After picking up the miners from this priority level, the hoist moves up and, if more room is available, it stops to carry additional miners from the levels above the priority level.

3. Option No. 3

Hoisting Option No. 3 requires selection of a level, which is above the level where the smoke originates. The hoist starts moving down, just as in Option No. 1, whenever a miner appears at a shaft station. The hoisting, however, is switched to an intermediate haul after the first time the hoist goes below the selected intermediate level. Then the miners below the intermediate level are hauled to that "safe" level, and not to the top. After the intermediate

haulage is completed, as indicated by a selected waiting period for the hoist, the miners on the intermediate level are hoisted to the top level. The miners on the other levels are hoisted afterwards.

The double drum hoist has two drums, called the main or the master hoist, which is directly connected to the drive and the clutched hoist or the slave hoist, which may be clutched in or declutched.

The slave hoist is clutched in after the first time the master hoist reaches a selected level, called the master level. After being clutched in, the slave hoist picks up miners from the master level when the master hoist reaches the top and discharges the miners to the top level when the master hoist reaches the master level. The process continues till one of the three events occur which necessitates declutching of the slave hoist:

1. Master hoist goes below the master level, in which case the slave hoist is declutched and left at the top.
2. Slave hoist does not find any miners at the master level, in which case it is kept at the master level.
3. Master hoist does not find any miners at the master level, in which case the slave hoist is declutched and kept at the top.

In case hoisting Option No. 3 is used, the slave hoist is not clutched in till the intermediate haul is completed.

If there are miners in the slave hoist, and the master hoist does not have to go to the master level, it is forced to go there, so that the slave hoist can reach to the top and discharge its miners.

When the fire is detected, the hoists are brought to the top level from whatever initial position they are at. If any configuration changes, such as changing the cage capacity, etc., are required, a certain time is spent before the hoist is ready to haul the miners.

During the hoisting operations, a breakdown can occur. Such a breakdown is assumed to occur only when the hoist is at the top level, and it may be simulated to last for any preselected time. If the hoist breakdown is temporary, the hoistman does not leave his post. However, if the breakdown is irreversible, the hoistman immediately departs.

The above discussion is summarized in Figure A-1. The figure has the description blocks distributed in five vertical groups:

1. Mine Characteristics

The blocks under this heading represent parameters which are basic to the mine.

2. Evacuation Strategy

The blocks covered by this group are the parameters relatively easy to change.

3. Fire Circumstances

The initial conditions in the mine and the position of the fire are described in this group of blocks. These parameters are uncontrolled and depend on chance.

4. Evacuation Progress

Events taking place during the evacuation are described by the blocks under this heading.

5. Results

Some of the results which can be derived from the simulation are represented by these blocks.

The blocks are interconnected according to influences each of them have on the other.

A. 3. 3 Program Structure

The computer program structure is shown in Figure 18. As shown in the figure, the program consists of a main program and thirteen subroutines. The subroutines have been programmed to perform specific functions and the main program coordinates the complete program execution.

The main program commences the program execution by initializing several indices used in the program and by calling subroutine PROGIO. Subroutine PROGIO reads and writes the input data and performs initial plotting calculations. It also assigns default values to the variables not specified in the input data.

The main program, then, initializes several other indices and sets appropriate initial values to the arrays describing various mine and miner characteristics. Subroutine LEVEL, which stores the information about the level the hoists have stopped at, is called for the hoists which are at the top level initially.

After performing the initial functions, the main program calls subroutines MINER, HOIST, SMOKE, and STENCH. These

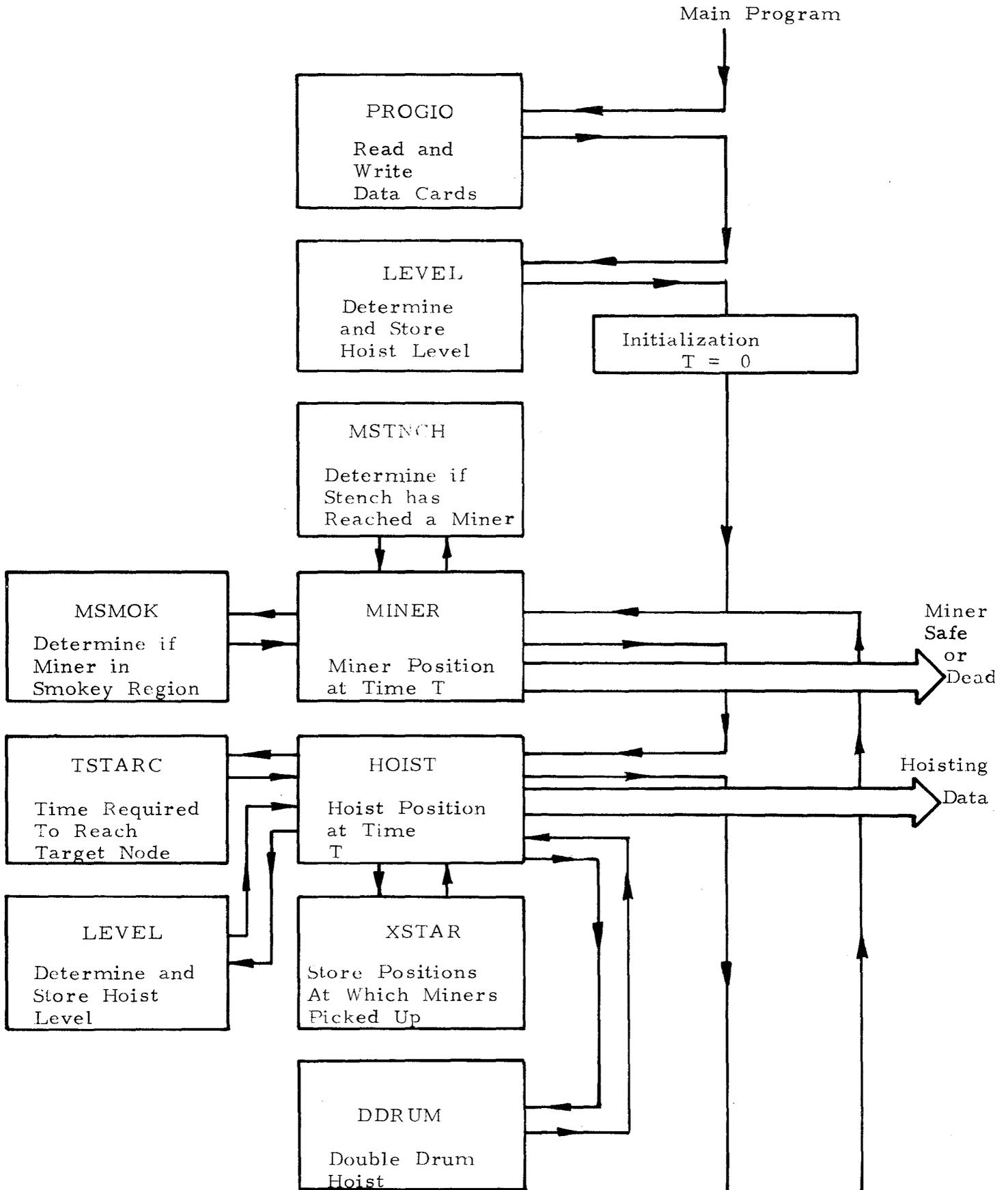


Figure 18 - Computer Program Structure

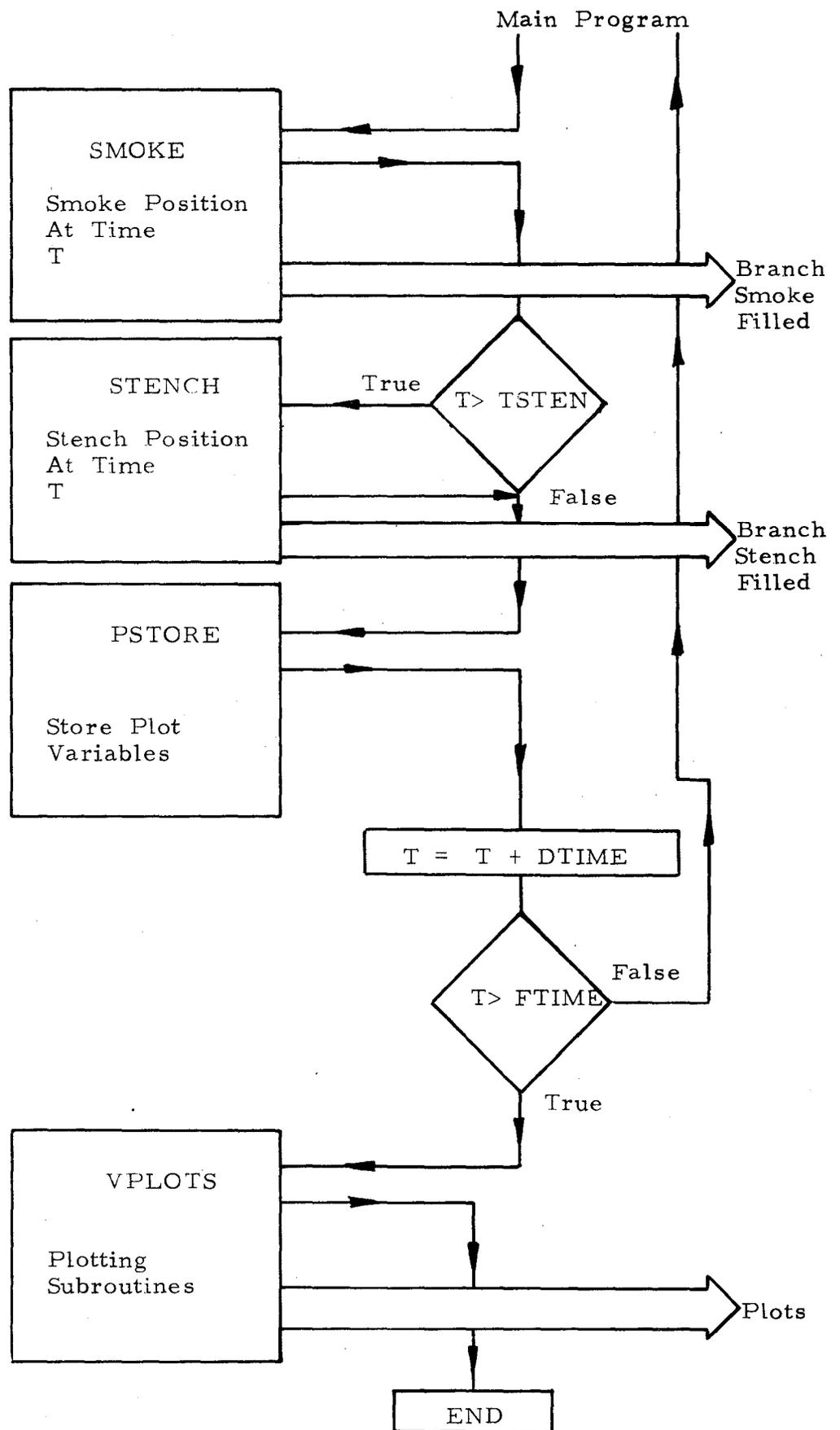


Figure 18 - (cont.) Computer Program Structure

subroutines determine positions of the miners, hoists, smoke and stench as a function of time and are called at every time step from the main program. Subroutine STENCH is called only after an initial delay period, TSTEN, is over.

In addition to the above four subroutines, the main program also calls subroutine PSTORE, which stores the data for the plots. Subroutine PSTORE may not be called every time step if the simulation is lengthy and the data is expected to exceed the allotted array size.

The process of calling the subroutines MINER, HOIST, SMOKE, STENCH and PSTORE ends when the time, T, exceeds the simulation time limit FTIME.

There are six supportive subroutines including subroutine LEVEL mentioned earlier, which are called from the subroutines MINER and HOIST.

Subroutine MSTNCH, called from subroutine MINER for each miner, determines if the stench has reached the miner. Subroutine MSMOK, also called from subroutine MINER for each miner, determines if the miner is in smoke filled region.

Everytime a new target mine level is decided, subroutine HOIST calls subroutine TSRARC to calculate time required to reach the target level. The subroutine TSRARC is also called by subroutine DDRUM to determine the last branch in the clutched (slave) hoist's travel to the top.

Subroutine XSTAR is called, along with subroutine LEVEL everytime a hoist stops at a mine level in subroutine HOIST. Subroutine XSTAR stores the information which plots stars in the hoist plots (see Figure A-9), and subroutine LEVEL stores the information which draws the dashed level lines and writes the level identification in the hoist plots.

Subroutine DDRUM is called from the subroutine HOIST for the clutched (or slave) hoist in a double drum arrangement. The subroutine calculates movement of the slave hoist and determines when it has to be declutched. Clutching in of the slave hoist is, however, determined by the subroutine LEVEL.

Finally, after the iteration has ended, the main program calls subroutine VPLOTS. Subroutine VPLOTS includes standard DISSPLA (a plotting software package) subroutines and it produces plots using the information stored by the subroutines PSTORE, LEVEL and XSTAR. The simulation is then terminated.

A.4 Illustrative Simulations

The capabilities of the program are demonstrated by simulating various evacuation cases in different situations for a particular mine. The mine selected for the illustrative simulations is the mine 'C', as described in Section 2, chosen particularly because of availability of mine characteristic data and mine evacuation results for test drills. These evacuation results can be used to verify validity of the predictions made by the program.

A.4.1 Mine Characteristics

A schematic diagram of the mine is shown in Figure 19. The figure shows all the major shafts, drifts, raises and stopes of the mine in the form of a network. There are four hoists, Hoist No. 1 and Hoist No. 2 are assumed to be single drum hoists and Hoists Nos. 3 and 4 form part of a double drum hoist, with Hoist No. 4 being the main hoist (master hoist).

The positions of the 133 miners, typically working in a day shift of the mine, are also shown in the figure. The miners are identified by a miner number, and their total number on each level is chosen from the data on the fire drill simulated as Case No. 1 in the illustrative simulations.

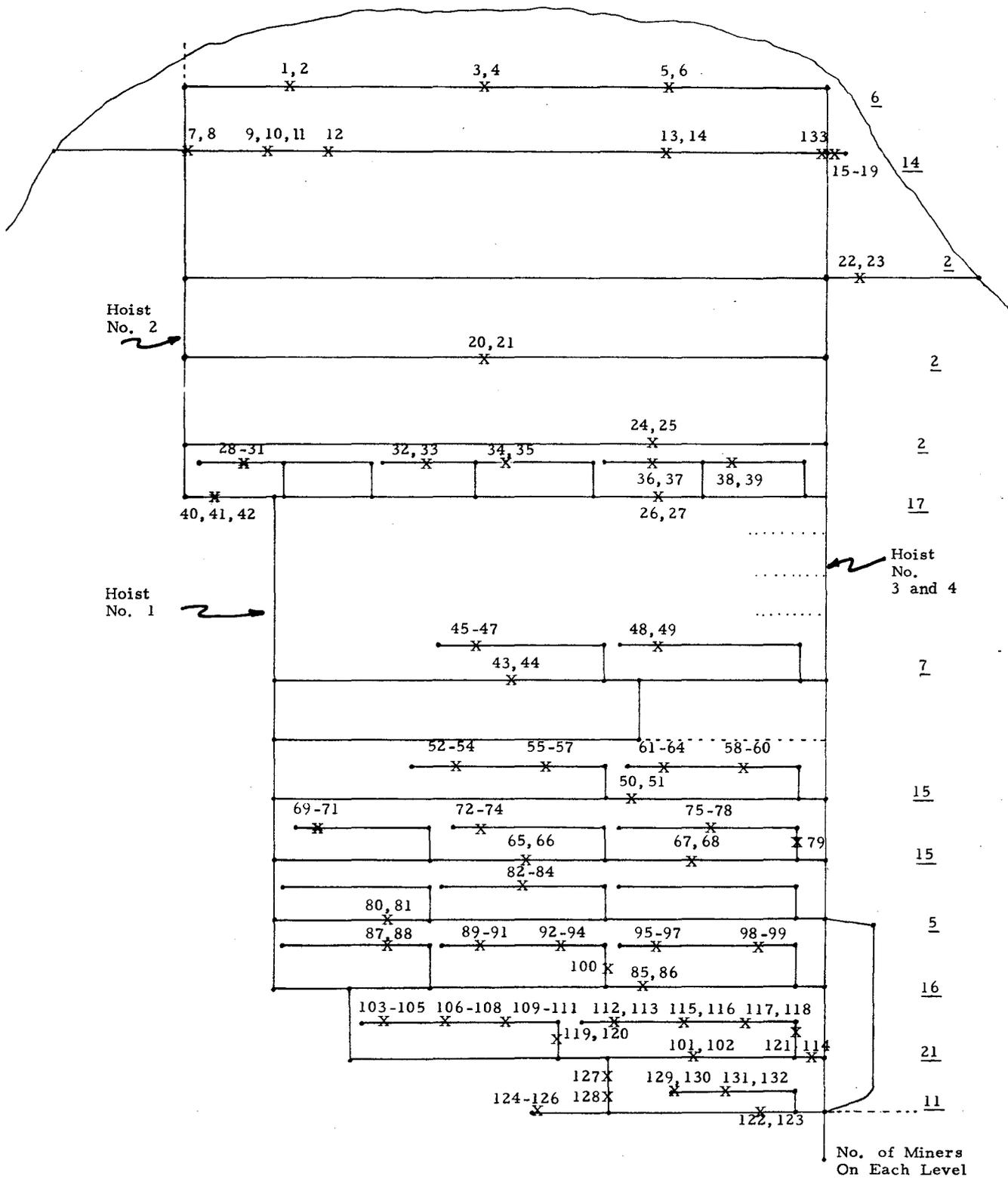


Figure 19 - Miner Distribution In The Illustrative Examples

The hoistman for the main hoist (No. 4) is assigned No. 133, according to the convention defined in Appendix B. The position of the hoistman is above the main hoist on the main level. The initial positions of the other miners on their levels is selected arbitrarily.

Each branch of the mine, which includes the shafts, drifts, stopes and raises, is assigned an identification number, as shown in Figure 20 and each node (where two or more branches meet) is also assigned an identification number, as shown in Figure 21. There are thirteen levels of the mine used in the simulated configurations and they are also assigned identification numbers, as shown in Figure 20.

Each branch of the mine is assumed to have ventilation air, with air velocities obtained from the available mine data, and compressed air with a constant air velocity (generally used in the mines). The smoke travels at the velocity of the ventilation air from the point of origin, where as the stench travels at the velocity of the compressed air from its point of origin, situated at the top of the main hoist (Hoist No. 4). It is also assumed that hoists no. 3 and 4 have three man cages attached initially in all cases, except case 10.

The detailed properties of the mine, including the ventilation data, lengths of the passages, characteristics of the hoists and initial positions of the miners are summarized in Appendix B.

A. 4.2 Simulation Cases

The simulations have been carried out for the following ten cases. The first case duplicates an actual fire drill as closely as possible, so that the results can be compared. The other nine cases predict what may happen in different selected situations and help substantiate some of the suggestions which may be considered while planning evacuation strategies. The cases are:

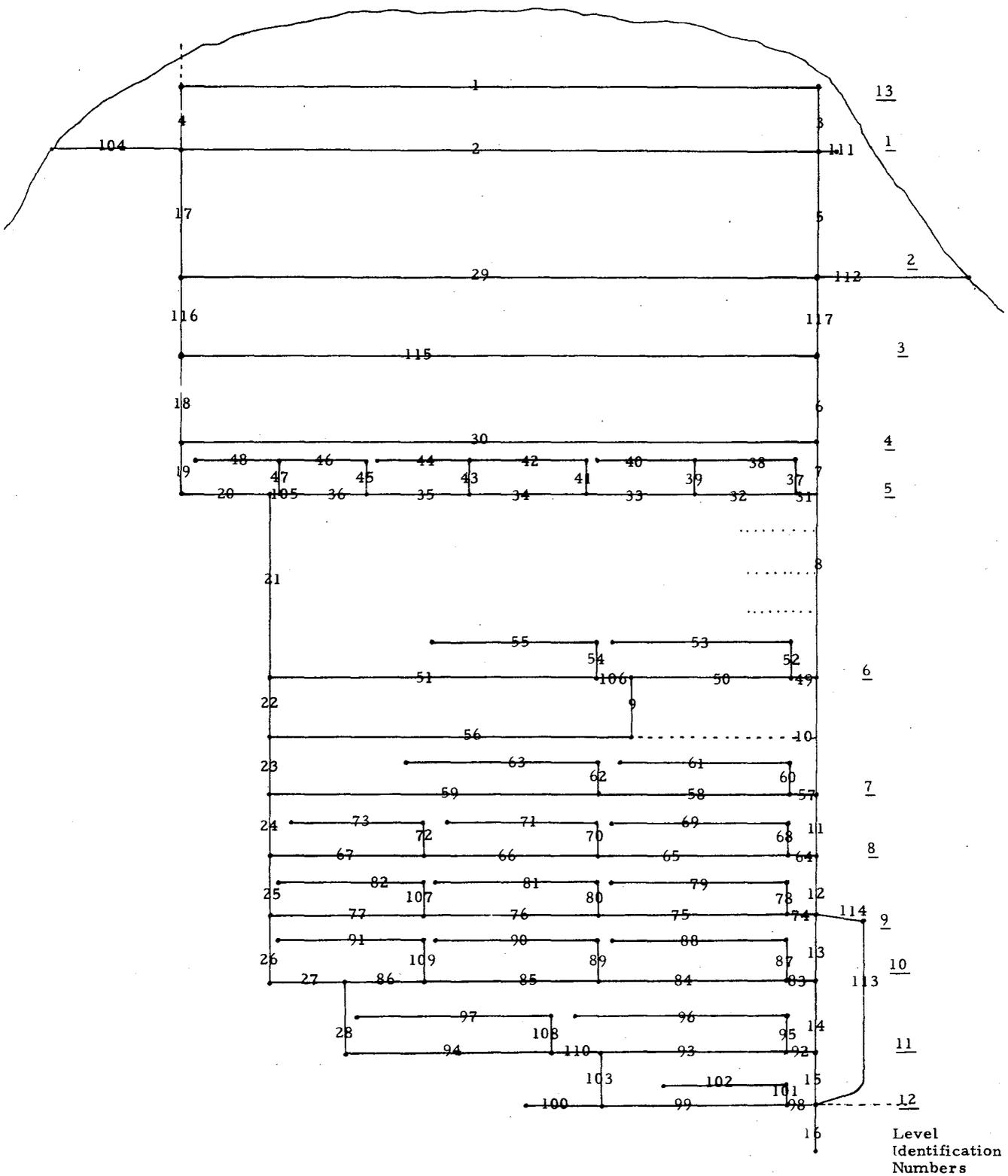


Figure 20 - Branch And Level Identification Numbers

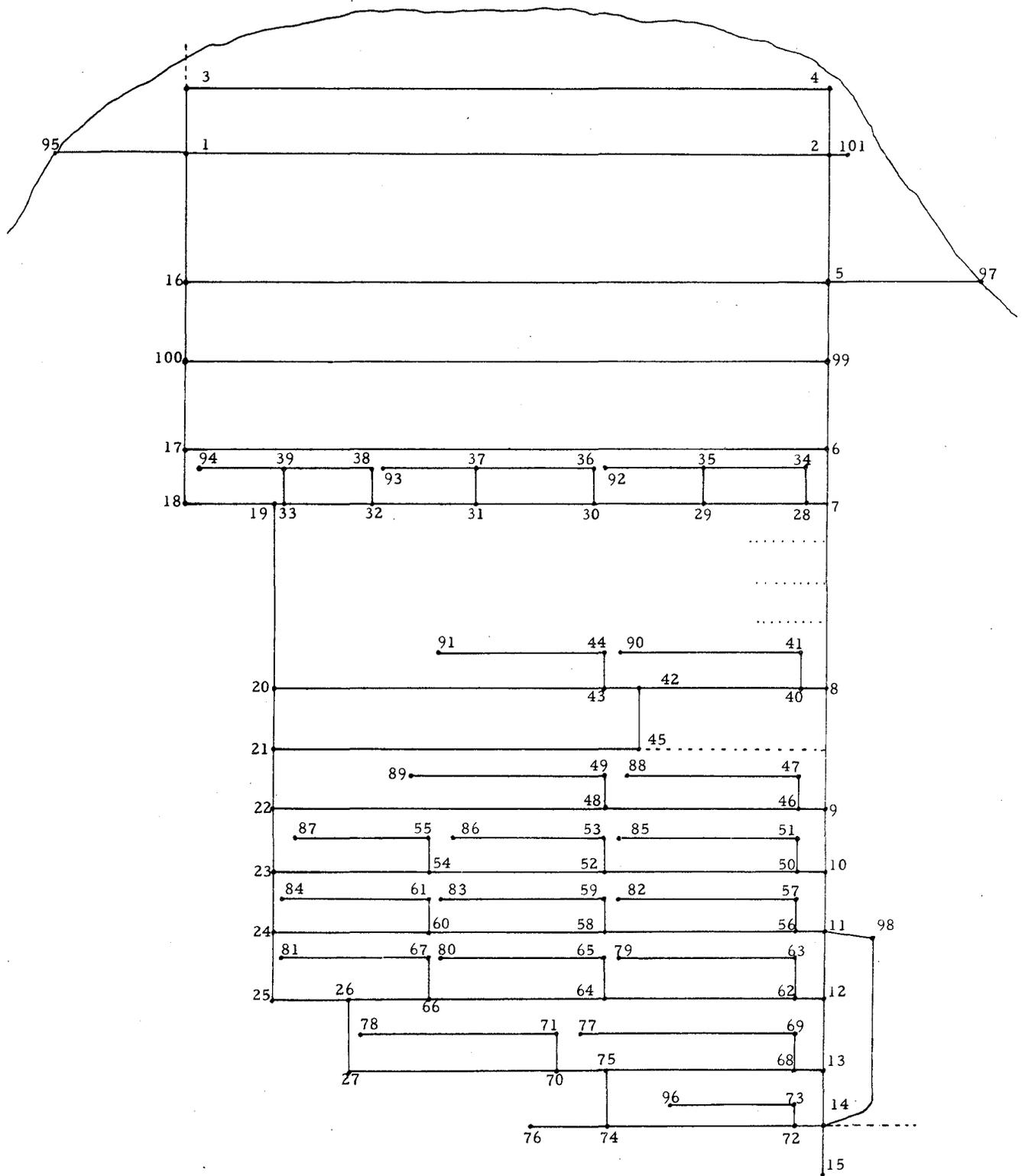


Figure 21 - Node Identification Number

1. Simulation of an Actual Fire Drill Conducted in the Mine

This case can also represent normal evacuation of the mine, as different from the emergency evacuation.

2. Emergency Evacuation of the Mine

Under emergency evacuation, these parameters are changed:

- a. Hoists Nos. 3 and 4 speeds are increased from 1500 ft/min to 2000 ft/min.
- b. Hoist loading and unloading times are changed from 4 minutes to 2 minutes and from 2.5 minutes in the case of No. 1 hoist to 1.5 minutes.
- c. Capacities of the hoists Nos. 3 and 4 are increased from 27 miners to 30 miners.

3. Emergency Evacuation of the Mine, with Usage of Trains in the Drifts

In addition to the parameter changes mentioned in Case 2, the trains in the drifts are also used to haul miners to the hoist stations.

4. Emergency Evacuation in Case of a Fire

With parameters as in Case 2, the evacuation is simulated for a case when there is a fire in a branch (Branch 83 in Figure 20).

5. Emergency Evacuation in Case of a Fire Using Hoisting Option No. 2

According to this option, the miners on level 10 are given a priority in evacuation. The fire is at the same place as in Case 4.

6. Emergency Evacuation in Case of Fire Using Hoisting Option No. 3

According to this option the miners on and below level 10 are hoisted to level 9 in an intermediate haul. Then all the miners on level 9 are evacuated along with those on the other levels. The fire is at the same place as in Case 4.

7. The Main Hoist Inoperative

The fire is simulated to occur in the main shaft and consequently the main hoists (Hoists Nos. 3 and 4) can not be used for evacuation. The miners have been instructed to wait for the main hoist and no secondary exit is available.

8. The Main Hoist is Inoperative, but Secondary Exit is Available

The situation is similar to Case No. 7 but the miners have been instructed to proceed to a secondary exit, in this case to the hoists Nos. 1 and 2, after waiting for the main hoist for a reasonable length of time. The "reasonable length" of time has been assumed to be 30 minutes after the fire has been detected or about 20-25 minutes after the miner has been notified.

9. Normal Evacuation Without the Clutched Hoist

The Case 1 simulation is repeated for a situation where the clutched hoist is not used.

10. Normal Evacuation with Low Capacity Cages

The Case 1 simulation is repeated for a situation where the capacities of Hoists Nos. 3 and 4 are reduced to 9 men from 27 men each.

The above cases have been simulated on a CDC 6600 Computer at the Cybernet Center, Waltham, Mass., and the results are summarized in the following section.

A.4.3 Simulation Results

The results of the simulation are summarized in Table VII and Figures 22 - 29. Detailed outputs of the simulations have not been included in this report because of the bulk, but a typical simulation output is shown in Appendix B.

The following describes salient points of the results for each case:

Case 1: As mentioned earlier, this case simulates a fire drill in the mine 'C'. The result of the evacuation time obtained in the simulation is 83.8 minutes. If the 15 minutes of the train ride to the surface and 10 minutes of the hoistman waiting time are subtracted from 83.8 minutes, the answer comes to 58.8 minutes for all miners to be on the top level, after the fire drill has been initiated. This compares extremely well with 56 minutes reported by the mine 'C' in actual fire drills.

TABLE VII

COMPARISON OF SIMULATION RESULTS

<u>No.</u>	<u>Parameter</u>	<u>Case</u>	<u>1</u>	<u>2</u>	<u>3</u>	<u>4</u>	<u>5</u>	<u>6</u>	<u>7</u>	<u>8</u>	<u>9</u>	<u>10</u>
1	Total number of miners in the mine.		133	133	133	133	133	133	133	133	133	133
2	Total number evacuated		133	133	133	133	133	133	25	76	133	133
3	Total number lost		0	0	0	0	0	0	108	57	0	0
4	Evacuation time for last miner* (minutes)		83.8	67.2	61.3	64.0	72.1	82.2	27.1	83.4	90.6	124.2
5	Delay in stench activation (minutes)		5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
6	Delay in notifying last miner after stench activation (minutes).		3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8	3.8
7	Total number of miners notified by stench.		132	132	132	129	129	129	127	127	132	132
8	Total number of miners notified by smoke.		0	0	0	3	3	3	5	5	0	0
9	Total number of miners exposed to smoke.		0	0	0	16	16	16	110	110	0	0
10	Average smoke exposure, (minutes) (taken over the total number of miners).		0	0	0	1.4	1.4	1.4	48.4	44.0	0	0
11	Average smoke exposure, (minutes) (taken over the number exposed to smoke).		0	0	0	12.1	12.1	12.1	59.2	53.2	0	0
12	Maximum individual smoke exposure (minutes).		0	0	0	15.8	15.8	15.8	60.0	63.9	0	0
13	Man minutes of smoke exposure.		0	0	0	193	193	193	6508	5848	0	0

* Includes the train ride to the surface and the delay time of the hoistman.

MINERS EVACUATED VS TIME

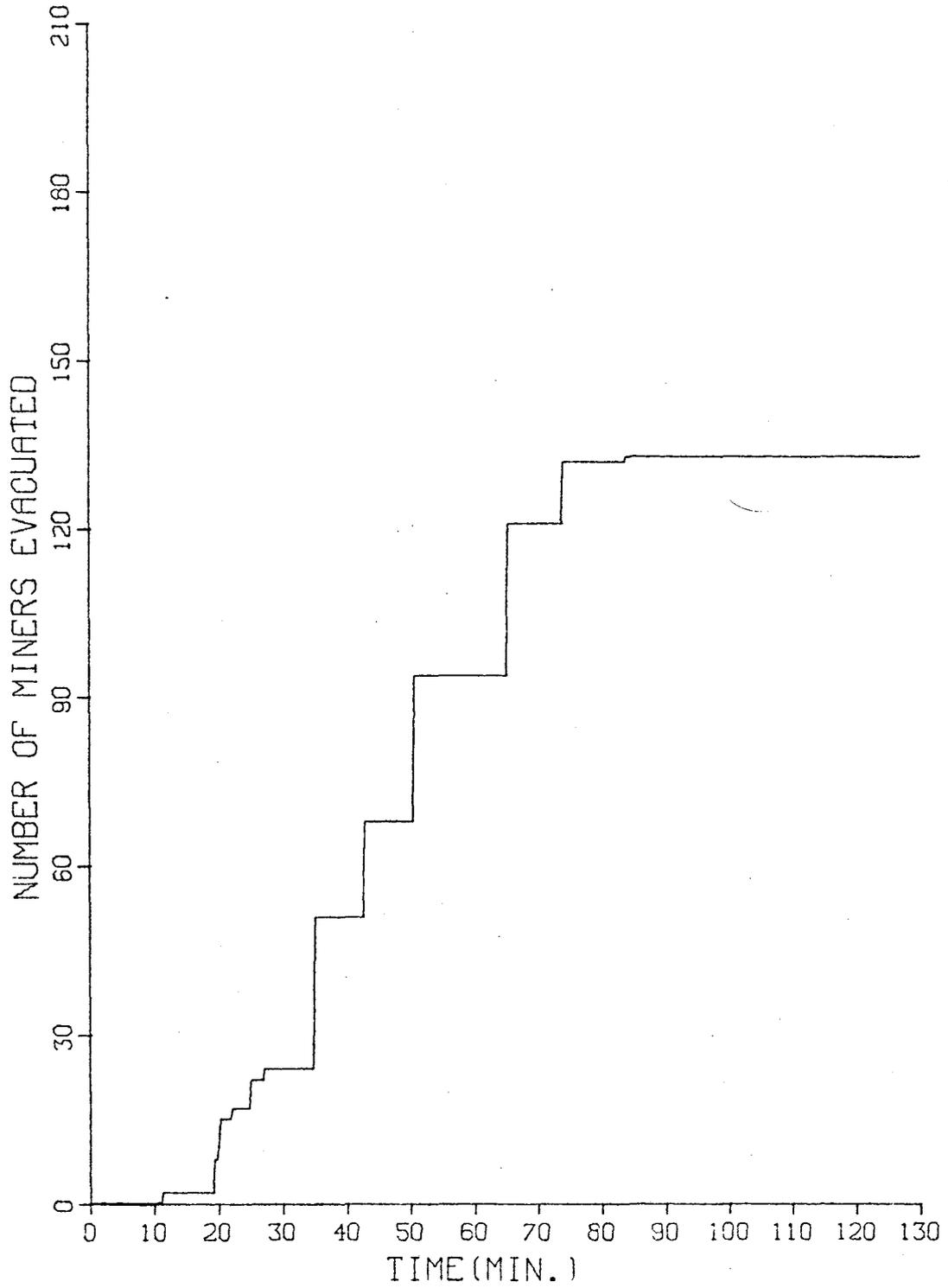


Figure 22 - Case 1, Miner Evacuation

HOIST NO. 2

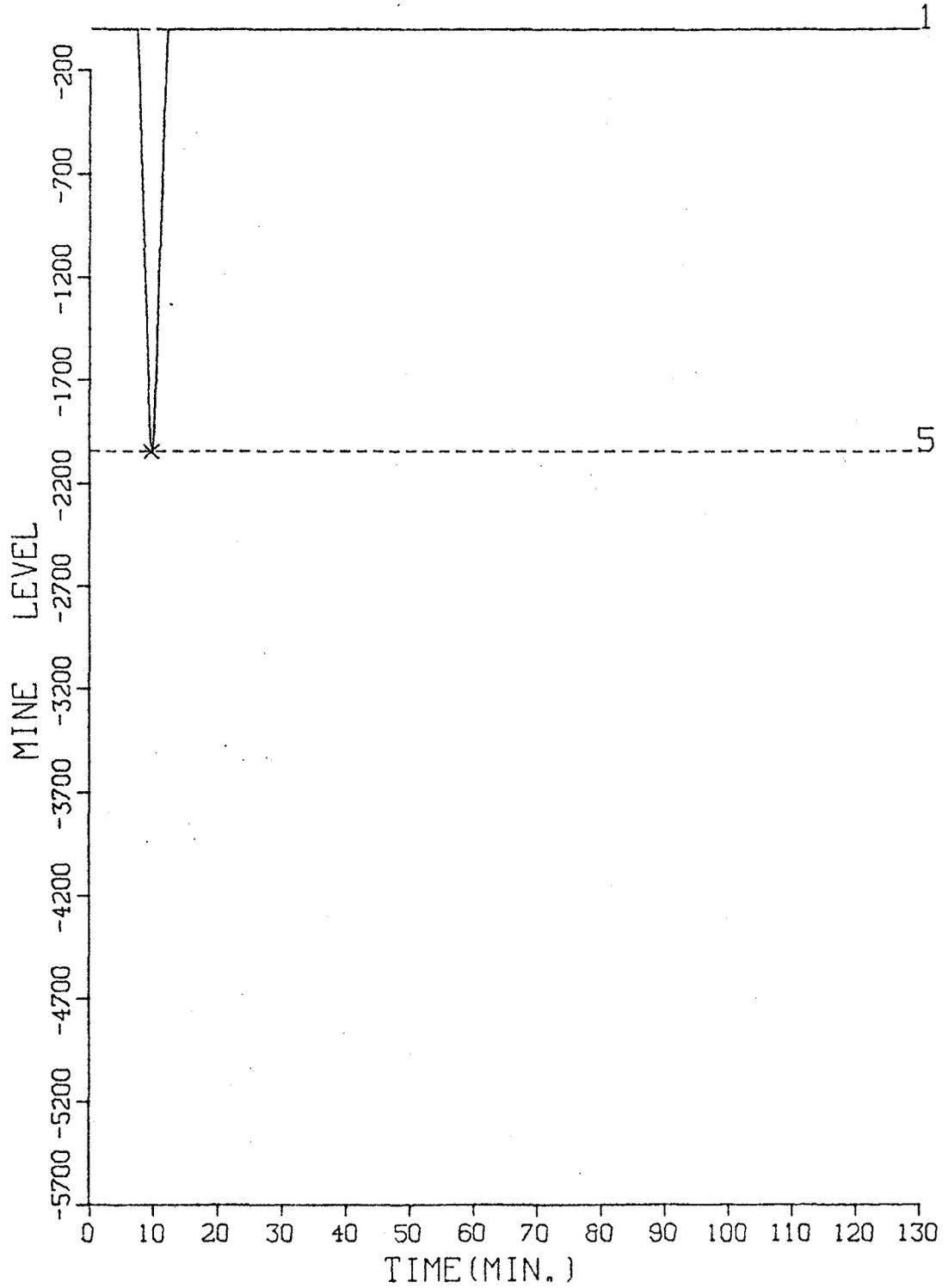


Figure 23 - Case 1, Hoist No. 2 Movement

HOIST NO. 3 (CLUTCHED)

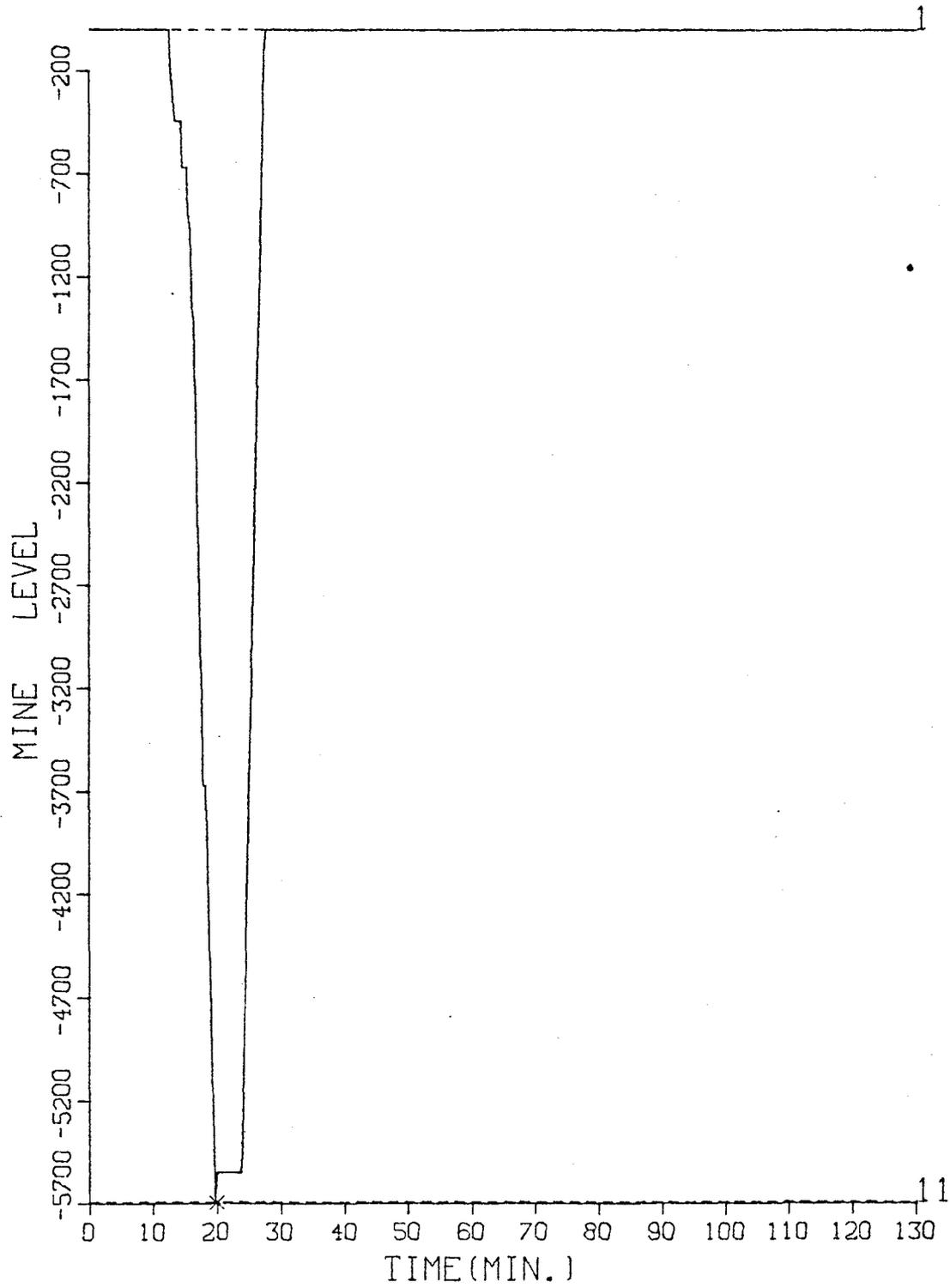


Figure 24 - Case 1, Hoist No. 3 Movement

HOIST NO. 4 (MAIN)

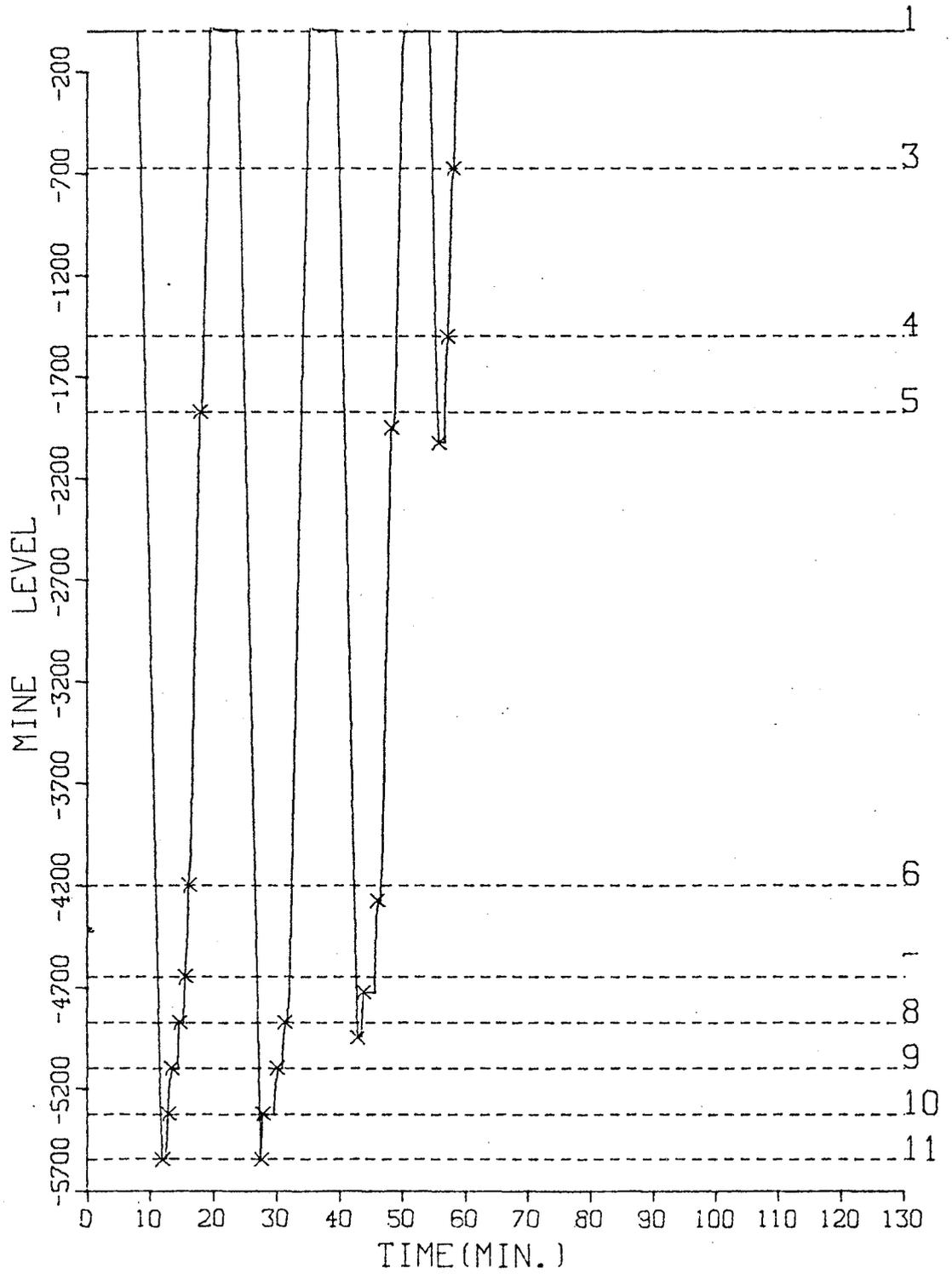


Figure 25 - Case 1, Hoist No. 4 Movement

Such a good prediction by the computer program substantiates its validity.

The stench warning system is predicted to alert every miner within 3.8 minutes after it has been activated, which also is in general agreement with the fire drill results. The results also reflect rather good performance of the stench warning system, at least as far as its dispersion in the mine is concerned. If compressed air usage was down, such as during lunch break, the stench warning may be ineffective.

Since the hoistman is assumed to be notified in the beginning of the simulation, he is not included in the notification results.

The plotted results for Case 1 are shown in Figures 22 - 25. The plot for miners evacuated vs. time shows big steps, since a number of miners are brought up by the hoists at the same time. The last miner to be evacuated is the hoistman who waits for 10 minutes after the last load of miners are in the hoist, before travelling to safety.

Hoist No. 2 makes only one trip to evacuate the three miners near that hoist on level 5. The x axis also shows the distance travelled by the hoist in feet.

Hoist No. 3, the clutched hoist, is clutched in at 11.9 minutes. After making one trip it is declutched at the time of 27.6 minutes, since the main hoist does not find any miners at level 11.

The main hoist, Hoist No. 4, makes 4 trips stopping at 9 levels for a total of 18 times. (The slight departures of the 'stars' from the intended levels is due to the numerical error, which can easily be reduced by reducing the simulation time step).

Case 2: By increasing the hoist speeds and capacities and by reducing the loading-unloading times, the evacuation time can be reduced by 16.6 minutes to 67.2 minutes. In that case the time required for all the miners to be on the top mine level is 42.2 minutes.

Case 3: A further 5.9 minutes is saved if the miners on the mine drifts can ride the trains instead of walking. In that case the evacuation time is predicted to be 61.3 minutes and the time required for all the miners to be on the top level is 36.3 minutes.

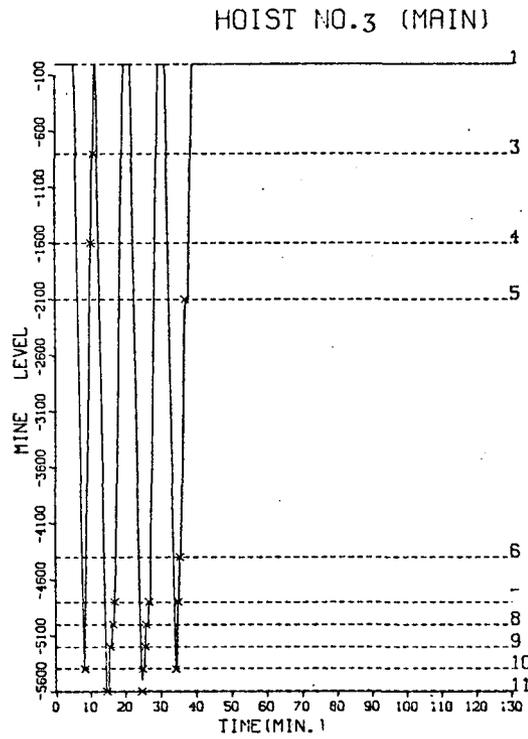
Case 4: Presence of the fire has a side effect which results in an evacuation time which is smaller than that for Case 2 where there is no fire. The side effect is warning of some of the miners due to smoke, instead of stench, which results in an earlier hoisting.

It should be noted that the fire is assumed not to have any thermal effects so actually it is more aptly described as a large and continuous discharge of smoke and carbon monoxide. Due to lack of the thermal effects the miners are allowed to walk through the branch where the fire is present.

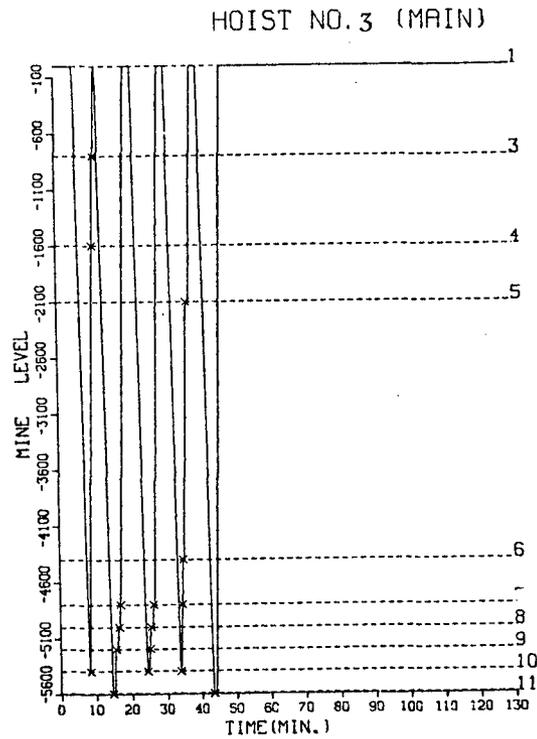
Sixteen miners get exposed to an average of 12.1 minutes of smoke, with the maximum exposure being of 15.8 minutes. However, the fire results in no deaths. Figure 26 shows the movement of the main hoist during the evacuation.

Case 5: When Option 2 is used in hoisting the miners, level 10 is given a priority. If any miner is waiting for the hoist on that level, he is evacuated before a miner on a level below him.

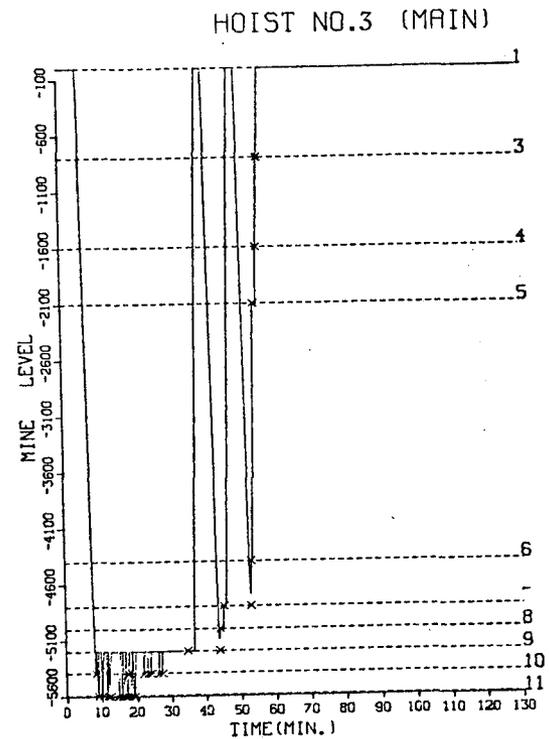
The results can best be shown in Figure 26. The priority given to the level 10 results in a delay in making the last trip to level 11. In fact, it can be calculated, from the detailed results not shown, that the miners on the level 10 are evacuated earlier by using Option 2 than by using Option 1.



Option 1
(Case 4)



Option 2
(Case 5)



Option 3
(Case 6)

(Level 10 is the fire level)

Figure 26 - Comparison of Hoist Movements For the Three Hoisting Options

However, the fire is located in such a way that the miners waiting for the hoist are not subjected to the smoke, at least in the model used to simulate the fire. Therefore, the smoke exposure in both Case 4 and Case 5 occur only when the miners are walking from their initial positions to the hoist station. This results in identical smoke exposure results for Cases 4, 5 and 6. The total evacuation time for Case 5 is higher than that for Case 4 (72.1 vs. 64.0 minutes).

Case 6: In Case 6 the miners on or below level 10 are hoisted to level 9 before being hoisted to the top. The intermediate hoisting is evident in Figure A-10, where the hoist is shown to make a large number (fourteen) of short trips before going to the top level.

Using hoisting Option 3 increases the evacuation time by 18.2 minutes over the Option 1 time. Also, since the smoke is exhausted in the opposite direction from the shaft station, the smoke exposure results do not change by using hoisting Option 3.

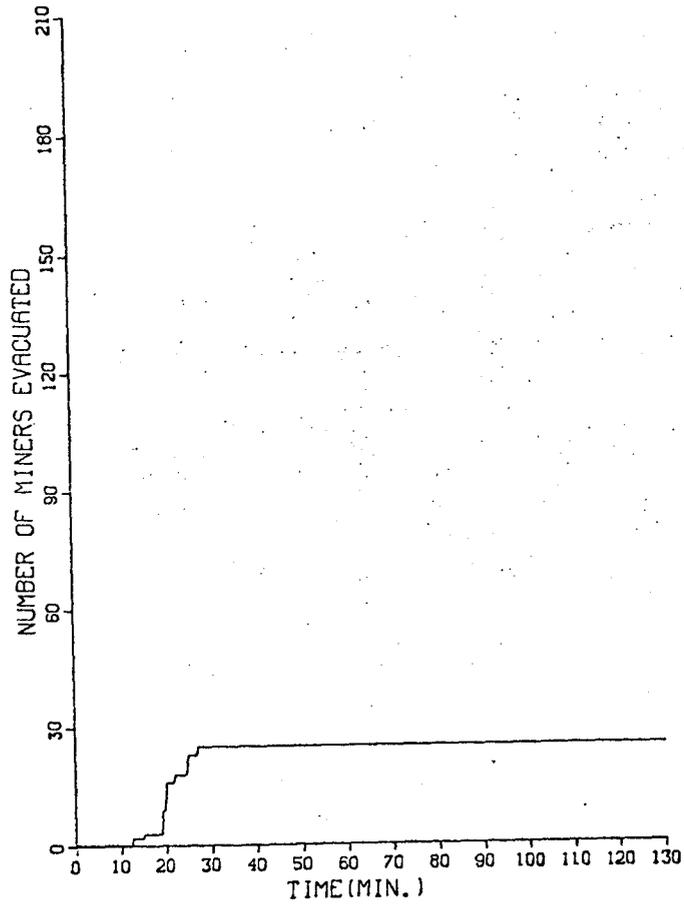
Case 7: The fire is simulated to occur in one of the worst places, i.e., in the main shaft on branch 5 (see Figure A-4). Due to the fire location the main hoists (Nos. 3 and 4) are not used and the miners keep waiting at the hoist station, since they have not been instructed to use a secondary exit.

The smoke spreads all over the mine in due time, resulting in the death of 105 miners on the levels below level 1. The smoke exposure time count stops when the self-rescuer limit is exceeded, therefore the maximum smoke exposure time is 60 minutes.

Five of the miners exposed to the smoke escape, two of them through the exit at node 97 and three of them using the Hoist No. 2 at node 95 through node 1.

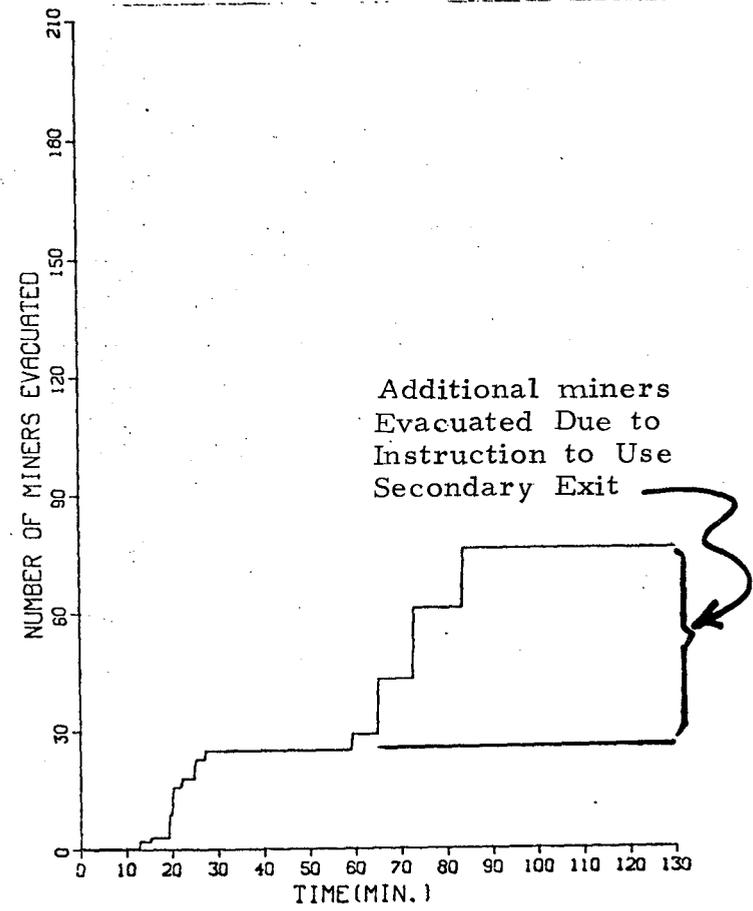
Figure 27 shows a plot of the miners evacuated vs. time for Case 7.

MINERS EVACUATED VS TIME



Case 7

MINERS EVACUATED VS TIME



Case 8

Figure 27 - Comparison of Miner Evacuation For Cases 7 and 8

Case 8: The fire is again in the same position as for Case 7. However, the miners have been instructed only to wait about 20-25 minutes at the main hoist station and then move to the secondary exit which uses Hoists Nos. 1 and 2.

Figure 28 shows the hoisting carried out by the two Hoists Nos. 1 and 2 which is initiated at about 45 minutes and completed at about 70 minutes after the fire has been detected.

Due to usage of the secondary exit, an additional 51 miners are evacuated, bringing the total evacuated to 76. This evacuation of the additional miners is apparent in the plot for miners evacuated vs. time in Figure 27.

Case 9: The clutched hoist, i.e., Hoist No. 3, is not used for evacuation in Case 9. There is no fire in the mine and the results are to be compared with Case 1 results to assess usefulness of the clutched hoist.

Comparing the results, the clutched hoist is found to save only about 6.8 minutes in the evacuation time.

Case 10: If the capacity of the main hoist (No. 4) and the clutched hoist (No. 3) is reduced to 9 miners from 27 miners the evacuation time increases substantially, as illustrated by Case 10. A plot of movement of the Hoist No. 4 and the miner evacuation plot are shown in Figure 29.

As shown in the Figure, the main hoist makes 11 trips (compared to 4 trips in Case 1) with 20 stops (compared to 18 stops in Case 1). The total evacuation time increases from 83.8 minutes to 124.2 minutes, an increment of 40.4 minutes. The miners are also evacuated in smaller batches, compared to the batches in Case 1.

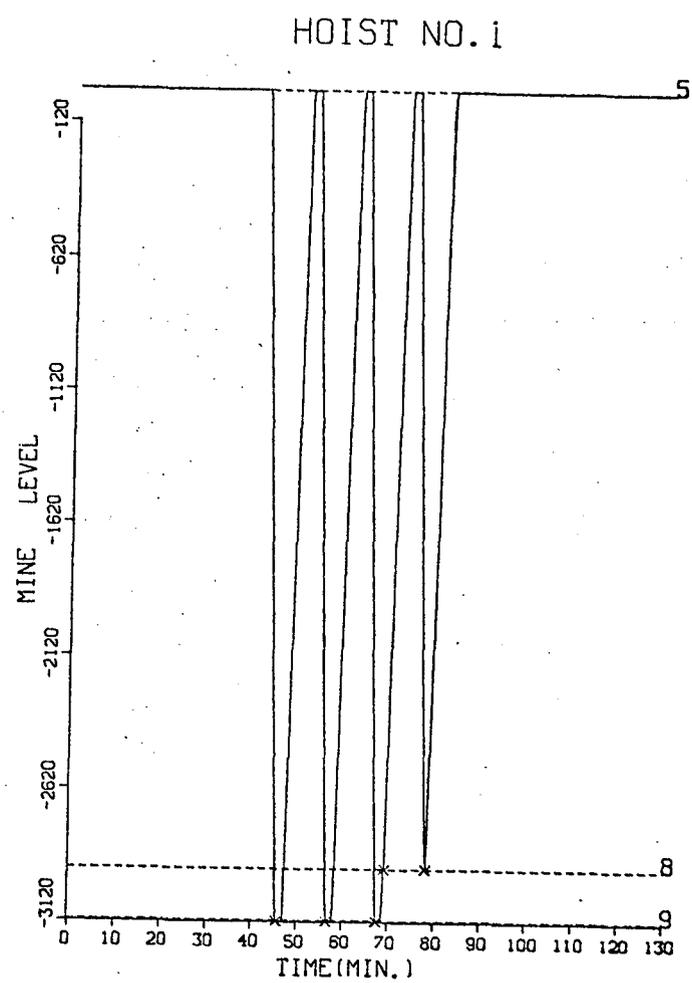
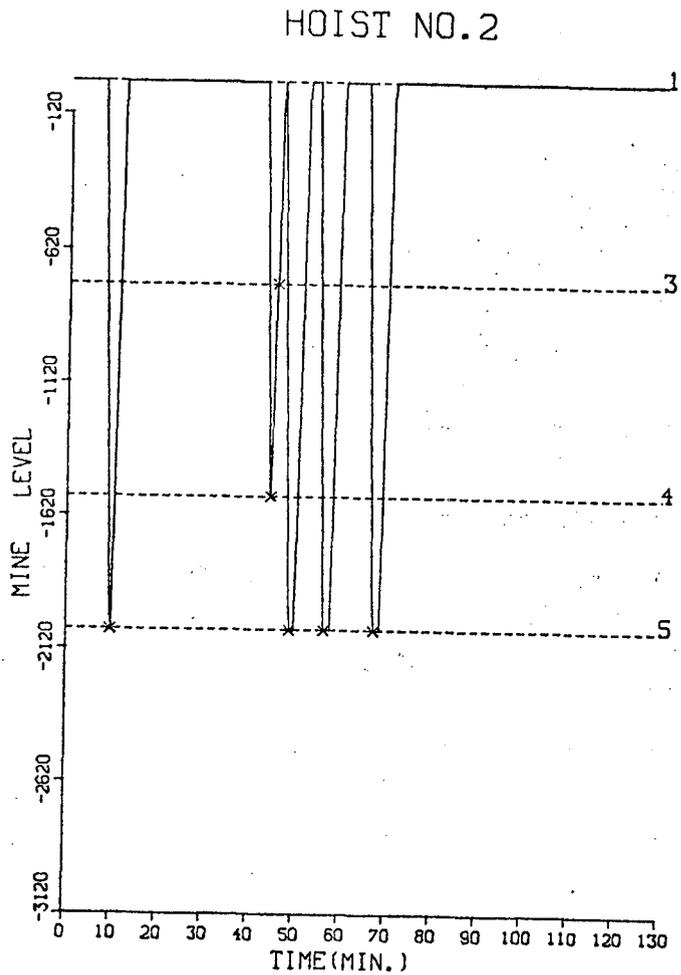


Figure 28 - Use of Hoists 1 and 2 As a Secondary Exit in Case 8

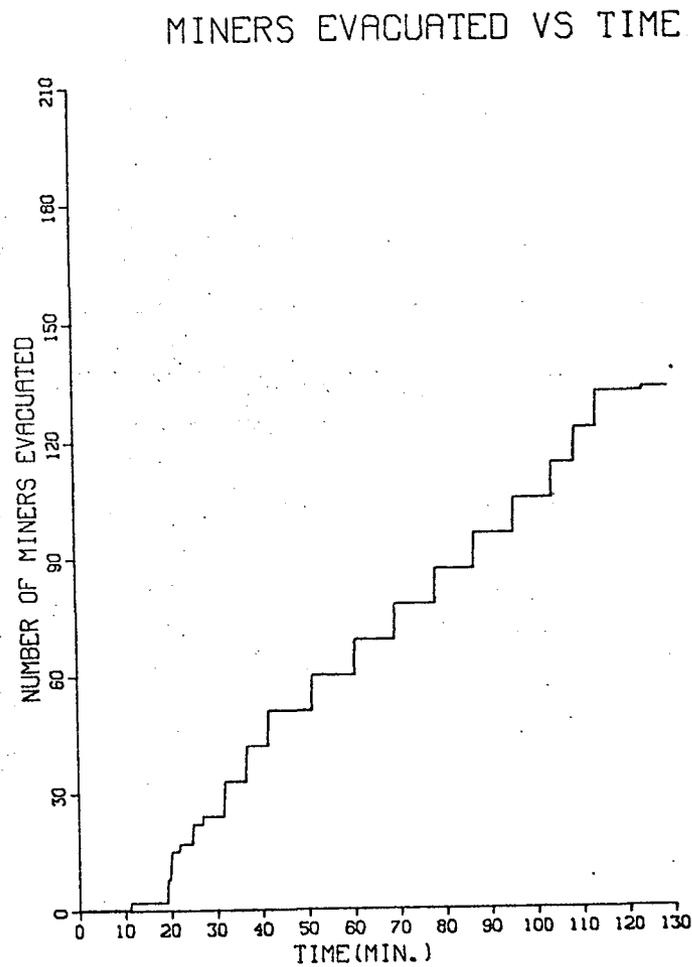
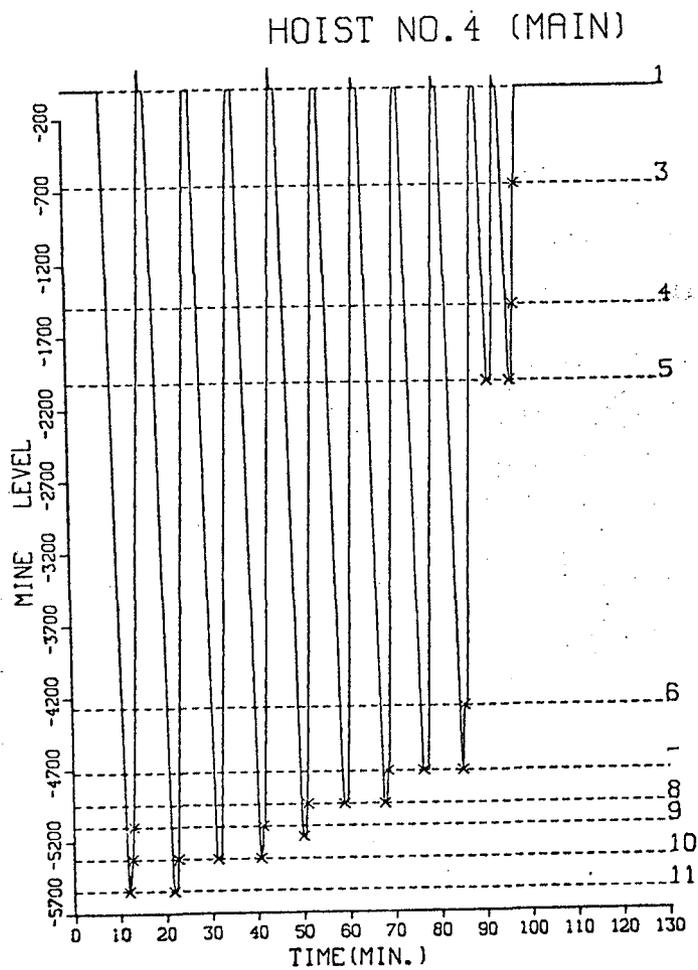


Figure 29 - Results of Case 10 Simulation

A. 4. 4 Discussion of the Results

The results of the simulations summarized in Section A. 4. 3 can help to make certain inferences about the mine evacuation. These inferences are made only for the mine characteristics and the miner configuration considered and they may not be necessarily true in general. However, they provide a guideline in preliminary considerations of a mine evacuation.

A significant reduction in the evacuation time can be made by increasing the hoist speed, hoist capacity and reducing loading-unloading time. The time saving is about 20 percent in the cases considered.

The evacuation time can be further reduced by using trains for transportation on the mine drifts. For the cases considered, the time saving is about 27 percent, compared to the normal evacuation time.

As far as total evacuation of the mine is concerned, the hoisting Option 1, i. e., giving priority to the miners on the lowest level, is the best among the three options considered.

Hoisting options 2 and 3 are better than hoisting option 1 only in the cases where the shaft stations are expected to be smoke filled. In those cases the Options 2 and 3 may result in reduced man-minute exposure to smoke.

If the mine has a secondary exit and the miners are instructed to use it after they have waited for a certain length of time at the main exit hoist, the improvements in evacuation are considerable. In the cases considered, where the fire is in the main hoist shaft, 51 additional miners are saved through the secondary exit, even though it lies in the exhaust air path.

In certain cases it may be advantageous not to use the clutched hoist in a double drum configuration. If the miners are dispersed on different levels, as in the cases considered, the clutched hoist is used only for one or two trips before it has to be declutched. The time savings, assuming it doesn't take any time to clutch or declutch the hoist, is only of the order of 7 minutes in the cases simulated.

It is of advantage to increase the hoist capacity by attaching additional man cages, even though it may consume some time initially. The evacuation time difference between the cases where the capacities are 9 miners and where the capacities are 27 miners is almost 41 minutes.

A.5 Conclusions and Recommendations

The illustrative simulations in the previous section have demonstrated:

1. Flexibility of the program to simulate a wide variety of configurations and cases.
2. Ability of the program to predict evacuation time within a small margin of error (5 percent in a case considered).
3. Usefulness of the program in making some of the evacuation decisions.

The above leads to a conclusion that the computer program can provide a useful tool in evaluating mine evacuation in the event of a fire.

At present the program can be used to make decisions regarding evacuation scheme improvement, while the scheme is being studied. However, significant software and hardware developments are

necessary to make the program available on a real time basis. It is envisioned that if such a real time simulation capabilities are achieved, the program can help evaluate various evacuation options in a very short time when there is a fire in a mine. The program, of course, can not replace a person in the mine with mine evacuation experience in making decisions, but it can provide concrete predictions which may greatly assist the decision making process. An implementable scheme, which can provide a real time evacuation option evaluation capabilities is described in the following:

REAL TIME ESCAPE OPTION EVALUATION USING A COMPUTER

Scheme

The source program, i. e., the mine fire simulation program with appropriate additions (ventilation routines, for example), is stored in a centrally located computer.

The data fed by each mine fall into one of the two categories:

1. Nominal data
2. Variable data

The nominal data is not changed significantly in day to day operation, where as the variable data is dependent on the day, shift, etc.

Nominal Data

Mine passages
Nominal miner speed
Ventilation
Hoist data
Self-rescuer data
Stench location, etc.

Variable Data

Branch a miner is on
Distance along that branch
Hoist operation status, etc.

The nominal data is updated periodically, whereas the variable data is gathered at each shift. Each miner punches in his probable position when he enters the mine. The hoist status data is supplied by the hoistman.

The variable data is fed to the centrally located computer via a teletype and the telephone line.

In case of a fire, the fire location is supplied to the computer, which evaluates several options in real time and makes recommendations.

Typical recommendations may be:

1. Hoist strategy, i. e. :
Use the clutched hoist.
Change over to cages from skip.
Clutch the hoist at level "X".
Hoisting option to be employed.
2. If ventilation should be changed to reduce smoke propagation.

In addition, probable evacuation time and number of fatalities may be predicted.

APPENDIX B

MINE EVACUATION SIMULATION PROGRAM - USER'S MANUAL

B.1 Introduction

Appendix B documents information necessary to use the emergency escape simulation program and to make modifications if necessary.

For a user interested in using the program as it exists, Sections B.2, B.5 and B.6 are particularly useful. The program listing (B.6) can be used to prepare a card deck and the data cards can be punched from the directions given in Section B.2. Typical input data and output printout summarized in B.5 provides guidelines for the program use.

Sections B.3 (Program Nomenclature) and B.4 (Subroutine Description) describe, in detail, the inner workings of the program and are particularly useful for a user interested in modifying the program.

B.2 Program Use

Instructions necessary to execute the program, after the card deck has been prepared, are summarized in the following.

B.2.1 Input Data Format

Input data is supplied to the program in two ways:

- a. By data cards that are read in after program compilation.
- b. By data specifications that are included within the program.

Method a. is used primarily to specify the parameter which constitute the mine characteristics, miner placement, fire position, etc., and are expected to be changed frequently. Method b. is used for parameter which are likely to be changed less frequently (e.g. the time hoistman waits before starting to move, etc.).

B.2.1.1 Data Cards

The data cards required to execute the program can be divided into the following subgroups.

- a. Mine characteristics
- b. Initial position of the miners
- c. Point of origin of the fire
- d. Stench dump position
- e. Time limit of the self rescuer
- f. Simulation data

The mine characteristics includes the properties of the branches and nodes into which the mine network has been divided, properties of the hoists and properties of each level of the mine. The simulation data includes the time step, time limit for the simulation, and information regarding the plots.

The program obtains the data through the following data cards.

<u>No. of Cards</u>	<u>Variable</u>	<u>Format</u>
1	TITL(K), K= 1, 8	8A10
1	IMAX (total no. of branches)	I10
IMAX (one for each branch)	II, IB(I), JB(I), ALB(I), VB(I), VENB(I), VENC(I)	3I10 4F10.3
1	JMAX (total no. of nodes), TSWITCH	I10, F10.3
JMAX (one for each node)	II, MN(J), NN(J), IN(J), JN(J), KN(J), LN(J), MN2(J), NN2(J)	7I10, 2I5
1	KMAX (total no. of miners)	I10
KMAX (one for each miner)	II, JM(K), XM(K), KM(K), TDM(K)	2I10, F10.3, I10, F10.3
1	LMAX (total no. of hoists)	I10
LMAX sets (one for each hoist)	1 II, MH(L), IH(L), VELNH(L), TDELAY(L), IHOIST(L), MSLAV(L), MALEV(L)	3I10, 2F10.3 3I10
	1 XHSTI(L), THSCH(L), NOPT(L), NODFI(L), TDELS(L), TDELF(L)	2F10.3, 2I10, 2F10.3
	1 (more if needed) LH(L, LL), LL = 1, MH(L)	8I10
1	MMAX (total no. of levels)	I10
MMAX (one for each level)	LEVN(M), LEVA(M, MM), MM= 1, 5	6I10
1	IBFIR, XBFIR (Fire data)	I10, F10.3
1	IBSTN, XBSTN, TSTEN (Stench Data)	I10, 2F10.3
1	TSRMAX (self-rescuer data)	F10.3
1	DTIME, FTIME, (Time data)	2F10.3
1	JPLT(K), K= 1, 40, TPLSTR, TPLSTP (plot card)	40I1, 2F10.3
One for each plot	LTITLE(K), K= 1, 3, LYNAME(K), K= 1, 3, LXNAME(K), K= 1, 2 (Title card)	8A10

Explanation of Symbols

TITL(K), K= 1, 8

Title of the simulation run. The title is printed at two places in the output, in the beginning of the printout and above the result summary

II Index used for numbering purpose.

Branch Properties

IMAX Total number of branches

IB(I) The nodes ith
JB(I) branch joins

ALB(I) Length of the branch in ft.

VB(I) Speed of travel on the branch in ft/min. under normal circumstances

e.g., = normal walking speed if the miners walk on that branch

= normal hoist speed if the miners ride a hoist on that branch

= normal climbing speed if the miners climb on that branch, etc.

VENB(I) Speed of smoke propagation on the branch in ft/min

Positive if from IB to JB
Negative if from JB to IB

VENC(I) Speed of stench propagation on the branch in ft/min

Positive if from IB to JB
Negative if from JB to IB

If VENC(I) is not specified, it is assumed to be equal to VENB(I)

Node Properties

JMAX Total number of nodes

TSWITCH Time at which the alternate escape route instructions come into effect. It is assumed to be a large number (10000) if not specified.

MN(J) Type of Node

= 1 If a miner selects a new branch when he encounters that node

= 2 If a miner is considered evacuated when he reaches that node

= 3 If a miner waits for the hoist at that node (hoist node)

NN(J) Instruction regarding branch to take when a miner reaches the jth node.

= 1 If IN(J) is the selected branch

= 2 If JN(J) is the selected branch

= 3 If KN(J) is the selected branch

= 4 If LN(J) is the selected branch

IN(J)	}	Branches which the jth node joins	
JN(J)		The branches to be specified starting from	
KN(J)			IN(J)
LN(J)			
MN2(J)		The node type (MN(J)) for the alternate (secondary) escape route instructions. It is assumed to be equal to MN(J) if not specified.	
NN2(J)		Branch selection (NN(J)) for the alternate escape route instructions. It is assumed to be equal to NN(J) if not specified.	

Miner Properties

KMAX	Total number of miners in the mine
JM(K)	Branch number on which the kth miner is positioned initially
XM(K)	Distance, in ft., at which the miner is positioned on the branch. a. from IB (JM(K)) node if KM(K) = 0 b. from JB(JM(K)) node if KM(K) = 1
KM(K)	Direction of motion along the branch JM(K). = 0 If he moves from IB(JM(K)) to JB(JM(K)) = 1 If he moves from JB(JM(K)) to IB(JM(K))
TDM(K)	Initial delay time for the miner

Hoist Properties

LMAX	Total number of hoists. The double drum hoists are considered as two hoists, and separate sets of cards are required for the main (master) hoist and the clutched (slave) hoist.
MH(L)	Total no. of nodes that the lth hoist connects
IH(L)	Capacity of that hoist (maximum no. of people)
VELNH(L)	Normal speed of that hoist in ft/minute
TDELAY(L)	Maximum delay at a stop in minute Either in filling completely or emptying completely
IHOIST(L)	Initial status of the hoist = 1 Inoperative = 2 Operating = 7 Operating (only for clutched hoist)

MSLAV(L) Hoist number (i. e. L) of the main hoist in a double drum. (To be punched only for the clutched hoist).

MALEV(L) Identification number of the master level at which the clutched hoist operates. e. g., 7500. (To be punched only for the clutched hoist).

XHSTI(L) Initial distance of the hoist from the top level, in ft.

THSCH(L) Delay time in implementing changes in the hoist. e. g., Replace skip by a cage.

NOPT(L) Hoisting option selected for the hoist. It is assumed to be option 1 if not specified.

NODFI(L) The priority node if option 2 if used for hoisting. The intermediate level node if option 3 is used for hoisting.
= 0 If option 1 is used.

TDELS(L) The time, in min., at which the hoist breaks down. It is assigned an arbitrary high value (10000) if unspecified

TDELF(L) The time, in min., at which the hoist is back in operation after the breakdown. It is assigned an arbitrary high value (10000) if unspecified.

LH(L, LL), LL The node number of the nodes connected by the hoist, starting from the bottom.
= 1, MH(L)

Level Properties

MMAX Total number of mine levels serviced by the hoists specified in the hoist cards.

LEVN(M) Identification number of the Mth level (e. g. 7500).

LEVA(M, MM) Node numbers of the hoist nodes on the Mth level.
MM= 1, 5

Fire Data

IBFIR Branch on which the fire starts

XBFIR Distance on the branch IBFIR where the fire starts, in ft.,

a. from IB if smoke propagates from IB to JB

b. from JB if it propagates from JB to IB

Stench Warning System Data

IBSTN Branch on which stench is dumped.
XBSTN Distance on branch IBSTN where the stench is dumped,
 in ft.,
 a. from IB if stench propagates from IB to JB
 b. from JB if it propagates from JB to IB
TSTEN Delay in dumping the stench, in minutes.
 a. after the fire has been detected, or
 b. after the hoistman has been notified in case
 of a fire drill simulation

Self Rescuer Data

TSRMAX Time limit of self rescuer in minutes (say 60.0)

Time

DTIME Time step of simulation in minutes (say 0.05)
FTIME Time limit for simulation

Plot Data

JPLT(K) Variables to be plotted.
 = 1 if Kth variable is to be plotted
 = 0 otherwise

 The variable number is decided in subroutine PSTORE and
 can be changed. Normally variable No. 1 is the total
 no. of miners evacuated and 2, 3 etc., are the hoist
 positions for hoist no. 1, 2 etc.
TPLSTR Plot start time - normally = 0.0
TPLSTP Plot stop time - normally = FTIME
LTITLE(K), The title of the plot (First 30 columns)
K= 1, 3
LYNAME(K), Label of Y axis (next 30 columns)
K= 1, 3
LXNAME(K), Label of X axis (last 20 columns)
K= 1, 2

NOTE:

The following should be noted:

1. Miner No. KMAX is the hoistman of the internal hoist. For him TDM(K) is arbitrary set to a high value (say 1000).

He starts moving only after he waits for TPAT minutes after the last load of miners in the hoist came up, or after he waits for TPAS minutes if the hoist remains on the top level throughout the simulation. Values of TPAT and TPAS are defined in the main program.

If there is no internal hoistman, the value of TDM(L) is set appropriately, but values of TPAT and TPAS are set to a high value (say 1000).

2. Hoist number LMAX is the hoist for which KMAX is the hoistman.
3. Only eight (8) plots can be drawn.

Plot No. 1 is reserved for the total miner evacuated vs. time plot. Subsequent plots are motion of the hoists.

i. e., plot No. 2 is motion of hoist No. 1 drawn as a function of time.

4. Only one double drum hoist can be simulated.
5. The initial delay for a miner (with exception of the hoistman), TDM(K), provides an easy way of taking into account various stopes and raises without making the mine network unnecessarily complex. Instead of including all the stopes and raises in the network, the estimated

time for the miner to walk on the raise from the working face and down the ladder can be specified as the delay time and the initial miner position can be specified as the place on the drift where he finds himself after the delay time.

6. The secondary hoists in the mine, which haul only a limited number of miners through a limited distance, need not be specified in the hoist data. They can be incorporated in the data as branches with higher speeds.
7. If both the fire data card and the stench warning system data card are left blank, the miners are assumed to be notified at time $T=0$.

B. 2. 1. 2 Internally Specified Data

The following three variables are not likely to be changed frequently and are therefore internally specified in the program.

TPAT = The time, in min., for which the hoistman must wait, after the last load of miners, before starting to move to safety. (say 10.0)

TPAS = The time, in min, for which hoistman must wait, if there is no call for hoisting at all (miners using an alternate route to escape), before starting to move to safety. (say 60.0)

TPAR = The time, in min., to wait, after the last load of miners, before the intermediate haul is considered to be terminated in option 3. (say 7.0)

The parameters TPAT and TPAS are specified in the main program whereas TPAR is specified in the subroutine HOIST.

B. 1. 2 Diagnostic Messages

The program may terminate prematurely due to several reasons, for example:

1. Incorrect data format
2. Missing data card
3. Incorrect data value

In case of premature termination, it is advisable to recheck all the data cards, since an error in one data card may generate more errors as the program execution progresses, causing a termination at an apparently unrelated part of the program.

At several places in the program, diagnostic messages are written if the execution is improper and the program is terminated. Due to the above mentioned error generating effect of the initial error, it is not possible to pinpoint the cause of the diagnostic message, however the following list summarizes possible causes.

- a. Hoist nodes improperly specified in the hoist data.
- b. The number of hoist nodes specified for the lth hoist is less than MH(L).
- c. Data regarding the branches connecting the hoist nodes incorrect.
- d. Value of NODFI(L) or MALEV(L) incorrect.

- e. The hoist nodes specified in the level data are incorrect.

Causes (a), (b), (d) or (e) may generate the following error message:

"ERROR IN FINDING NODEA IN SUBROUTINE TSTARC"

Cause (c) may generate:

"ERROR IN FINDING BRANCH IN TSTARC"

Cause (a) or (b) may generate:

"ERROR IN TERMINATING TSTARC"

and cause (a), (b), or (c) may generate:

"ERROR IN MINER SEARCH WHILE GOING UP ROUTINE"

B.3 Principle Program Nomenclature

The principal variable names used in the computer program are defined below. The following dimensions are applicable, unless otherwise indicated.

Distance - Ft.

Velocity - Ft./Minute

Time - Minute

ALB(I) Length of the ith branch

AVSMO Average exposure to smoke by the miners, the average having been taken over the total number of miners (KMAX).

BVSMO Average exposure to smoke by the miners, the average having been taken over the total number of miners exposed to smoke (NMSMO).

DTIME Simulation time step.

FTIME Simualtion time limit.

IB(I) One of the two nodes for the ith branch. (JB(I) is the other).

IBFIR Branch number of the branch where the fire started.

IBSTN Branch number of the branch where the stench is dumped.

ICOUNT Counter used to limit calling the subroutine LEVEL only once, when it is called from the subroutine HOIST.

IDISC Index used to determine if the clutched (slave) hoist should be declutched.

IDISC = 1 If the slave hoist is to be declutched the next time it reaches the top.

IDISC = 0 Otherwise.

IERROR Program error index

I ERROR = 0 If no errors

IERROR = 1 If certain errors exist

IFORCD IFORCD = 1 If the main (master) hoist is being forced down to the master level, MALEV(L), so that the slave hoist can discharge the miners.

IFORCD = 0 Otherwise

IFORCE(L) IFORCE(L) = 1 If the lth hoist is being forced down to the intermediate node, despite the presence of miners at nodes below that node (hoisting option 2).

IFORCE(L) = 0 Otherwise.

IH(L) The maximum number of miners lth hoist can carry in a trip.

IHOIST(L) Status of lth hoist.

IHOIST(L) = 1 Inoperative, either during the entire simulation or during part of it.

= 2 Waiting at the top, or at the intermediate node in case of the intermediate haul (hoisting option 3).

= 3 Moving down towards a target node.

= 4 Picking up miners.

= 5 Going up to the top level or the intermediate node in case of the intermediate haul (hoisting option 3).

= 6 Going up to a target node
 = 7 Unclutched (slave hoist).
 = 8 Clutched (slave hoist).
 = 9 Miners being picked up (only for the slave hoist).
 = 10 Miners being discharged (only for the slave hoist).

IMAST Hoist number of the master hoist (double drum hoist).

IMAX The total number of mine branches.

IMINER(K) Status of the kth miner

IMINER(K)

= 1 Dead
 = 2 Travelling on foot
 = 3 Evacuated
 = 4 Waiting for the hoist
 = 5 Riding up any hoist except the clutched (slave hoist)
 = 6 Waiting in the hoist (when it is picking up other miners)
 = 7 Riding up the clutched (slave) hoist
 = 8 Riding up the hoist engaged in an intermediate haul
 (hoisting option 3)

IMINS(K) Smoke index for the kth miner

IMINS(K) = 0 The miner out of the smoke filled region
 IMINS(K) = 1 The miner in the smoke filled region

LMINT(K) Stench index for the kth miner

LMINT(K) = 0 The miner out of the stench filled region
 LMINT(K) = 1 The miner in the stench filled region

IN(J) The first branch the jth node joins (must be nonzero)

INDEX Index used to determine MH2(L)

INL(L) The total number of levels at which the lth hoist makes
 a stop during the simulation

INSTRCT Index used to execute the instruction switch.

INSTRCT = 0 If the instruction switch has already
 taken place
 INSTRCT = 1 Otherwise

INX(L) Total number of stops lth hoist makes during a
 simulation

IOPT(L) Index used to monitor progress of the intermediate
 haulage in the hoisting option 3.

IOPT(L) = 0 Before the intermediate haulage
 = 1 During the intermediate haulage
 = 2 After the intermediate haulage
 IRD Device number for the card reader
 ISCOB(I) Smoke status of the ith branch
 ISCOB(I) = 0 Clear of smoke
 = 1 Partly smoke filled
 = 2 Completely smoke filled
 ISLAVE Hoist number of the slave (clutched) hoist in the double
 drum hoist.
 ISTNB(I) Stench status of the ith branch
 ISTNB(I) = 0 Clear of stench
 = 1 Partly stench filled
 = 2 Completely stench filled
 IWT Device number of the printer
 IXT Index for counting plotting points in a plot
 IXT maxm. = JPL
 JB(I) The second node for the ith branch
 (IB(I) is the first node)
 JH(L) Total number of miners riding in the lth hoist
 JM(K) Branch number of the branch the kth miner is on
 JMAX The total number of nodes in the mine
 JN(J) The second branch the jth node joins
 JPL Total number of data points to be plotted in a plot.
 Must be less than LIMP.
 JXT Index used for skipping points when storing plot data.
 KGHOST The miner number for the "ghost" created to direct
 the hoist motion, in case there is no miner alive
 when the hoist reaches the target node.
 KM(K) Direction of motion for the kth miner
 KM(K) = 0 If he moves from IB(JM(K)) node to
 JB(JM(K))
 KM(K) = 1 If he moves from JB(JM(K)) node to
 IB(JM(K))
 KMAX The total number of miners in the mine.
 KN(J) The third branch the jth node joins
 KNOTF(K) Notification index for the kth miner

KNOTF(K) = 0 If the miner is not yet notified
 KNOTF(K) = 1 If the miner is notified
 KNOTF(KMAX) is always 1

LGHOST(L) The number of "ghosts" riding up the lth hoist. The ghosts are created to direct the hoist motion in case there is no miner alive when the hoist reaches the target node.

LEVA(M, J) Node number of the jth node on the mth level at which a hoist can make a stop. J can be maximum 5.

LEVN(M) Identification number of the mth level of the mine (e. g. 2200 etc.)

LLEP(L, I) Identification number of the ith level at which the lth hoist stops
 I = 1, INL(L)

LH(L, LL) The node number of the llth node at which the lth hoist stops, counting from the bottom. LL = 1, MH(L)

LIMP Limit on the total number of data points that can be plotted in a plot

LMAX The total number of hoists in a mine, (The double drum hoist is counted as two hoists).

LN(J) The fourth branch joined by the jth node.

LSLBR The branch number of the branch joining the top two nodes of the slave hoist.

MALEV(L) The identification number of the master level at which the slave hoist operates. It is non zero only for the slave hoist.

MANOD The node number of the node on the master level at which the slave hoist can stop.

MDE(K) MDE(K) = 0 Do not print if kth miner safe or dead
 = 1 Print number safe or dead
 = 2 The kth miner is riding a hoist and can not go to MDE(K) = 1 without going through MDE(K) = 0

MDEAD The total number of deaths in the simulation

MH(L) The total number of nodes the lth hoist connects

MH1(L) Used to store MH(L) if the lth hoist is operated in option 3

MH2(L) The total number of nodes the lth hoist can stop during the intermediate haulage in option 3

MINH(L, K) The miner number of the kth miner riding the lth hoist

MMAX The total number of levels in the mine

MN(J) Type of the jth node

MN(J) = 1 If the miner does not wait at that node
 = 2 If the miner reaching that node is considered evacuated (safe node)
 = 3 If the miner reaching that node has to wait for a hoist (hoist node)

MN2(J) Type of the jth node(MN(J)) after the instruction switch

MNP(J) The total number of miners waiting at the jth node (valid only for MN(J) = 3)

MNSMOK The total number of miners warned by smoke

MNSTEN The total number of miners notified by stench

MSAFE The total number of miners evacuated

MSLAV(L) The hoist number of the master hoist for the lth hoist, if the lth hoist is a slave (clutched) hoist

NMSMO The total number of miners exposed to smoke

NMT(K) The node number of the last node passed by the kth miner

NOPT(L) The hoisting option being used by the lth hoist
 NOPT(L) = 0 Option 1 in which preference is given to the bottom most miners
 NOPT(L) = 2 Option 2 in which preference is given to the miners on the intermediate node (NODFI(L))
 NOPT(L) = 3 Option 3 in which the miners below the NODFI(L) node are hauled to the NODFI(L) node before being hoisted to the top

NN(J) Instruction given to the miners on which branch to take at the jth node
 NN(J) = 1 If the IN(J) branch is to be taken
 = 2 If the JN(J) branch is to be taken
 = 3 If the KN(J) branch is to be taken
 = 4 If the LN(J) branch is to be taken

NN2(J) Instruction to the miner reaching the jth node (NN(J)) regarding which branch to take, after instruction switch

NODEA The lower node in calculations of estimated time to reach the target node for a hoist

NODEB The upper node in the calculations of estimated time to reach the target node for a hoist

NODFI(L) The intermediate node for the lth hoist if option 2 or 3 is used.

NOODL The node at which the hoist has stopped
 NPLT(I) The variable number for the ith plot
 NPLTM The total number of plots
 NSTAR(L) The target node for the lth hoist
 NXT The number of data points to be skipped while plotting
 PLT(I, J) The jth point in the ith plot
 T Time
 TDEL(L) Delay in loading or unloading the lth hoist with JH(L) miners
 TDELAY(L) The maximum delay time for loading or unloading of the lth hoist
 TDELF(L) The time at which the lth hoist is back in operation after a breakdown
 TDELS(L) The time after which the lth hoist breaks down when it reaches the top
 TDHD(L) Total initial delay time for the lth hoist. This delay time includes the delay for bringing the hoist to the top level (THSRH(L)) and for configuration change (THSCH(L))
 TDM(K) Initial delay time for the kth miner. Changed to the total time elapsed, before the miner gets moving on a branch, later in the program.
 TENOT Time taken by the stench to reach the last miner, who hasn't already been warned by the smoke.
 TEVAC Evacuation time, i.e., Time taken by the last miner to reach safety after detection of fire or beginning of a fire drill.
 THSCH(L) Delay time for the lth hoist in implementing configuration changes e.g., changing cages.
 THSRH(L) Time taken by the lth hoist to reach to the top from it's initial position.
 TITL(K) Array storing the simulation title
 TMAXSMO The maximum individual smoke exposure
 TMOVE(L) The time for which the lth hoist has been travelling when moving towards the target node NSTAR(L)
 TOTSMO Man minute of smoke exposure
 TPAR Time to wait after the last load of miners before the intermediate haul is considered terminated, in option 3.

TPAS The time for which the hoistman must wait before starting to move to safety. This is used only in case the hoist hasn't been called to evacuate any miners.

TPAT The time for which the hoistman must wait, after the last load, before starting to move to safety.

TPLSTP The final time for the plot, Normally equal to FTIME.

TPLSTR The initial time for the plot. Normally equal to zero.

TSEFR(K) The accumulated time for which the kth miner uses his self-rescuer during the simulation.

TSRMAX Time limit of the self-rescuer.

TSTAR(L) Estimated time to reach the target node while moving down, for the lth hoist.

TSTEN Delay in activating the stench warning system after the fire has been detected.

TSWITCH Time at which the second set of instructions for the miner become effective.

TTRAV The time for which the hoist has been travelling between NODEA and NODEB.

TWAIT(L) The time for which the lth hoist has been waiting at a level.

TUP(L) The time for which the lth hoist has been moving towards the top.

VB(I) Speed of travel on the ith branch under normal conditions e.g. VB(I) = Normal walking speed if the miners walk along that branch.
 = Normal hoist speed if the miners ride on the hoist along that branch, etc.

VELM(K) Speed of the kth miner at any instant.

VELNH(L) Normal speed of the lth hoist.

VENB(I) Smoke propagation speed in the ith branch.
 VENB(I) is positive if the smoke propagates from IB(I) node to JB(I) node.
 VENB(I) is negative if the smoke propagates from JB(I) node to IB(I) node.

VENC(I) Stench propagation speed in the ith branch.
VENC(I) is positive if the stench propagates from IB(I) node to JB(I) node.
VENC(I) is negative if the stench propagates from JB(I) node to IB(I) node.

XBFIR Distance of the fire on IBFIR branch, from IB(IBFIR) if VENC(IBFIR) is positive.
From JB(IBFIR) if VENC(IBFIR) is negative.

XBSTN Distance at which the stench has been dumped on IBSTN branch, from IB(IBSTN) if VENC(IBSTN) is positive.
From JB(IBSTN) if VENC(IBSTN) is negative.

XHMAX The maximum distance travelled by any hoist from the top.

XHST(L) Distance of the lth hoist from the top at any instant.

XHSTI(L) Distance from the top to the intermediate haulage level for the lth hoist, if hoisting option 3 is used.

XLEP(L,I) Negative distance of the ith level, from the top, at which the lth hoist stops.

XM(K) Distance on branch JM(K), at which the kth miner is located,
From IB(JM(K)) node if KM(K) = 0
From JB(JM(K)) node if KM(K) = 1

XMAST Distance of the master level from the top (double drum hoist)

XSMOK(I) Length of the smoke filled section on the ith branch.

XSTN(I) Length of the stench filled section on the ith branch.

XXP(L, J) The time at which the lth hoist makes the jth stop.

XYP(L, J) Negative distance from the top at which the lth hoist makes the jth stop.

B.4 Description of Subroutines

There are thirteen subroutines in the program:

PROGIO
HOIST
MINER
SMOKE
STENCH
MSMOK

MSTNCH
TSTARC
PSTORE
VPLOTS
XSTAR
LEVEL
DDRUM

A description of the functions of each subroutine along with a flow diagram representing their interactions with the program and between each other is given in Section A.3.3. However for some of the subroutines a more detailed explanation is necessary to show how the program logic is translated to specific program statements. These subroutines, along with the main program are described in the following. The part of the subroutine being discussed is referenced through a location number (left side column of numbers in the listing Appendix B.6), and it is identified by paranthesis.

B.4.1 Main Program

The initial part of the main program is devoted to acquiring data from the data cards through subroutine PROGIO and setting the arrays to zero or initial values. The parts which need explanation are:

(162) If the hoist is not at the top initially, subroutine LEVEL should not be called.

(217) - (253) The first DO loop determines the level number of the master level and stores it as M. The second DO loop determines the specific hoist node on the master level and stores it as MANOD.

(267) -(306) When the miner instructions are changed, INSTRCT makes certain that the part which implements the change is not repeated at every time step after T> TSWITCH.

Values of MN(J) and NN(J) are changed to new values, if necessary, using two DO loops.

(306) - (326) The data for plotting is stored only if the following three conditions are satisfied simultaneously.

1. The user requires plots ($NPLTM \neq 0$)
2. The time is within the plot "time window", i. e. $TPLSTR < T < TPLSTP$.
3. The value of IT is zero. IT becomes zero at every NXT steps.

(332) - (445) The hoistman leaves the post if any of the following four conditions are satisfied.

1. The hoist, LMAX, has not been used ($INX(LMAX) = 1$) and the waiting time $TWAIT(LMAX)$ is greater than TPAS.
2. The hoist, LMAX, has been used ($INX(LMAX) > 1$) and the waiting time is greater than TPAT.
3. The hoist, LMAX, is inoperative throughout the simulation i. e., $IHOIST(LMAX) = 1$, and the breakdown times are left unspecified.
4. $TDELS(LMAX)$, i. e. the breakdown starting time, is specified but breakdown end time, $TDELF(LMAX)$ is not specified, making the breakdown irreversible. Then the hoistman then leaves the post when $T > TDELS(LMAX)$.

The hoistman is made to leave the post by resetting his delay time from initially specified high value, e.g. 1000, to $0.9 * T$. When he leaves the post, IHOIST(LMAX) is made equal to 1, thereby making his hoist inoperative.

Rest of the main program deals with calculating the simulation summary parameters, and is self-explanatory.

B. 4. 2 Subroutine Hoist

Subroutine HOIST determines status and position of each of the LMAX hoists as a function of time. A DO loop which envelopes the subroutine from beginning to the end executes the subroutine for each hoist.

Initially the control is passed to statement No. 8 when the hoist is moving up from its initial position and to statement No. 9 when it is delayed for configuration changes. When the control is directed to No. 8, only the hoist position is up-dated, but when it is directed to No. 9 LEVEL is called to store the information about the top level. Index ICOUNT makes sure that LEVEL is called only once.

After T becomes greater than TDHD(L), the control is directed to statement No. 1, 2, 3, 4, 5, 6 or 7 depending on the value of IHOIST(L). For IHOIST(L) equal to or greater than 7, subroutine DDRUM is called because IHOIST(L) assumes such values only for the clutched part of the double drum hoist. For other IHOIST(L) values, the control is passed to the statement number equal to the value of IHOIST(L).

1. Hoist Inoperative

This part of the program is executed when IHOIST(L) = 1.

If IHOIST(L) is equal to 1 in the input data (i. e. the hoist is inoperative throughout the simulation), a message "HOIST NO. L INOPERATIVE" is printed in the output. If IHOIST(L) is made 1 due to a breakdown at $T > 0$, such a statement is not printed and value of time is checked to determine of the breakdown period is finished ((55) - (61)). At $T > TDEL(L)$, the breakdown period is considered completed, a message "HOIST NO. L BACK IN OPERATION AT TIME T" is printed, and IHOIST(L) is made equal to 2.

An exception to the above is a case when the hoistman for the hoist No. LMAX, (the only hoist which can have a hoistman according to the program constraints), has left the position due to any of the reasons mentioned earlier in B. 4. 1. Then the hoist does not come back in operation even after $T > TDEL(L)$.

2. Hoist Waiting At Top

Initially it is determined whether the waiting period for the hoist, TWAIT(L) has exceeded the time necessary for unloading the hoist, TDEL(L). TDEL(L) is determined from TDELAY(L) according to the fractional capacity of the hoist occupied by the miners, and it is set to zero initially. For TWAIT(L) < TDEL(L), the following is accomplished.

1. TWAIT(L) is increased by a time step (77).
2. If $TDELS(L) < T < TDEL(L)$, i. e. if the hoist is inoperative, IHOIST(L) is made equal to 1 and a statement regarding the breakdown is printed.
3. The values of XHST(L), GHOST(L), NSTAR(L), TMOVE(L), JH(L) and MINH(L,I) are set to zero.

An exception to the rule is the case when the hoist L is undergoing the intermediate haul in hoisting option 3, as indicated by the value of $IOPT(L) = 1$. Then $XHST(L)$ is not set to zero, but to $XHSTIN(L)$, which is the distance of the intermediate level from the top level.

When $TWAIT(L) \geq TDEL(L)$, the hoist is made ready to move. Under normal circumstances the control is passed to statement No. 25 (306). The logic used from (306) to (340) is devoted to determining the target node for the hoist to head down to and it is best explained by a flow diagram in Figure B.1. The hoist generally (option 1 and option 3 for most of the time) selects the bottom most node where there are miners waiting, i.e. MNP is non zero. This is accomplished by starting from node $LH(L,1)$ (the bottom most node), checking for value of MNP and going to the next higher node ($LL = LL+1$) if the value is zero. If values of MNP for all the nodes are zero, the control is passed to the end, i.e. statement No. 20, and the search is resumed at the next time step.

When the target node, $NSTAR(L)$ is finally selected, $IHOIST(L)$ is made = 3, and estimated time to reach that node, $TSTAR(L)$, is determined by calling subroutine $TSTARC$.

There are three exceptions to the rule, when $TWAIT(L) \geq TDEL(L)$:

1. (207) - (221) If hoisting option 2 is used for the hoist L, i.e. $NOPT(L) = 2$, MNP for $NODFI(L)$ is checked. If it is found to be non zero, $NODFI(L)$ is made the target node and $IFORCE(L)$ is made 1 to indicate that the hoist is being forced down to the priority level.

2. (223) - (246) If the hoist L is the master hoist ($L = \text{MAST}$), and there are miners in the slave hoist ($\text{JH}(\text{ISLAVE}) \neq 0$), the master level node, MANOD , is made the target node and IFORCD is made 1 to show that the hoist is being forced down to the master level.

3. (262) - (306) If the hoist is operating in option 3 intermediate haul, as indicated by value of $\text{IOPT}(L) = 1$, the value of $\text{TWAIT}(L)$ is compared with the selected waiting time TPAR . If $\text{TWAIT}(L) > \text{TPAR}$, the intermediate haulage is considered finished, and the hoist is prepared for regular haulage status. This is accomplished by making $\text{IOPT}(L) = 2$, $\text{MH}(L) = \text{MH1}(L)$ (Total nodes served by the hoist expanded to the initial number), $\text{IHOIST}(L) = 4$ (The hoist in waiting node before moving up), $\text{NSTAR}(L) = \text{NODFI}(L)$ (The priority node assigned the target node status) and by making $\text{TWAIT}(L)$ and $\text{TMOVE}(L)$ zero. The control is then passed to statement 4, in the hoist-waiting-at-target-node part of the program.

If both exceptions 1 and 2 exist simultaneously, exception 1 is given a priority.

3. Hoist Heading Down

When $\text{IHOIST}(L) = 3$, this part of the subroutine is executed. Normally the hoist stays in status 3 as long as $\text{TMOVE}(L)$, which is incremented at every time step, is less than $\text{TSTAR}(L)$ - the time necessary to reach the target node.

To determine if any miners exist below the target node to which the hoist is heading down, the target node selection loop (Figure 30) is executed at every time step (400). In the selection loop the search again begins from the bottom most node, and if the target node already selected is re-selected, no changes are made (statement No. 26). If however a node MMM , lower than $\text{NSTAR}(L)$ is found to have miners waiting, $\text{NSTAR}(L)$ is made equal

Note: T = True
F = False

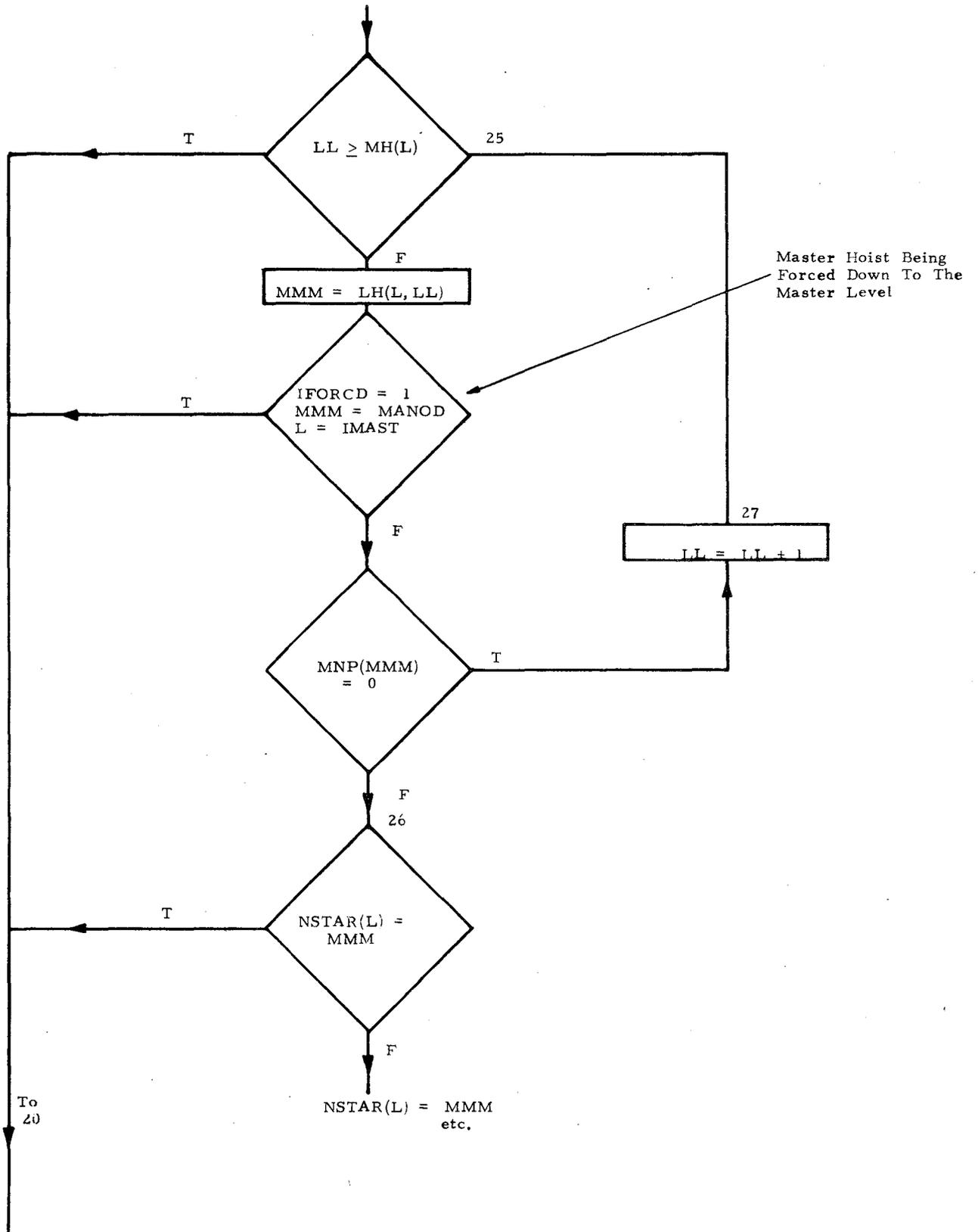


Figure 30 - Flow Diagram For Target Node Selection

to MMM, a new value of TSTAR(L) is calculated and TMOVE(L) is set back to zero.

If the hoist is being forced down to either the priority level in option 2 (366) or to the master level (314), the selection loop is not executed from this part of the program.

When TMOVE(L) becomes \geq TSTAR(L), IHOIST(L) is made = 4 and the hoist passes to the next status.

4. Hoist Waiting At Target Node

The purpose of this part of the subroutine is to load the miners in the cages and to prepare the hoist for moving up after waiting for the loading time. Under normal circumstances the sections of the part 4 of the subroutine executed are:

(407) - (417) Index IFORCE(L) is made zero if it is 1. The control is passed to statement No. 41 if this part has been executed once (411).

(456) - (460) Subroutines LEVEL and XSTAR are called to store the information about the level, to be used later in plotting.

(502) - (507) Parameter XHMAX is used to specify length of the Y axis in hoist displacement plots. The largest value of XHST(L), for any hoist, is stored as XHMAX.

TDEL(L) is made zero, because it may vary for every loading, depending on the number of miners loaded.

(511) - (561) The miner loading is best explained by the flow diagram in Figure 31. The criteria for an eligible miner is that he should be on the same hoist node as the hoist (512) and that he is not dead (IMINER(K) \neq 1). The miners

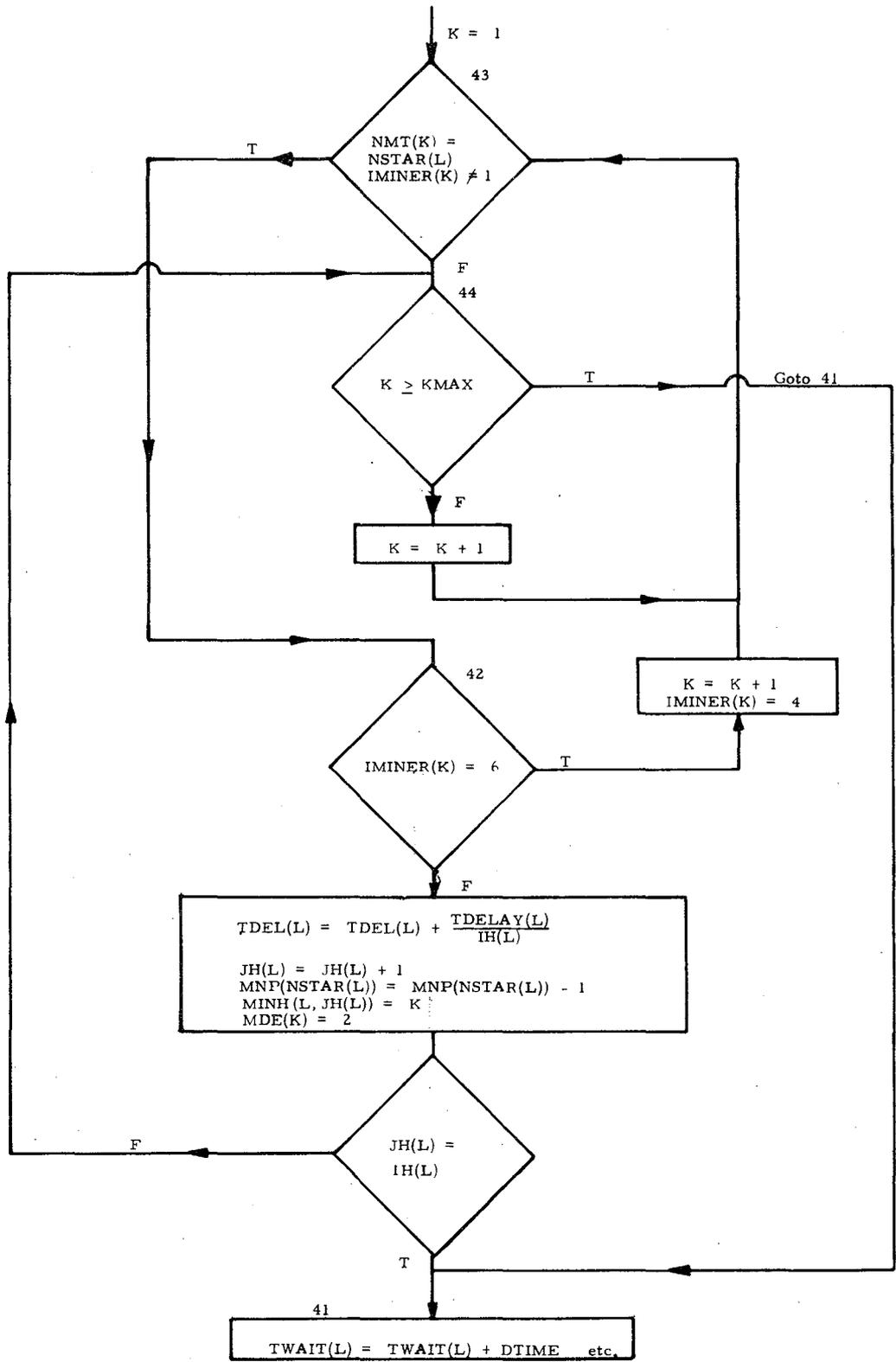


Figure 31 - Flow Diagram For Miner Loading

already in the hoist also satisfy these two criteria, so they are separated by checking if $IMINER(K) = 6$. If $IMINER(K) = 6$, the next miner is considered for loading. If $IMINER(K) \neq 6$, the miner is "loaded" by increasing $JH(L)$ by one, reducing the number of miners waiting on the node by one, storing his number in array $MINH$, making $MDE(K) = 2$ (making him immune to death while riding), and increasing value of $TDEL(L)$ by a fraction $TDELAY(L)/IH(L)$. It is then checked if the hoist is full ($JH(L) = IH(L)$). If it is not full, the miner number K is compared to the total number $KMAX$, and if it is found to be smaller than $KMAX$ the next miner is considered for loading. The loading is completed when either (1) all miners are considered ($K = KMAX$) or (2) the hoist is full ($JH(L) = IH(L)$), and the control is passed to statement No. 41.

(562) - (565) The value of $TWAIT(L)$ is increased by $DTIME$ and if it is greater than $TDEL(L)$, the hoist is prepared for the journey up.

(567) - (573) and (651) - (671) The hoist status is changed to 5 for the hourney up, $TWAIT(L)$ and $TUP(L)$ are set to zero, the status of all the miners in the hoist is changed to 5 (except in the intermediate haul case where the status is changed to 8) and the control is passed to the end of the subroutine, i. e. statement No. 20.

The exceptions to the "normal circumstances" are the following.

1. (421) - (456) The intermediate haul, in hoisting option 3, commences if the target node $NOODL$ ($NSTAR(L)$) is below the intermediate level. This is determined by comparing value of $NOODL$ to all the nodes serviced in the intermediate haulage (a total of $MH2(L)$ nodes). If $NOODL$ is equal to any of those nodes, the intermediate haulage is made to commence by making $MH(L) = MH2(L)$ (fooling the hoist into believing it has to serve only $MH2(L)$ nodes). If $NOODL$ is the node on the intermediate

level, then the status of the hoist is changed to 2, TWAIT(L), TDEL(L) are set to zero and the control is passed to the end of the subroutine.

2. (462) - (502) If hoist L is the master hoist, the level where the hoist has stopped is the master level and the slave hoist is in going up status (IHOIST (ISLAVE)= 8), the status of the slave hoist is changed to the miner discharge status (IHOIST (ISLAVE)= 10).

3. (574) - (647) The position of the hoists, with respect to the network, is determined by the position of the miners riding the hoist. The node which the miner MINH(L,1) has just passed, is compared with the top hoist node to find out if the hoist has reached the top. If there are no miners alive at the target node when the hoist reaches there, MINH(L,1) is zero and the above-mentioned scheme stops working. Therefore in that case, a "ghost" miner is created to guide the hoist up. The miner number for the ghost, KGHOST, is initially set to KMAX, therefore the statement (574) assigns a number KMAX + 1 or higher to the ghost. MINH(L,1) is assigned the ghost miner number and rest of the miner properties, MDE(K), NMT(K), JM(K), KNOTF(K) and KM(K) are created appropriately. If the hoist is the master hoist, in a double drum, IDISC is assigned value 1 thereby signalling the clutched (slave) hoist to declutch.

5. Hoist Heading To Top

Everytime the hoist is in status 5, and there is room in the hoist ($JM(L) < IH(L)$), a sequence ((1017) - (1063)) is executed to determine if there are any miners waiting at the nodes above who can be picked up on the way up. The sequence is explained in Figure 32.

As shown in the Figure, initially the value of LL is set to a value so that $LH(L,LL) = NMT(MINH(L,1))$, i. e. the value of LL is such that $LH(L,LL)$ gives the node the hoist that has

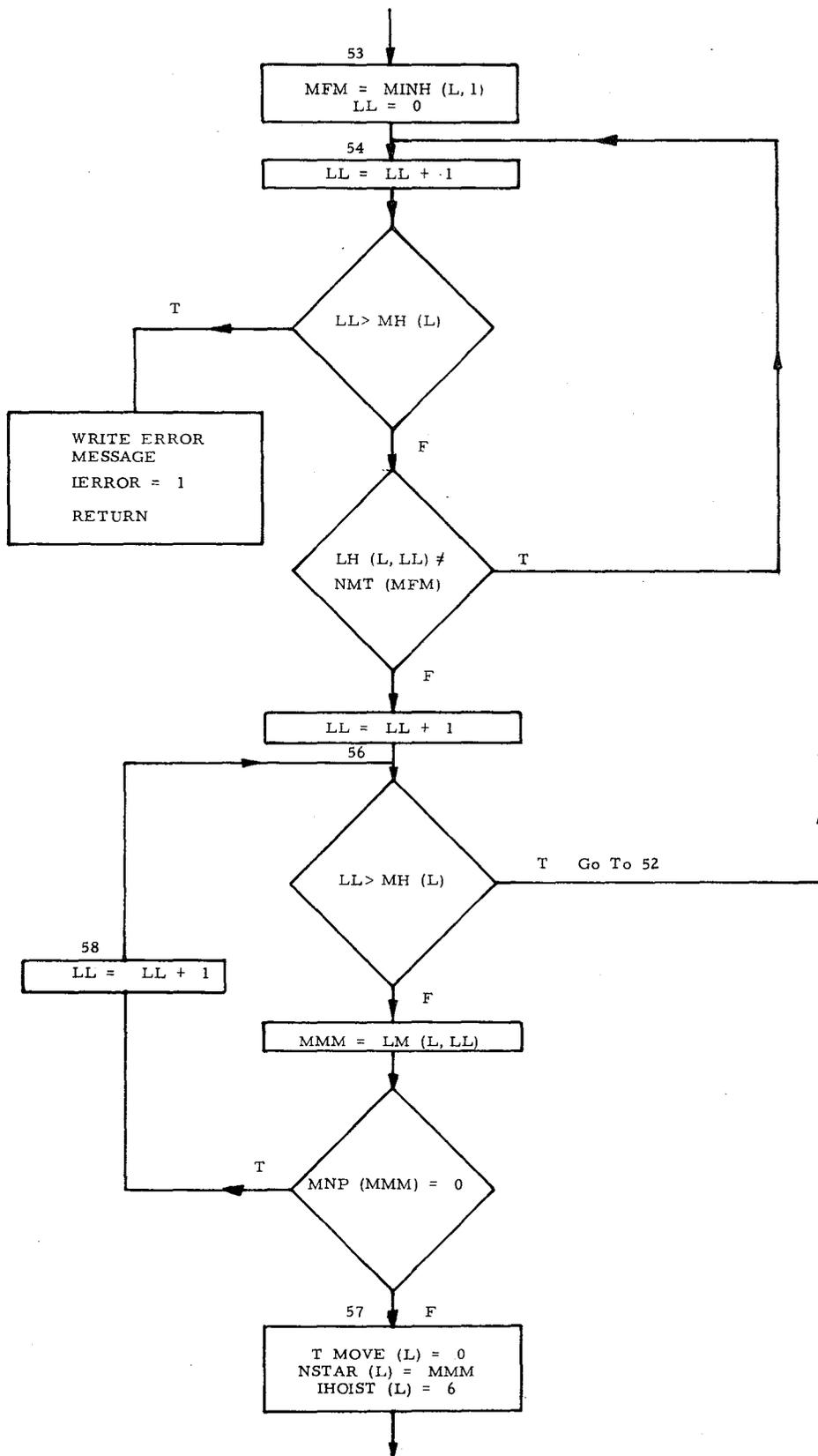


Figure 32 - Flow Diagram for Miner Search While Going Up

just passed. Then the values of MNP are checked for nodes LH(L, LL+1) to LH(L, MH(L)). If a node where MNP is positive is found, it is selected as the target node and the hoist status is changed to 6.

If there is no space in the hoist or if no miners are found to be waiting on the nodes above, the values of TUP(L) and XHST(L) are updated and NMT(MINH(L, 1)) (the node the first miner in the hoist, and consequently the hoist, has just passed) is compared with the top node LH(L, MH(L)) to see if the hoist has reached the top.

When the hoist does reach the top, IHOIST(L) is made equal to 2 (hoist-waiting-at-the-top status), the total number of miners reaching the top is determined (JH(L) minus the number of "ghosts", if any), and a statement regarding the event is printed. In addition TUP(L), TWAIT(L) are set to zero, a value of time required for unloading (TDEL(L)) is determined from the fractional capacity of the hoist occupied, and the status of the miners riding the hoist is changed appropriately. If the hoist has been involved in the intermediate haul in option 3, than the "top" is actually the intermediate level, and so the miner status is changed to the miner-waiting-for-hoist status and the number of miners waiting for the hoist at NODFI(L) is increased by the required number ((763) - (771)). For other cases, the miner status is changed to 2, and MDE(K) is returned to zero value.

(732) - (745) If the hoist is the master hoist and the slave hoist is in going down status (status 8), the slave hoist status is changed to 9, i. e. miners picking up status.

6. Hoist Heading Up To A Target Node

The values of TMOVE(L) and XHST(L) are updated everytime the subroutine is called and IHOIST(L) is 6.

The node number of the target node, $NSTAR(L)$ is compared to the last node the hoist has passed, $NMT(MINH(L,1))$ to determine if the hoist has reached the target node.

When the hoist does reach the target node, $IHOIST(L)$ is assigned value 4, $TMOVE(L)$ and $TWAIT(L)$ are set to zero and all the miners riding the hoist are assigned status 6 to distinguish them from the miners waiting for the hoist at the target node.

B.4.3 Subroutine Miner

The subroutine determines position and status of each of the miners at every time step. A DO loop covers the whole subroutine, so that the appropriate parts of the subroutine are executed for each miner. The limit of the DO loop index is set to $KGHOST$, instead of $KMAX$ so that the subroutine is executed even for the "ghosts" created to guide the hoists upwards.

Each miner k has his notification status checked initially. If he is not notified yet ($KNOTF(K)=0$), subroutines $MSMOK(K)$ and $MSTNCH(K)$ are called. These subroutines determine if the smoke has reached the miner (which makes $IMINS(K)=1$) or if the stench has reached the miner ($IMINT(K)$ becomes 1) respectively. In either case, $KNOTF(K)$ becomes 1 and appropriate notification message is written down. Variables $MNSMOK$, $MNSTEN$ and $TENOT$ record the event for the summary of results at the end of the program.

Then the time is compared to the updated delay time. If $T < TDM(K)$, the control is directed to statement No. 4 where the miner's smoke exposure is determined. However, if the miner is the hoistman, the control is directed to the end of the subroutine, since he is assumed to be safe from the smoke exposure until he leaves his post.

When $T > TDM(K)$, the part of the subroutine executed is determined by value of $IMINER(K)$. For $IMINER(K) = 1, 2, 3, 4$ or 7 , the control is directed to the corresponding statement number, however for $IMINER(K) = 5, 6$ or 8 the control is directed to statement No. 2.

1. Miner Dead

The value of $IMINER(K)$ must be 1 for this part of the subroutine to be executed. Initially the node, from which his present distance is measured, is determined (130) - (134). An extra index $MDE(K)$ is employed to make sure that the data about his death is written only once. It is set to 1 only at time of his death (or evacuation) and then set to zero.

2. Miner Travelling

This part of the subroutine is executed for four values of $IMINER(K)$, as indicated in the comment cards. $IMINER(K) = 2$ considered to be the base case in the structure of this part of the subroutine, with appropriate modifications made for the other three values of $IMINER(K)$.

The execution begins with determining branch velocity of the branch on which the miner is located at time T , i.e. $VB(JM(K))$ ((166) - (170)). Subroutine $MSMOK$ is then called to determine if the miner is in smoke filled region or not. The index $IMINS(K)$ is set to 1 if he is in the smoke filled region and it is kept 0 otherwise. If $IMINS(K) = 1$ and the miner is travelling under his own power ($IMINER(K) = 2$) his speed is assumed to be reduced by 50 percent due to lack of visibility (174).

The self-rescuer performance is checked next ((210) - (232)). The time for which the self-rescuer has been used is incremented by the time step $DTIME$, if $IMINS(K) = 1$. If

TSELEFR(K), i. e. the time for which the self-rescuer has been used, exceeds TSRMAX, the time limit, and the miner has not been riding any of the hoists ($MDE(K) \neq 2$), the miner is assumed to die and his status is changed to 1. To avoid printing the death data for the "ghosts", which are created to guide hoists in exceptional cases (see details of the subroutine HOIST), MDE(K) is made 1 only if the miner no. K is less than or equal to KMAX.

The value of miner displacement along the branch is updated using the velocity information on that branch (255). For a case when $T < DTIME$, the displacements are reset to the original values to coordinate the values generated by subroutine MINER with those generated by subroutine HOIST. (A problem can arise due to the fact that the subroutine HOIST is called after subroutine MINER. Therefore the positions of the hoists can be out of step with the miner positions). Due to the same reason the displacements are reset in case $IMINER(K) = 6$, i. e. the miner in the hoist has just arrived at a higher level where the hoist is going to pick up additional miners (270).

If the total distance moved by the miner along the branch $JM(K)$ is less than length of the branch, the control is directed to the subroutine end. If however the distance is more than $ALB(JM(K))$, a new branch for travel has to be chosen. This is accomplished in the following way.

First the node that the miner has arrived at is determined from knowing the nodes which the branch $JM(K)$ connect (IB or JB) and the direction in which he has been moving (KM). That node is stored as NMT(K). If NMT(K) is 2, thereby making the node a "safe" node, the miner is considered evacuated by assigning a value 3 to his status variable, and if $K \leq KMAX$ (he is not a "ghost"), MDE(K) is made 1, so that the event can be printed in the output ((341) - (347)).

If $NMT(K)$ is not equal to 2, the branch on which the miner is going to travel is found from the value of NN (miner instruction) for the node $NMT(K)$ and from the branches connected to the node (IN, JN, KN, LN) ((314) - (341)). The direction parameter $KM(K)$ for the miner travel in the new branch is found from determining whether he is on the IB or JB node of the new branch ((350) - (354)).

If the node $NMT(K)$ is a "hoist node", the miner is not allowed to travel on the new branch until picked up by hoist. This is accomplished by changing the miner status to 4 and increasing the number of miners waiting at that node by 1 ($MNP(NMT(K)) = MNP(NMT(K)) + 1$). If the miner is in status 5 (riding a hoist) or 8 (riding a hoist in intermediate haul), he doesn't wait at the hoist node. If the miner is in status 6 he is expected to exit from this part of the program at (276).

3. Miner Safe

This part of the subroutine is executed only when $IMINER(K) = 3$, i.e. when the miner is evacuated. The information about the event is printed only when $MDE(K)$ is 1, and after printing $MDE(K)$ becomes 0 to avoid repeated printing. Values of $MSAFE$ and $TEVAC$ are updated.

4. Miner Waiting For Hoist

This part of the subroutine is executed for two cases.

1. $IMINER(K) = 4$, i.e. the miner is waiting for the hoist.
2. $T \leq TDM(K)$ and $K \neq KMAX$, i.e. the miner has received the notification but is delayed before moving (not true for the hoistman).

Subroutine MSMOK is called to determine if the miner is in smoke filled region. If he is, IMINS(K) is set to 1 and TSELEFR(K) is updated. If TSELEFR(K) exceeds the self-rescuer time limit TSRMAX, several events may happen.

1. If MDE(K) is not equal to 2 (miner is not riding the hoist), the miner is assumed to die and his status number changes to 1 (477).
2. If the miner is not a "ghost" miner ($K \leq KMAX$) MDE(K) is set to 1 so that the event can be printed when the subroutine is called at the next time step (514).
3. If IMINER(K)= 4, the number of miners waiting at the node is reduced by one, since the dead miner is left at the hoist station ((437) - (454)).

If the miner instruction switch takes place when the miner K is in status 4, it may result into MN(NMT(K)) no longer being 3, i.e. the hoist node may no longer be the hoist node and the miner has to turn back and seek the alternate escape route. This requires the miner status to be changed to 2, his direction reversed (556) and his displacement adjusted according to the convention ((543), since now the displacement has to be measured from the other node).

7. Miner Riding In The Slave (Clutched) Hoist

A special status no., IMINER(K)= 7, is assigned to the miner when he is riding the clutched hoist, because in that case his position is determined not by the branch velocities, but by what the main (master) hoist does. The only action to be taken in status 7 is to determine if the instruction switch has taken place ($T > TSWITCH$). Because if it has taken place, the miner should get out of the clutched hoist and start travelling, this being accomplished by changing his status no. to 2, and changing his direction and displacement values.

B. 4. 4 Subroutine Smoke

Subroutine SMOKE determines progress of smoke in different branches. The logic used in the subroutine is illustrated by a flow diagram in Figure 33.

As shown in the subroutine, a DO loop envelopes the complete subroutine so that it is executed for each branch. If ISCOB(I) \neq 1, the branch is either completely full of smoke or it is clear of smoke, in either case the progress of smoke is not to be determined. So the control is passed to the end of the subroutine and the next branch is selected.

If ISCOB(I)= 1, the smoke filled region is advanced, as determined by the velocity VENB(I). If the length of the smoke filled region, XSMOK(I), is less than the branch length, the control is again directed to the end of the subroutine. If XSMOK(I) > ALB(I), the branch is considered filled with smoke and data of the event are printed in the output. An exception is the case of the branch where the fire has started (I= IBFIR) which is not completely filled with smoke filled even when XSMOK(I) > ALB(I) (The region from distance 0 to XBFIR is clear of smoke).

Variable JFIR stores the node number of the node the smoke has just reached. The branch where the smoke will spread next is determined in the following way.

1. The branches connected to the node JFIR are determined ((40) - (60)).
2. The branches, where the ventilation air is flowing from node JFIR to the other node, are isolated by knowing whether JFIR is IB node or JB node and whether VENB is positive or negative.

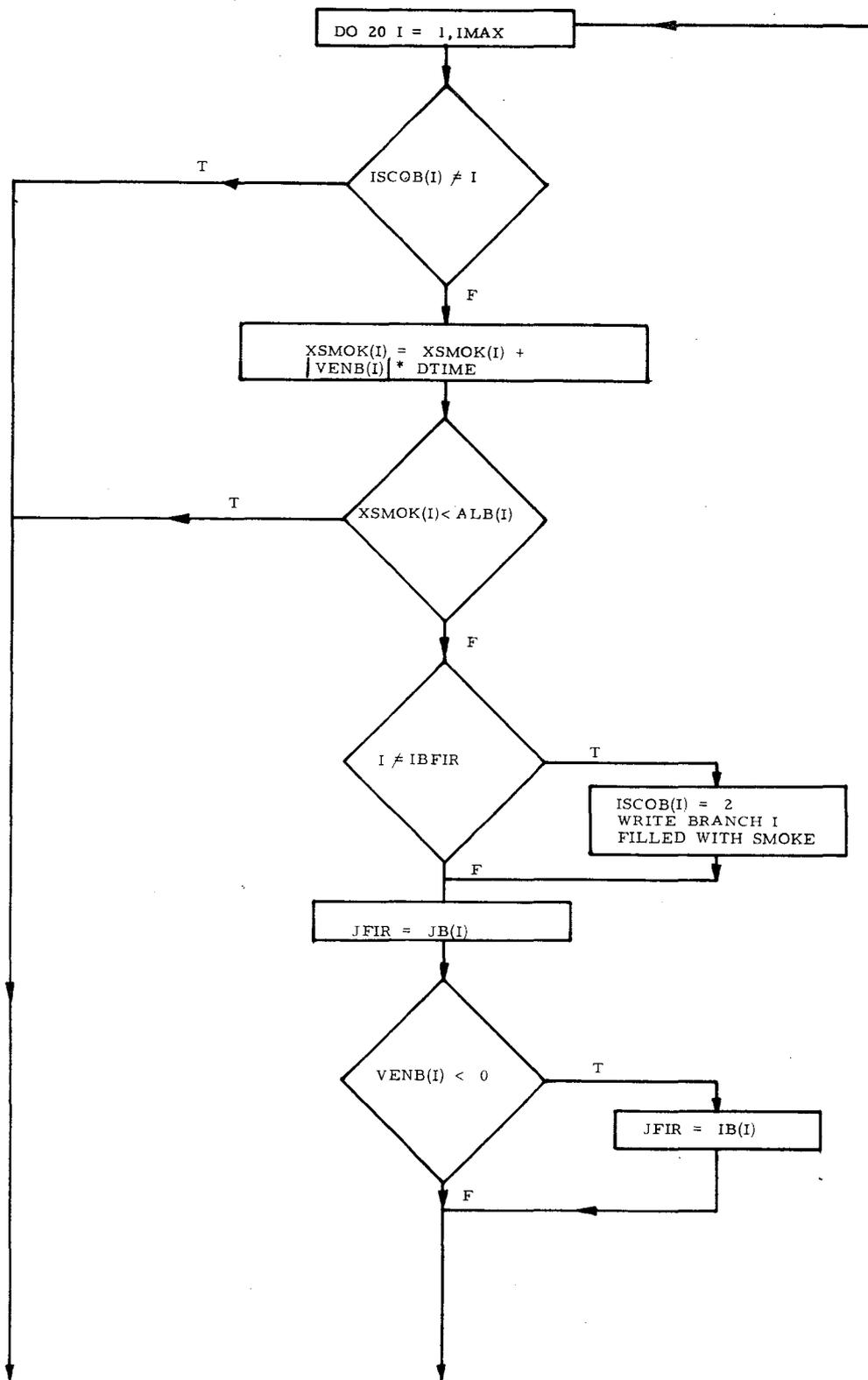


Figure 33 - Flow Diagram For Subroutine SMOKE

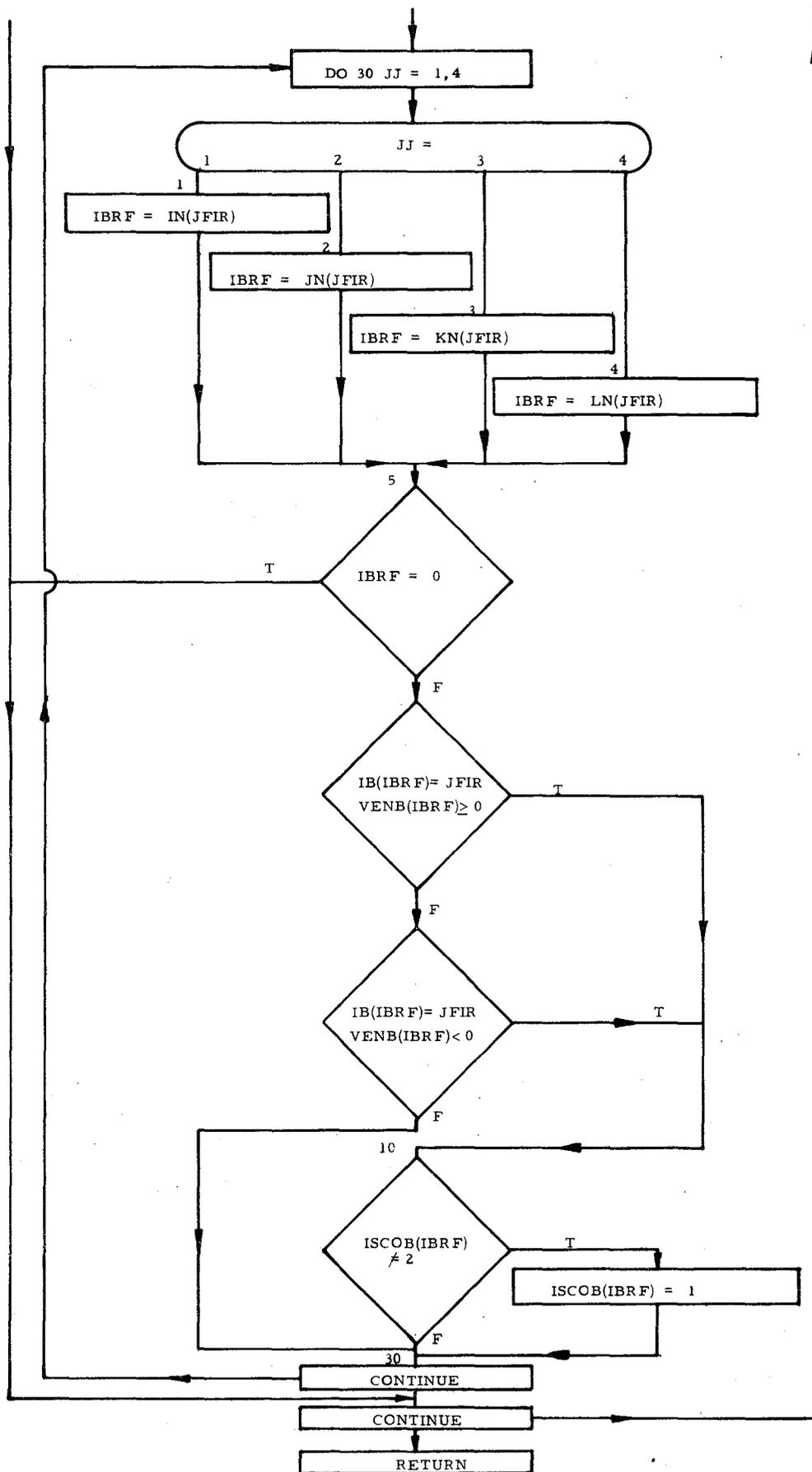


Figure 33 - Flow Diagram For Subroutine SMOKE (cont.)

For those isolated branches ISCOB(I) is set to 1, if it is not 2 already.

B. 4. 5 Subroutine Stench

The logic used in subroutine STENCH is similar to that used in subroutine SMOKE, with stench parameters substituting the smoke parameters.

B. 4. 6 Subroutine MSMOK

A flow diagram of the subroutine appears in Figure 34. The subroutine is used to determine if the Kth miner is in the smoke filled region or not. If he is not in the smoke filled region, IMINS(K)= 0, if he is in the smoke filled region IMINS(K)= 1.

Variable JM(K) is the branch on which the miner is located. If ISCOB(JM(K))= 0, the branch is completely clear of smoke (see description of the subroutine SMOKE), and IMINS(K)= 0. If ISCOB(JM(K))= 2, the branch is completely filled with smoke and IMINS(K)= 1. In the case of partially filled branch, i. e. when ISCOB(JM(K))= 1, the matter is a little more complicated.

When ISCOB(JM(K))= 1, properties of KM(K) and VENB(JM(K)) are used to determine if the miner is walking in a direction opposite to the smoke propagation, or in the same direction.

The miner is walking in the same direction if either,

1. $KM(K)= 0$ and $VENB(JM(K)) \geq 0$ (both are advancing from the IB node of JM(K) to the JB node , or
2. $KM(K)= 1$ and $VENB(JM(K)) < 0$ (both are advancing from the JB node to the IB node).

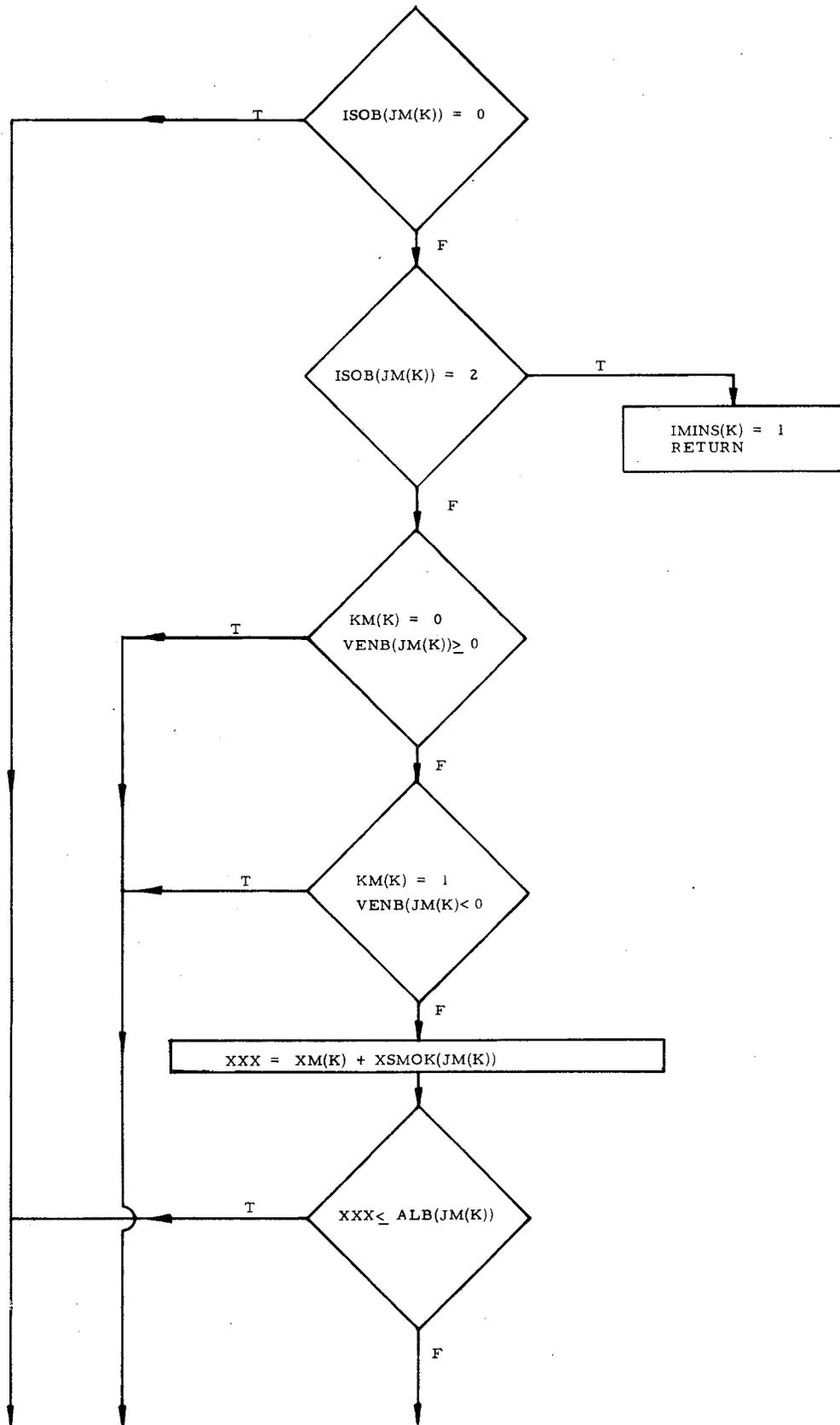


Figure 34 - Flow Diagram For Subroutine MSMOK

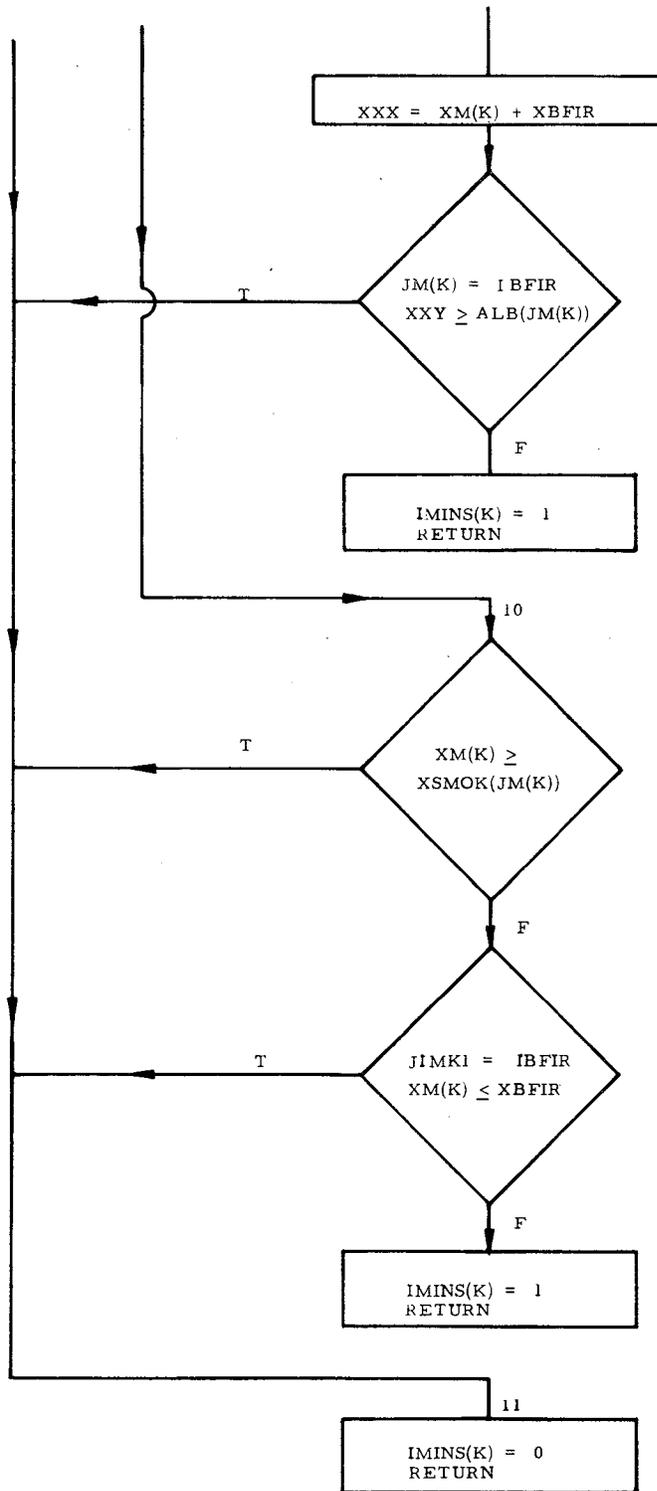


Figure 34 - Flow Diagram For Subroutine MSMOK (cont.)

In that case the miner is in the smoke filled region if $XM(K) < XSMOK(JM(K))$ (statement No. 10).

If the miner is advancing in a direction opposite to the smoke, i. e. propagation direction, if either,

1. $KM(K) = 0$ and $VENB(JM(K)) < 0$ or
2. $KM(K) = 1$ and $VENB(JM(K)) \geq 0$ then the miner is in the smoke filled region if

$XM(K) + XSMOK(JM(K)) > ALB(JM(K))$ (location No. (41)).

An exception to the rule is the branch where the smoke originates (IBFIR branch), since in that branch the smoke is present only after distance XBFIR (from IB node if VENB is positive, from JB node otherwise). In that branch the miner is not in the smoke filled region if the miner and smoke are advancing in the opposite directions and,

1. $XM(K) + XSMOK(JM(K)) \leq ALB(JM(K))$ or
2. $XM(K) + XBFIR \geq ALB(JM(K))$

The second condition comes due to the fact that after the miner passes the smoke origination point, there is no smoke in the upstream direction.

If the miner and the smoke are advancing in the same directions and

1. $XM(K) \geq XSMOK(JM(K))$ or
2. $XM(K) \leq XBFIR$

then the miner is not in the smoke filled region. There again another condition appears due to the fact that the miner does not encounter smoke till he is in downstream direction from the point of origination of smoke.

B. 4.7 Subroutine MSTNCH

The logic used in subroutine MSTNCH is similar to that used in subroutine MSMOK (and described in Section B. 4.6), with stench parameters replacing the smoke parameters.

B. 4.8 Subroutine TSTARC

35 The subroutine, represented by a flow diagram in Figure has two functions,

1. Supply value of TSTAR(L) (estimated time needed to reach the target node from the present position of hoist L) to subroutine HOIST.
2. Supply branch number of the top branch, LSLBR, in the hoist shaft, whenever needed by the subroutine DDRUM.

The information supplied to the subroutine include hoist No. (L), the lower of the two nodes between which the hoist is travelling (NODEA), the upper node (the top node - NODEB), and the time for which the hoist has already been travelling between NODEB and NODEA (TTRAV).

The NODEA is first identified in the array LH(L, LL) which contains all the nodes served by the hoist L.

When NODEA becomes equal to LH(L, LL), it is stored also as NODEC. If the node cannot be identified in the array LH(L, LL)

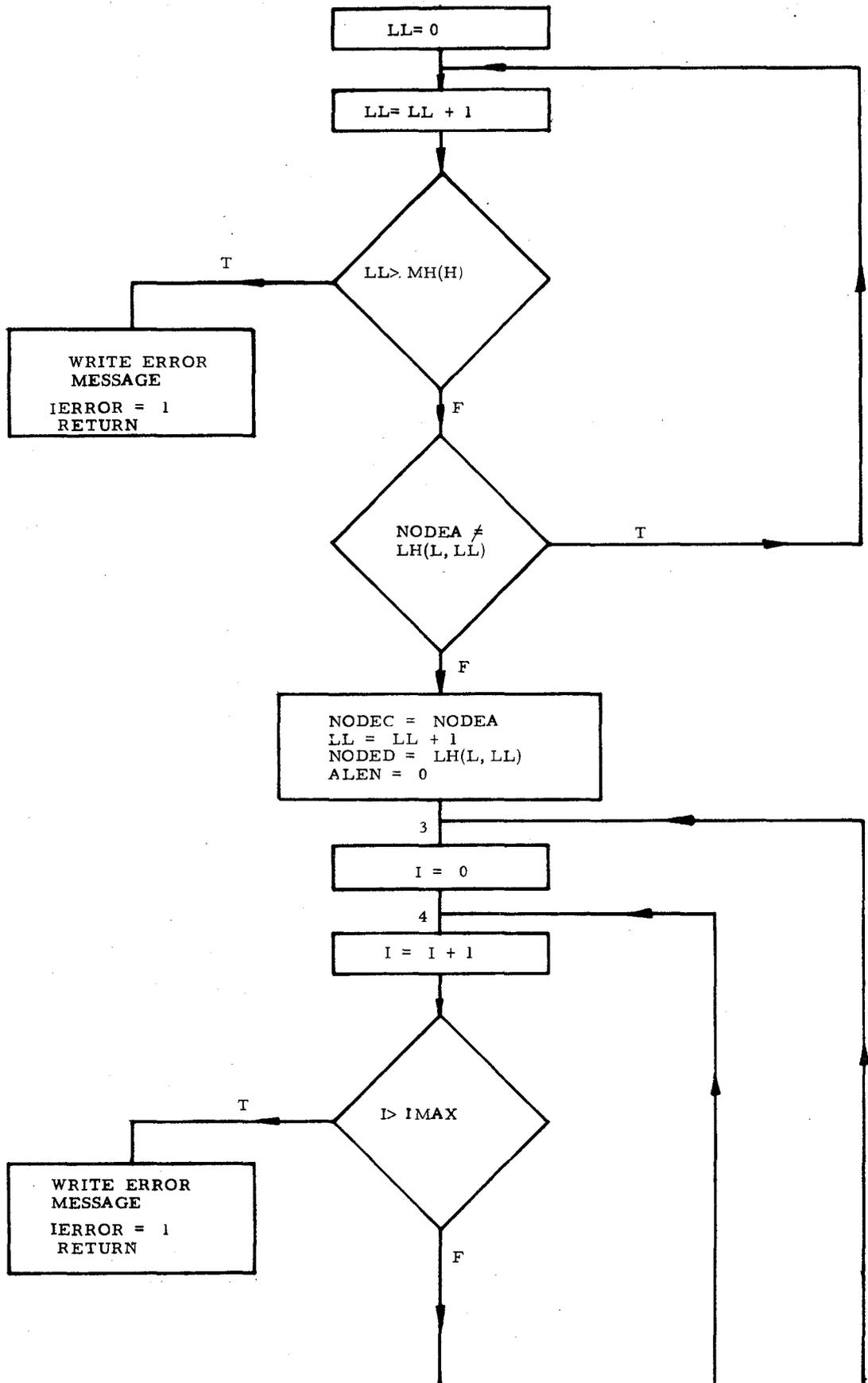


Figure 35 - Flow Diagram For Subroutine TSTARC

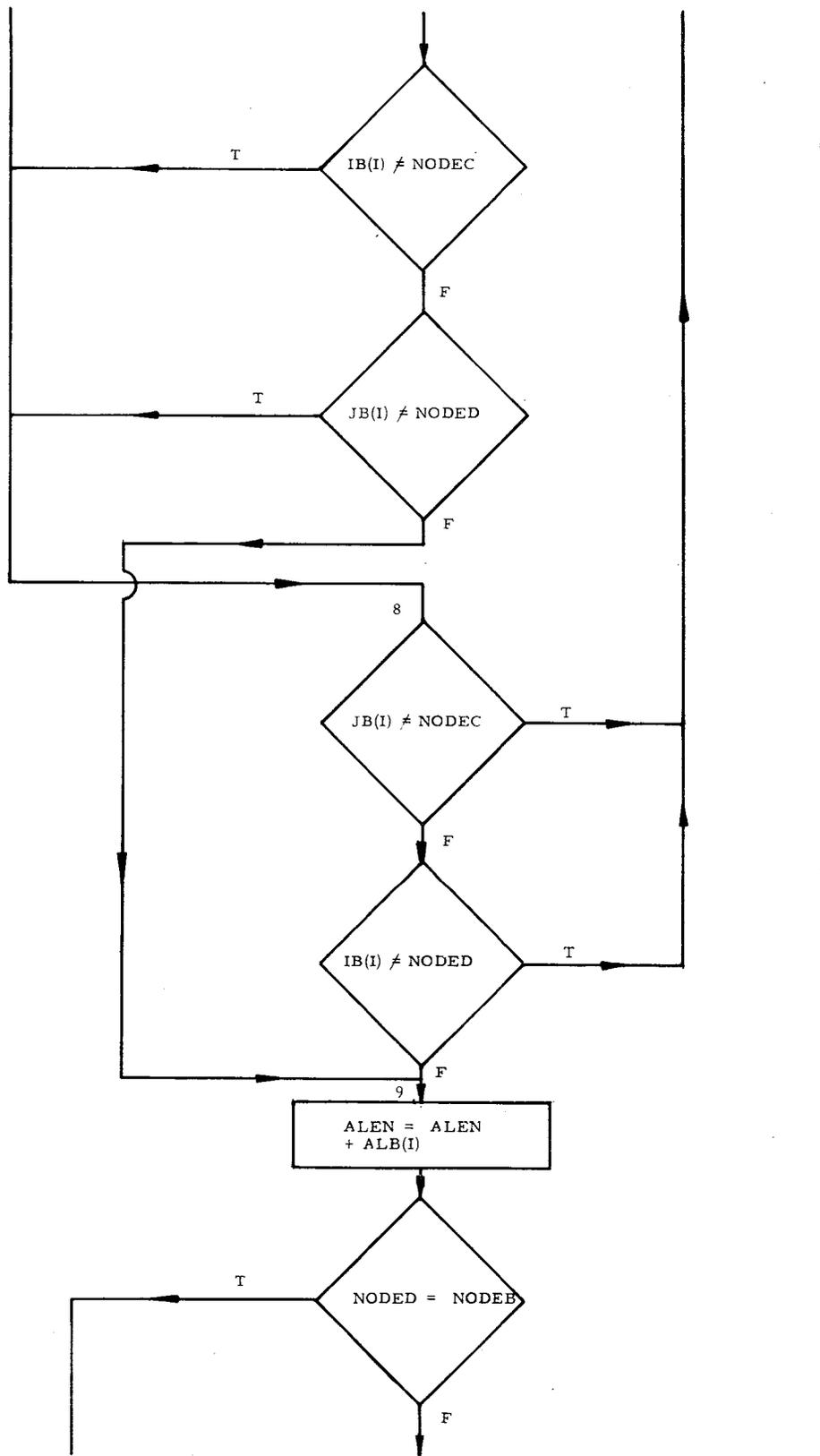


Figure 35 - Flow Diagram For Subroutine TSTARC (cont.)

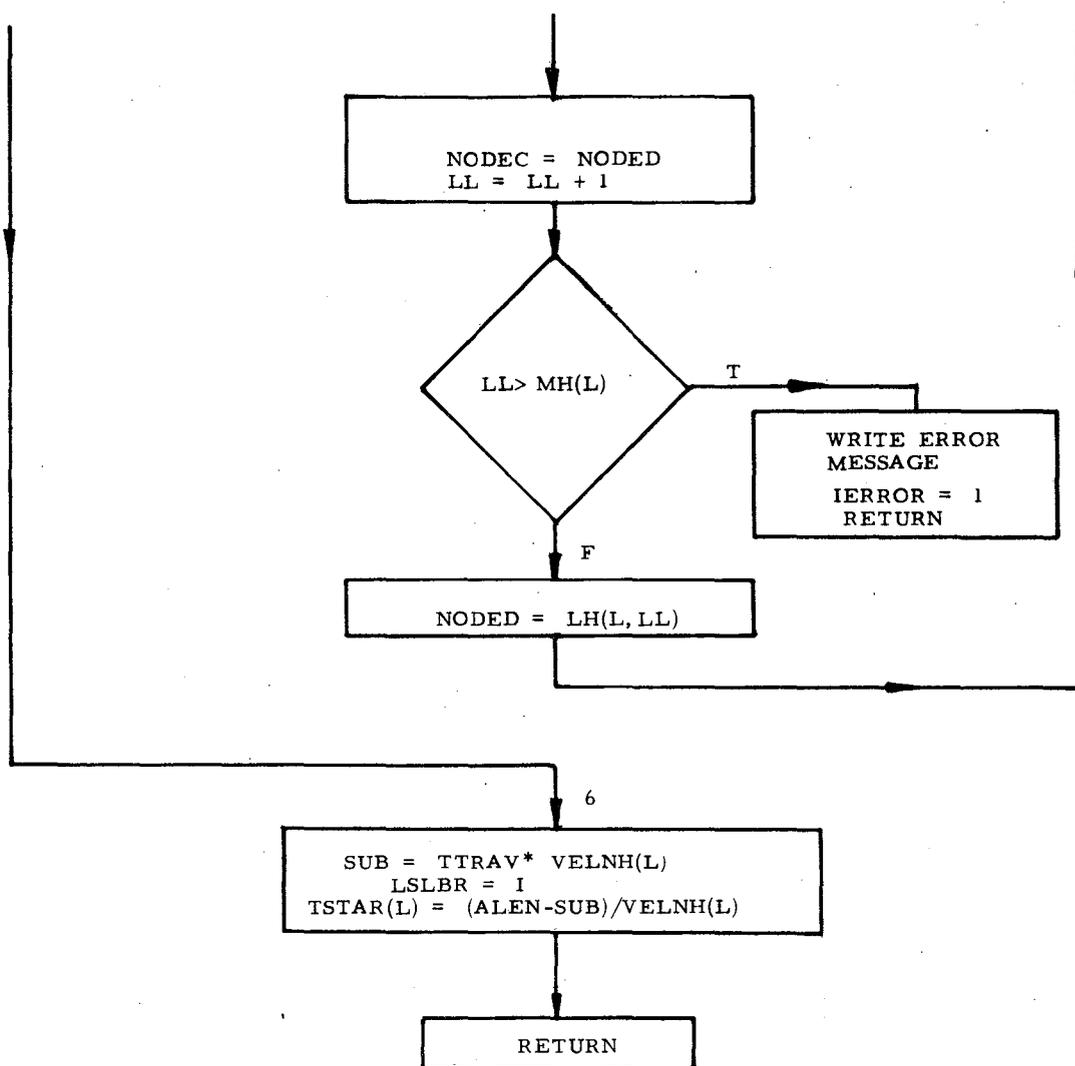


Figure 35 - Flow Diagram For Subroutine TSTARC (cont.)

an error message is written and the program terminated as something is definitely wrong in the data cards. The next higher node, i. e. $LH(L, LL + 1)$ is stored as NODED. Distance between the nodes NODEA and NODEB is stored as ALEN, and it is initially set to zero.

Next, each branch is tested to determine the branch I for which either,

1. $IB(I) = NODEC$ and
 $JB(I) = NODED$ or
2. $JB(I) = NODEC$ and
 $IB(I) = NODED$.

This is accomplished by ((45) - (76)).

If $I = IMAX$ and such a branch is not found, an error message is written and the program is terminated. When the branch I is found, ALEN is incremented by the branch length $ALB(I)$. Then NODED is stored as NODEC and a new NODED stores node number of the next higher node ($LH(L, LL+1)$). The process of finding branch I is then repeated.

When $NODED = NODEB$, all the branches between NODEA and NODEB have been included in the iteration and the iteration is terminated.

Finally $TSTAR(L)$ is found from the total distance between the nodes NODEA and NODEB (ALEN) minus the distance already travelled by the hoist ($TTRAV * VELNH(L)$) and dividing the difference by the hoist speed ($VELNH(L)$). LSLBR is equal to I since at the end of the iteration I represents the top branch in the shaft branch chain.

B.4.9 Subroutine LEVEL

There are two functions of subroutine LEVEL, a flow - diagram for which is shown in Figure 36.

1. Store information about the level at which the hoist has stopped. The information consists of the identification number of the level (LEVN) and the distance of the level from the top (XHST(L)).
2. Determine if the slave (clutched) hoist in the double drum should be clutched in.

The information given to the subroutine includes NOODL, the node number at which the hoist is located and L, the hoist number.

Initially all the hoist nodes on different levels (LEVA (M, MM)) are compared to NOODL to find a hoist node for which $LEVA (M, MM) = NOODL ((5) - (12))$ when that node is found, M is the level number on which the hoist is located. IDEN stores the identification number for the Mth level, i. e. LEVN(M). If IDEN is found equal to any value already stored in array LLEP(L, I), the value is not stored again, otherwise $LLEP(L, INL(L)) = IDEN$ where INL(L) is a counter which is incremented everytime the hoist stops at a new level. Similary XLEP(L, INL(L)) stores the value of XHST(L) (with a negative sign to produce plots right side up).

There is no need to determine whether the slave hoist should be clutched or not if any of the following three conditions exist.

1. ISLAVE= 0, i. e. no double drum hoist included in the input.
2. IHOIST(ISLAVE)= 1, i. e. the slave hoist is inoperative.

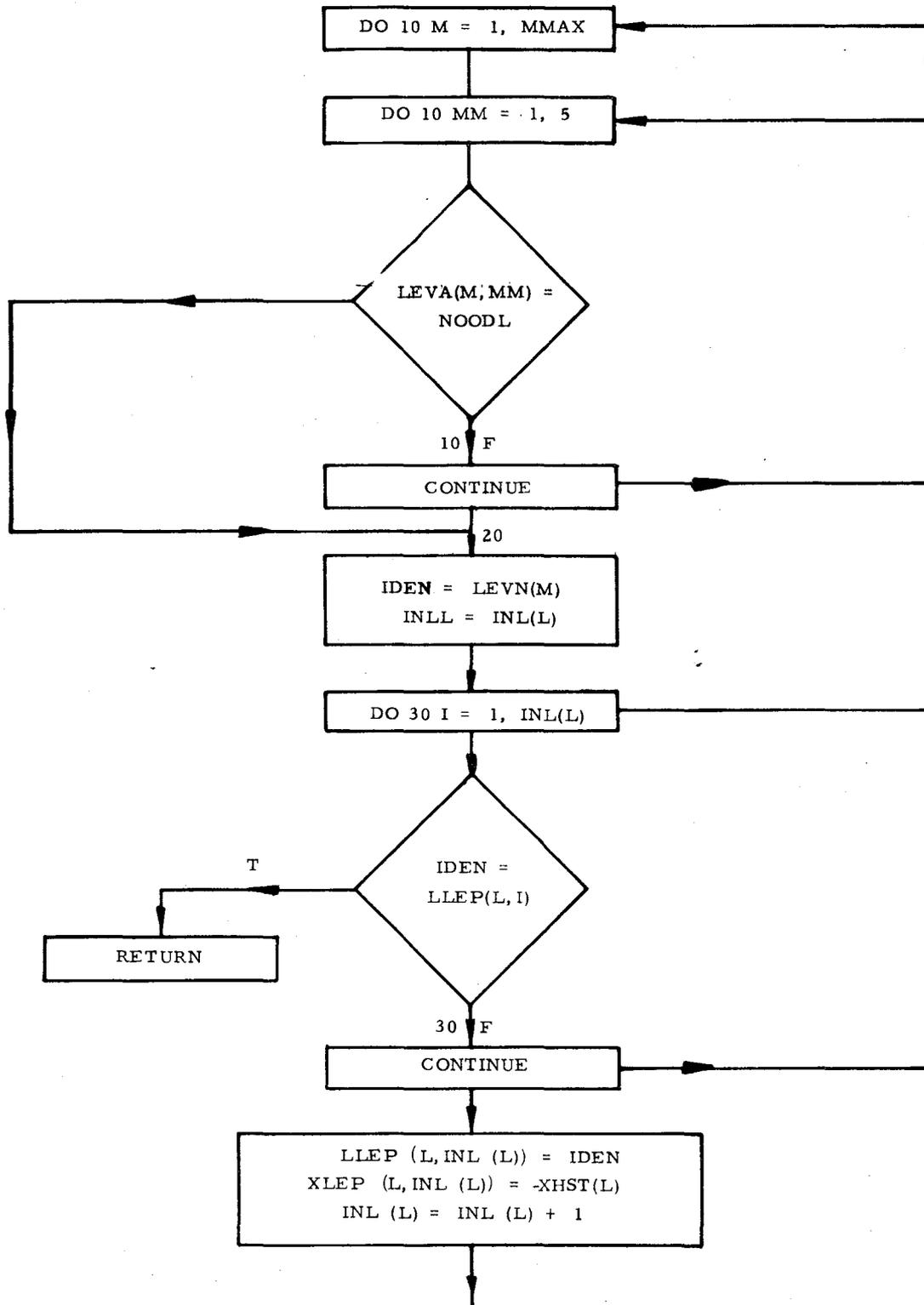


Figure 36 - Flow Diagram for Subroutine LEVEL

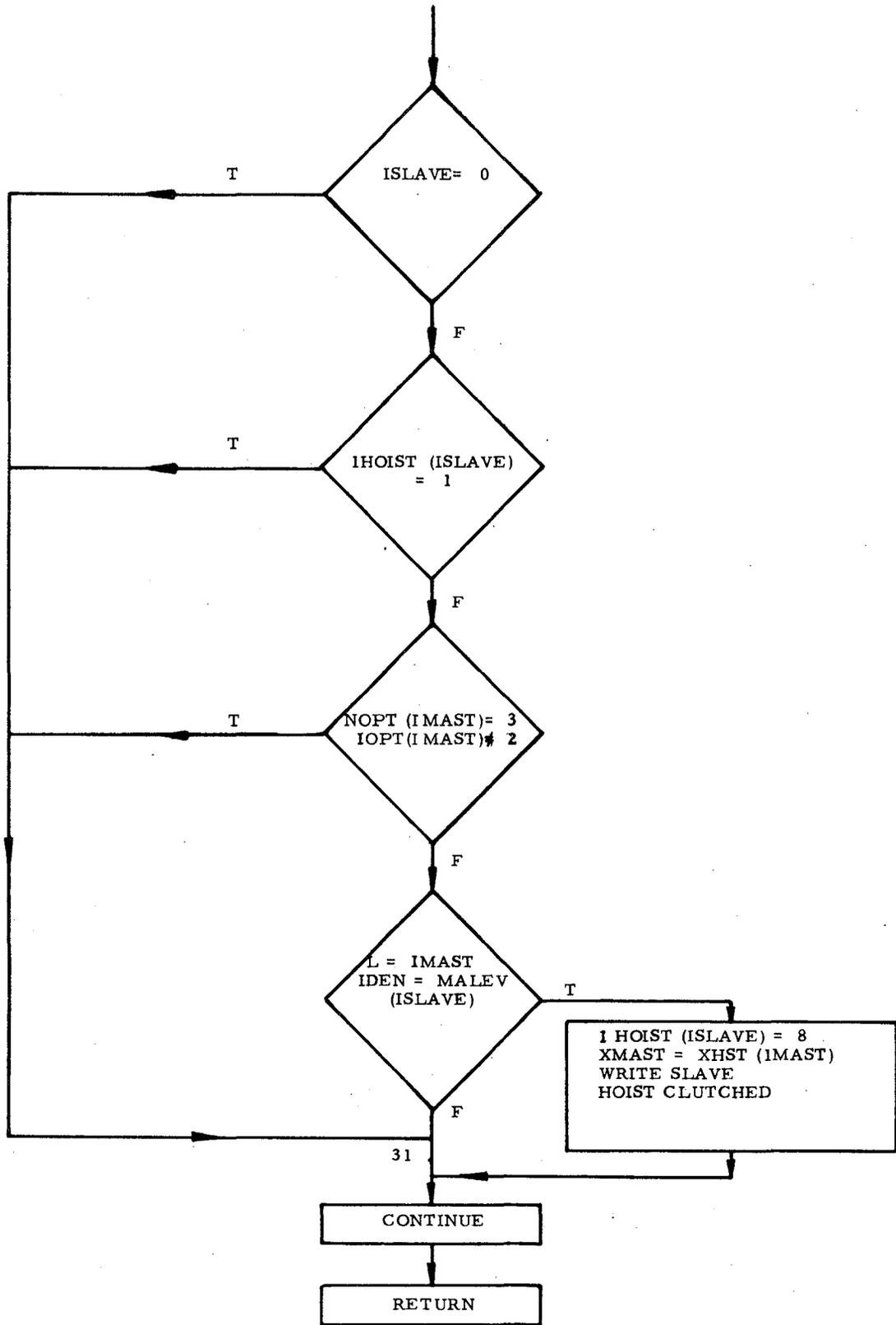


Figure 36 Continued - Flow Diagram for Subroutine LEVEL

3. NOPT(IMAST)= 3 and IOPT(IMAST)≠ 2. When the main hoist is in option 3, the clutched hoist is not called in till the intermediate haul is completed.

If none of these three conditions exist, the slave hoist is clutched in if the following is true:

1. L = IMAST and
2. IDEN = MALEV(ISLAVE)

i. e. the hoist being considered is the master hoist and it has stopped at the master level.

If the slave hoist is clutched in, IHOIST(ISLAVE) becomes 8, XMAST (sum of the distances, from the top, of the master and the slave hoist, which should remain a constant) is set equal to XHST(IMAST), and the event is printed out.

B.4.10 Subroutine DDRUM

Subroutine DDRUM is called from subroutine hoist when the (slave clutched) hoist in a double drum hoist is being considered, i. e. when L= ISLAVE. Subroutine DDRUM determines status and position for the slave hoist, with an algorithm which is quite different from that employed in subroutine HOIST, since the position and status of the slave hoist are largely dependent on the position and status of the master hoist.

The part of the subroutine executed depend on value of IHOIST(L):

7. Unclutched Slave Hoist

The control is returned to the end of the subroutine.

8. Clutched Slave Hoist

When the slave hoist is clutched, it's distance from the top (XHST(L)) is found by subtracting the value of XHST(L) of the main hoist from XMAST, since the sum of the XHST for the two hoist has to be equal to XMAST

If NSTAR(IMAST) equals the hoist node on the master level, MANOD, the master hoist is heading towards the master level and the rest of this section of the subroutine is skipped.

Otherwise, the value of XHST(L) is checked, and if found to be negative, meaning thereby that the master hoist is heading to a node below the master level, XHST(L) is set to zero and IHOIST(L) is set to 10 so that the miners can be discharged, and the slave hoist can be declutched.

9. Miners Picked Up By Slave Hoist

This section of the subroutine is executed if IHOIST(ISLAVE)= 9 (set by the master hoist in subroutine HOIST at location No. (733)).

This section needs to be executed only once, everytime the slave hoist is on the master level, so IHOIST(ISLAVE) is made 8 in the beginning. Subroutines LEVEL and XSTAR are then called to store information about the level, and the value of XHST(L) is checked with XHMAX, to make sure that XHMAX is the largest value of XHST(L) for any L.

The next part, i.e. ((57) - (111)), selects the miners for loading in the same manner as that explained earlier in B.3.1 and shown in Figure B-2. If there are no miners alive at the master node, MANOD, (JH(L)= 0), the slave hoist is declutched, and the event is printed in the output. If JH(L)≠ 0, all the miners loaded

in the hoist, as identified in the array MINH, are assigned a special status No. 7 and their node values, NMT(K), are set to zero.

10. Miners Discharged By Slave Hoist

When IHOIST(ISLAVE) is set to 10 (subroutine HOIST (463)), this part of the subroutine is executed. Since this part of the subroutine is executed only once, everytime the slave hoist reaches the top level, IHOIST(L) is converted to 8 in the beginning.

If IDISC equals 1, meaning thereby that the master hoist has found no miners at the master level (see subroutine HOIST, location (644)), IHOIST(L) is set to 7 and the declutching event is printed in the output. One more way declutching can take place is if the master hoist is heading below the master level. The necessary conditions for that to happen are,

1. IHOIST(IMAST)= 3, i.e. the master hoist is moving down
2. NSTAR(IMAST)≠ MANOD. These conditions are not sufficient, since the master hoist can be heading to a level above the master level. However if JH(L)= 0, the slave hoist must have been at the master level and therefore the master hoist must be beneath the master level. In fact the events that take place when the master hoist starts going below the master hoist are the following,
 1. IHOIST(L) is set to 10 at (35) since XHST(L) < 0 and NSTAR (IMAST)≠ MANOD.

2. Since $JH(ISLAVE) \neq 0$, $IHOIST(ISLAVE)$ is set to 8 and not 7 when the part 10 is executed the first time.
3. The miners are discharged ((222) - (306)) and $JH(L)$ is set to 0.
4. $IHOIST(L)$ is again set to 10 at (35).
5. This time $IHOIST(SLAVE)$ is set to 7 at (156) since all the conditions are met.
6. Since $JH(L) = 0$, the control is passed to statement No. 1 from (220).

The rest of the subroutine deals with discharging the miners. Initially $IFORCD$ is reset to 0, and the event of miner haulage is printed in the output. Then subroutine $TSTARC$ is called to determine value of $LSLBR$, which is the branch no. of the top branch in the hoist shaft.

Since all the miners riding the slave hoist have been in status 7, their distance, branch and direction parameters, ($XM(K)$, $JM(K)$ and $KM(K)$ resp.) have not been updated. The value of $LSLBR$ helps determine all three in the following way,

$$\begin{aligned}
 JM(K) &= LSLBR \\
 XM(K) &= ALB(LSLBR) \\
 KM(K) &= 0 \text{ if } JB(LSLBR) = LH(L, MH(L)), = 1 \text{ otherwise} \\
 &\text{where } LH(L, MH(L)) \text{ is the top node for the hoist.}
 \end{aligned}$$

Finally, status of all the miners riding the slave hoist is changed to 2 and $JH(L)$ is set to 0.

B.5 Typical Input - Output

The input data and the printed output for case 8 of the simulations (Section A.4) are shown in the following. The branch, level, node, miner and hoist numbers mentioned in the input and output refer to the corresponding numbers in Figures A-3, A-4 and A-5. The plotted output, already shown in Figures A-11 and A-12 is not repeated.

The input data shown does not include the following simulation parameters:

```
DTIME = 0.05
FTIME = 130.
JPLT(K) = 1 for K = 1, 2, 3
          = 0 for other K
TPLSTR = 0.0
TPLSTP = 130.
```

MINE C SIMULATION CASE 8

INPUT DATA

BRANCHES

I	I9(I)	J3(I)	ALB(I)	V3(I)	VENB(I)	VENC(I)
1	3	4	1900.000	264.000	-107.000	-1720.000
2	1	2	1900.000	926.000	514.000	-1720.000
3	2	4	200.000	1000.000	375.000	1720.000
4	1	3	200.000	25.000	40.000	1720.000
5	2	5	500.000	2600.000	1015.000	1720.000
6	99	6	800.000	2000.000	987.000	1720.000
7	6	7	500.000	2000.000	962.000	1720.000
8	7	8	2300.000	2000.000	919.000	1720.000
9	42	45	200.000	13.000	108.000	1720.000
10	8	9	400.000	2000.000	778.000	1720.000
11	9	10	200.000	2000.000	701.000	1720.000
12	10	11	200.000	2000.000	652.000	1720.000
13	11	12	200.000	2000.000	485.000	1720.000
14	12	13	200.000	2000.000	230.000	1720.000
15	13	14	200.000	2000.000	40.000	1720.000
16	14	15	200.000	13.000	20.000	1720.000
17	16	1	500.000	1000.000	.000	1720.000
18	17	100	800.000	1000.000	822.000	1720.000
19	18	17	500.000	1000.000	795.000	1720.000
20	19	18	400.000	264.000	1000.000	1720.000
21	20	19	2300.000	800.000	689.000	1720.000
22	21	20	200.000	800.000	634.000	1720.000
23	22	21	200.000	800.000	611.000	1720.000
24	23	22	200.000	800.000	558.000	1720.000
25	24	23	200.000	800.000	508.000	1720.000
26	25	24	200.000	800.000	457.000	1720.000
27	26	25	400.000	264.000	457.000	1720.000
28	27	26	200.000	13.000	743.000	1720.000
29	5	16	1900.000	264.000	36.000	1720.000
30	6	17	1900.000	264.000	36.000	1720.000
31	7	28	200.000	264.000	57.000	1720.000
32	28	29	325.000	264.000	57.000	1720.000
33	29	30	325.000	264.000	57.000	1720.000
34	30	31	325.000	264.000	57.000	1720.000
35	31	32	275.000	264.000	57.000	1720.000
36	32	33	25.000	264.000	57.000	1720.000
37	28	34	180.000	25.000	15.000	1720.000
38	34	35	325.000	200.000	15.000	1720.000
39	29	35	180.000	25.000	15.000	1720.000
40	35	37	300.000	200.000	15.000	1720.000

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42	36	37	325.000	200.000	15.000	1720.000
43	31	37	190.000	25.000	15.000	1720.000
44	37	93	310.000	200.000	15.000	1720.000
45	32	38	195.000	25.000	15.000	1720.000
46	38	39	25.000	200.000	15.000	1720.000
47	33	39	190.000	25.000	15.000	1720.000
48	39	94	350.000	200.000	15.000	1720.000
49	8	40	200.000	264.000	105.000	1720.000
50	40	42	300.000	264.000	105.000	1720.000
51	43	20	850.000	264.000	74.000	1720.000
52	40	41	155.000	25.000	15.000	1720.000
53	41	90	310.000	200.000	15.000	1720.000
54	43	44	170.000	25.000	15.000	1720.000
55	44	91	315.000	200.000	15.000	1720.000
56	45	21	1000.000	264.000	31.000	1720.000
57	9	46	200.000	264.000	71.000	1720.000
58	46	48	450.000	264.000	71.000	1720.000
59	48	22	850.000	264.000	71.000	1720.000
60	46	47	172.000	25.000	15.000	1720.000
61	47	88	350.000	200.000	15.000	1720.000
62	48	49	180.000	25.000	15.000	1720.000
63	49	89	335.000	200.000	15.000	1720.000
64	10	50	260.000	264.000	67.000	1720.000
65	50	52	410.000	264.000	67.000	1720.000
66	52	54	420.000	264.000	67.000	1720.000
67	54	23	470.000	264.000	67.000	1720.000
68	50	51	185.000	25.000	15.000	1720.000
69	51	85	375.000	200.000	15.000	1720.000
70	52	53	188.000	25.000	15.000	1720.000
71	53	86	460.000	200.000	15.000	1720.000
72	54	55	175.000	25.000	15.000	1720.000
73	55	97	400.000	200.000	15.000	1720.000
74	11	56	200.000	264.000	223.000	1720.000
75	56	58	415.000	264.000	223.000	1720.000
76	58	60	420.000	264.000	223.000	1720.000
77	60	24	455.000	264.000	223.000	1720.000
78	55	57	170.000	25.000	15.000	1720.000
79	57	82	390.000	200.000	15.000	1720.000
80	58	59	165.000	25.000	15.000	1720.000
81	59	93	385.000	200.000	15.000	1720.000
82	61	94	430.000	200.000	15.000	1720.000
83	12	52	200.000	264.000	245.000	1720.000
84	52	54	415.000	264.000	245.000	1720.000
85	64	66	440.000	264.000	245.000	1720.000
86	66	26	45.000	264.000	245.000	1720.000
87	62	63	145.000	25.000	15.000	1720.000
88	63	79	400.000	200.000	15.000	1720.000
89	64	65	150.000	25.000	15.000	1720.000
90	65	80	420.000	200.000	15.000	1720.000
91	67	81	410.000	200.000	15.000	1720.000
92	13	58	200.000	264.000	156.000	1720.000
93	68	75	400.000	264.000	156.000	1720.000
94	70	27	350.000	264.000	212.000	1720.000
95	68	69	130.000	25.000	15.000	1720.000
96	69	77	380.000	200.000	15.000	1720.000
97	71	78	355.000	200.000	15.000	1720.000
98	14	72	200.000	264.000	54.000	1720.000
99	72	74	400.000	264.000	54.000	1720.000
100	74	76	250.000	264.000	15.000	1720.000
101	72	73	100.000	25.000	15.000	1720.000
102	73	96	305.000	200.000	15.000	1720.000
103	74	75	200.000	25.000	188.000	1720.000
104	1	95	12000.000	926.000	-514.000	1720.000
105	33	19	25.000	264.000	57.000	1720.000
106	42	47	150.000	264.000	71.000	1720.000

108	70	71	125.000	25.000	15.000	1720.000
109	66	57	155.000	25.000	15.000	1720.000
110	75	70	150.000	264.000	212.000	1720.000
111	101	2	10.000	264.000	15.000	1720.000
112	5	97	2000.000	264.000	500.000	1720.000
113	14	98	600.000	1000.000	-40.000	1720.000
114	98	11	10.000	264.000	-40.000	1720.000
115	99	100	1900.000	264.000	36.000	1720.000
116	100	16	200.000	1000.000	822.000	1720.000
117	5	99	200.000	2000.000	987.000	1720.000

NODES

TSWITCH =		30.000						
J	MN(J)	NN(J)	IN(J)	JN(J)	KN(J)	LN(J)	MN2(J)	NN2(J)
1	1	4	2	4	17	104	-0	-0
2	1	1	2	3	5	111	-0	-0
3	1	2	1	4	-0	-0	-0	-0
4	1	2	1	3	-0	-0	-0	-0
5	3	1	5	117	29	112	1	3
6	3	1	6	7	30	-0	1	3
7	3	1	7	8	31	-0	1	3
8	3	1	8	10	49	-0	1	3
9	3	1	10	57	11	-0	1	2
10	3	1	11	12	64	-0	1	3
11	3	1	12	13	74	114	1	3
12	3	1	13	14	83	-0	1	-0
13	3	1	14	15	92	-0	1	-0
14	1	4	15	16	98	113	-0	3
15	1	1	15	-0	-0	-0	-0	-0
16	3	1	17	116	29	-0	-0	-0
17	3	1	18	19	30	-0	-0	-0
18	3	1	19	20	-0	-0	-0	-0
19	1	1	20	21	105	-0	-0	-0
20	3	1	21	22	51	-0	-0	-0
21	3	1	22	23	56	-0	-0	-0
22	3	1	23	24	59	-0	-0	-0
23	3	1	24	25	67	-0	-0	-0
24	3	1	25	26	77	-0	-0	-0
25	3	1	26	27	-0	-0	-0	-0
26	1	1	27	28	86	-0	-0	-0
27	1	1	28	94	-0	-0	-0	-0
28	1	1	31	32	37	-0	-0	2
29	1	3	33	39	32	-0	-0	1
30	1	3	34	41	33	-0	-0	1
31	1	3	35	43	34	-0	-0	1
32	1	3	36	45	35	-0	-0	1
33	1	3	105	47	36	-0	-0	1
34	1	2	38	37	-0	-0	-0	-0
35	1	2	40	39	-0	-0	-0	-0
36	1	2	42	41	-0	-0	-0	-0
37	1	2	44	43	-0	-0	-0	-0
38	1	1	45	46	-0	-0	-0	-0
39	1	2	48	47	46	-0	-0	-0
40	1	3	50	52	49	-0	-0	1
41	1	2	53	52	-0	-0	-0	-0
42	1	3	106	9	50	-0	-0	1
43	1	3	51	54	106	-0	-0	1
44	1	2	56	54	-0	-0	-0	-0
45	1	2	56	9	-0	-0	-0	-0
46	1	3	58	60	57	-0	-0	1
47	1	2	61	60	-0	-0	-0	-0
48	1	3	59	62	58	-0	-0	1
49	1	2	63	62	-0	-0	-0	-0

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51	1	2	69	68	-0	-0	-0	-0
52	1	3	66	70	65	-0	-0	1
53	1	2	71	70	-1	-0	-0	-0
54	1	3	67	72	66	-0	-0	1
55	1	2	73	72	-0	-0	-0	-0
56	1	3	75	78	74	-0	-0	1
57	1	2	79	78	-0	-0	-0	-0
58	1	3	76	80	75	-0	-0	1
59	1	2	81	80	-0	-0	-0	-0
60	1	3	77	107	76	-0	-0	1
61	1	2	82	107	-0	-0	-0	-0
62	1	3	84	87	83	-0	-0	1
63	1	2	88	87	-0	-0	-0	-0
64	1	3	85	89	84	-0	-0	1
65	1	2	90	89	-0	-0	-0	-0
66	1	3	86	109	85	-0	-0	1
67	1	2	91	109	-0	-0	-0	-0
68	1	3	93	95	92	-0	-0	-0
69	1	2	96	95	-0	-0	-0	-0
70	1	3	94	108	110	-0	-0	1
71	1	2	97	108	-0	-0	-0	-0
72	1	3	99	101	98	-0	-0	1
73	1	2	102	101	-0	-0	-0	-0
74	1	3	100	103	99	-0	-0	2
75	1	3	110	103	93	-0	-0	1
76	1	1	100	-0	-0	-0	-0	-0
77	1	1	96	-0	-0	-0	-0	-0
78	1	1	97	-0	-0	-0	-0	-0
79	1	1	88	-0	-0	-0	-0	-0
80	1	1	90	-0	-0	-0	-0	-0
81	1	1	91	-0	-0	-0	-0	-0
82	1	1	79	-0	-0	-0	-0	-0
83	1	1	81	-0	-0	-0	-0	-0
84	1	1	82	-0	-0	-0	-0	-0
85	1	1	69	-0	-0	-0	-0	-0
86	1	1	71	-0	-0	-0	-0	-0
87	1	1	73	-0	-0	-0	-0	-0
88	1	1	61	-0	-0	-0	-0	-0
89	1	1	63	-0	-0	-0	-0	-0
90	1	1	53	-0	-0	-0	-0	-0
91	1	1	55	-0	-0	-0	-0	-0
92	1	1	40	-0	-0	-0	-0	-0
93	1	1	44	-0	-0	-0	-0	-0
94	1	1	48	-0	-0	-0	-0	-0
95	2	1	104	-0	-0	-0	-0	-0
96	1	1	102	-0	-0	-0	-0	-0
97	2	1	112	-0	-0	-0	-0	-0
98	1	1	114	113	-0	-0	-0	-0
99	3	1	117	115	6	-0	1	2
100	3	1	116	115	18	-0	-0	-0
101	1	1	111	-0	-0	-0	-0	-0

MINERS

K	JM(K)	XN(K)	KM(K)	TDN(K)
1	1	400.000	0	-0.000
2	1	400.000	0	-0.000
3	1	300.000	0	-0.000
4	1	900.000	0	-0.000
5	1	1600.000	0	-0.000
6	1	1600.000	0	-0.000
7	104	0.000	0	-0.000
8	104	0.000	0	-0.000
9	2	1750.000	0	-0.000

11	2	1750.000	1	-.000
12	2	1550.000	1	-.000
13	2	400.000	1	-.000
14	2	400.000	1	-.000
15	111	5.000	0	-.000
16	111	5.000	0	-.000
17	111	5.000	0	-.000
18	111	5.000	0	-.000
19	111	5.000	0	-.000
20	115	1300.000	1	-.000
21	115	1000.000	1	-.000
22	112	500.000	0	-.000
23	112	500.000	0	-.000
24	30	1400.000	1	-.000
25	30	1400.000	1	-.000
26	33	275.000	1	-.000
27	33	275.000	1	-.000
28	48	175.000	1	-.000
29	48	175.000	1	-.000
30	48	175.000	1	-.000
31	48	175.000	1	-.000
32	44	100.000	1	-.000
33	44	100.000	1	-.000
34	42	275.000	0	-.000
35	42	275.000	0	-.000
36	40	150.000	1	-.000
37	40	150.000	1	-.000
38	38	200.000	0	-.000
39	38	200.000	0	-.000
40	20	300.000	0	-.000
41	20	300.000	0	-.000
42	20	300.000	0	-.000
43	51	600.000	1	-.000
44	51	600.000	1	-.000
45	55	50.000	1	-.000
46	55	50.000	1	-.000
47	55	50.000	1	-.000
48	53	75.000	1	-.000
49	53	75.000	1	-.000
50	58	150.000	1	-.000
51	58	150.000	1	-.000
52	63	100.000	1	-.000
53	63	100.000	1	-.000
54	63	100.000	1	-.000
55	63	200.000	1	-.000
56	63	200.000	1	-.000
57	63	200.000	1	-.000
58	61	250.000	1	-.000
59	61	250.000	1	-.000
60	61	250.000	1	-.000
61	61	100.000	1	-.000
62	61	100.000	1	-.000
63	61	100.000	1	-.000
64	61	100.000	1	-.000
65	66	240.000	1	-.000
66	66	240.000	1	-.000
67	65	220.000	1	-.000
68	65	220.000	1	-.000
69	73	20.000	1	-.000
70	73	20.000	1	-.000
71	73	20.000	1	-.000
72	71	20.000	1	-.000
73	71	20.000	1	-.000
74	71	20.000	1	-.000
75	69	210.000	1	-.000

77	69	210.000	1	-0.000
78	69	210.000	1	-0.000
79	68	90.000	1	-0.000
80	77	350.000	1	-0.000
81	77	350.000	1	-0.000
82	81	150.000	1	-0.000
83	81	150.000	1	-0.000
84	81	150.000	1	-0.000
85	84	80.000	1	-0.000
86	84	80.000	1	-0.000
87	91	350.000	1	-0.000
88	91	350.000	1	-0.000
89	90	50.000	1	-0.000
90	90	50.000	1	-0.000
91	90	50.000	1	-0.000
92	90	360.000	1	-0.000
93	90	360.000	1	-0.000
94	90	360.000	1	-0.000
95	88	60.000	1	-0.000
96	88	60.000	1	-0.000
97	88	60.000	1	-0.000
98	88	220.000	1	-0.000
99	88	220.000	1	-0.000
100	89	75.000	1	-0.000
101	93	200.000	1	-0.000
102	93	200.000	1	-0.000
103	97	15.000	1	-0.000
104	97	15.000	1	-0.000
105	97	15.000	1	-0.000
106	97	175.000	1	-0.000
107	97	175.000	1	-0.000
108	97	175.000	1	-0.000
109	97	320.000	1	-0.000
110	97	320.000	1	-0.000
111	97	320.000	1	-0.000
112	96	30.000	1	-0.000
113	96	30.000	1	-0.000
114	92	160.000	1	-0.000
115	96	160.000	1	-0.000
116	96	160.000	1	-0.000
117	96	340.000	1	-0.000
118	96	340.000	1	-0.000
119	108	50.000	1	-0.000
120	108	50.000	1	-0.000
121	95	70.000	1	-0.000
122	99	300.000	1	-0.000
123	99	300.000	1	-0.000
124	100	.000	1	-0.000
125	100	.000	1	-0.000
126	100	.000	1	-0.000
127	103	180.000	0	-0.000
128	103	180.000	1	-0.000
129	102	150.000	1	-0.000
130	102	150.000	1	-0.000
131	102	.000	1	-0.000
132	102	.000	1	-0.000
133	2	.000	1	1000.000

HOISTS

L MH(L) IH(L) VELNH(L) TDELAY(L) IHOIST(L) MSLAV(L) MALEV(L)
 XHSTI(L) THSCH(L) NOPT(L) NODFI(L) TDELS(L) TDELF(L)
 LH(L,LL),LL=1,MH(L)...

25	24	23	22	21	20	19	
2	5	18	1000.000	1.500	2	-0	-0
.000	.300	-0	-0	10000.000	10000.000		
18	17	100	16	1			
3	12	30	2000.000	2.000	7	4	11
.000	.000	-0	-0	10000.000	10000.000		
14	13	12	11	10	9	8	7
6	99	5	2				
4	12	30	2000.000	2.000	1	-0	-0
.000	.000	-0	-0	10000.000	10000.000		
14	13	12	11	10	9	8	7
6	99	5	2				

MINE LEVELS

LEVN(M) LEVA(M,MM),MM=1,5...

1	2	1	-0	-0	-0
2	5	16	-0	-0	-0
3	99	100	-0	-0	-0
4	6	17	-0	-0	-0
5	7	19	18	-0	-0
6	8	20	-0	-0	-0
7	9	22	-0	-0	-0
8	10	23	-0	-0	-0
9	11	24	-0	-0	-0
10	12	25	-0	-0	-0
11	13	-0	-0	-0	-0
12	14	-0	-0	-0	-0

FIRE POSITION

I3FIR XBFIR
5 100.000
STENCH WARNING SYSTEM

I3STN XBSTN TSTEN
111 .300 5.000
SELF RESCUER

TSRMAX
60.000

OUTPUT DATA

232<

CHRONOLOGICAL EVENTS

HOIST NO. 4 INOPERATIVE

MINER 22 BRANCH 117 FILLED COMPLETELY WITH SMOKE AT TIME .550 MINUTES
 22 NOTIFIED AT TIME 1.400 BY SMOKE

MINER 23 NOTIFIED AT TIME 1.400 BY SMOKE

 BRANCH 6 FILLED COMPLETELY WITH SMOKE AT TIME 1.400 MINUTES
 BRANCH 7 FILLED COMPLETELY WITH SMOKE AT TIME 1.900 MINUTES
 BRANCH 112 FILLED COMPLETELY WITH SMOKE AT TIME 4.300 MINUTES
 BRANCH 8 FILLED COMPLETELY WITH SMOKE AT TIME 4.400 MINUTES
 BRANCH 10 FILLED COMPLETELY WITH SMOKE AT TIME 4.900 MINUTES

MINER 15 NOTIFIED AT TIME 5.100 BY STENCH
 MINER 16 NOTIFIED AT TIME 5.100 BY STENCH
 MINER 17 NOTIFIED AT TIME 5.100 BY STENCH
 MINER 18 NOTIFIED AT TIME 5.100 BY STENCH
 MINER 19 NOTIFIED AT TIME 5.100 BY STENCH

 BRANCH 11 FILLED COMPLETELY WITH SMOKE AT TIME 5.150 MINUTES
 BRANCH 3 FILLED COMPLETELY WITH STENCH AT TIME 5.200 MINUTES

MINER 13 NOTIFIED AT TIME 5.350 BY STENCH
 MINER 14 NOTIFIED AT TIME 5.350 BY STENCH

 BRANCH 5 FILLED COMPLETELY WITH STENCH AT TIME 5.350 MINUTES
 BRANCH 31 FILLED COMPLETELY WITH SMOKE AT TIME 5.400 MINUTES

MINER 5 NOTIFIED AT TIME 5.450 BY STENCH
 MINER 6 NOTIFIED AT TIME 5.450 BY STENCH

 BRANCH 12 FILLED COMPLETELY WITH SMOKE AT TIME 5.450 MINUTES
 BRANCH 117 FILLED COMPLETELY WITH STENCH AT TIME 5.450 MINUTES
 BRANCH 114 FILLED COMPLETELY WITH SMOKE AT TIME 5.650 MINUTES

MINER 3 NOTIFIED AT TIME 5.850 BY STENCH
 MINER 4 NOTIFIED AT TIME 5.850 BY STENCH

 BRANCH 13 FILLED COMPLETELY WITH SMOKE AT TIME 5.850 MINUTES
 BRANCH 5 FILLED COMPLETELY WITH STENCH AT TIME 5.950 MINUTES

MINER 20 NOTIFIED AT TIME 6.050 BY STENCH
 MINER 21 NOTIFIED AT TIME 6.050 BY STENCH
 MINER 12 NOTIFIED AT TIME 6.100 BY STENCH
 MINER 1 NOTIFIED AT TIME 6.150 BY STENCH
 MINER 2 NOTIFIED AT TIME 6.150 BY STENCH
 MINER 3 NOTIFIED AT TIME 6.150 BY STENCH
 MINER 10 NOTIFIED AT TIME 6.150 BY STENCH
 MINER 11 NOTIFIED AT TIME 6.150 BY STENCH

 BRANCH 2 FILLED COMPLETELY WITH STENCH AT TIME 6.200 MINUTES
 BRANCH 7 FILLED COMPLETELY WITH STENCH AT TIME 6.200 MINUTES

MINER 7 NOTIFIED AT TIME 6.250 BY STENCH
 MINER 8 NOTIFIED AT TIME 6.250 BY STENCH
 MINER 24 NOTIFIED AT TIME 6.250 BY STENCH
 MINER 25 NOTIFIED AT TIME 6.250 BY STENCH

 BRANCH 49 FILLED COMPLETELY WITH SMOKE AT TIME 6.300 MINUTES
 BRANCH 74 FILLED COMPLETELY WITH SMOKE AT TIME 6.300 MINUTES

 BRANCH 4 FILLED COMPLETELY WITH STENCH AT TIME 6.300 MINUTES
 BRANCH 31 FILLED COMPLETELY WITH STENCH AT TIME 6.300 MINUTES
 BRANCH 1 FILLED COMPLETELY WITH STENCH AT TIME 6.350 MINUTES
 BRANCH 37 FILLED COMPLETELY WITH STENCH AT TIME 6.400 MINUTES
 BRANCH 29 FILLED COMPLETELY WITH STENCH AT TIME 6.450 MINUTES
 BRANCH 32 FILLED COMPLETELY WITH STENCH AT TIME 6.450 MINUTES

MINER 26 NOTIFIED AT TIME 6.500 BY STENCH
 MINER 27 NOTIFIED AT TIME 6.500 BY STENCH

 BRANCH 112 FILLED COMPLETELY WITH STENCH AT TIME 6.500 MINUTES

MINER 38 NOTIFIED AT TIME 6.550 BY STENCH
 MINER 39 NOTIFIED AT TIME 6.550 BY STENCH

BRANCH 39	FILLED COMPLETELY WITH STENCH AT TIME	6.550 MINUTES
BRANCH 33	FILLED COMPLETELY WITH STENCH AT TIME	6.600 MINUTES
BRANCH 115	FILLED COMPLETELY WITH STENCH AT TIME	6.600 MINUTES
MINER 35	NOTIFIED AT TIME 6.650 BY STENCH	
MINER 37	NOTIFIED AT TIME 6.650 BY STENCH	
BRANCH 83	FILLED COMPLETELY WITH SMOKE AT TIME	6.650 MINUTES
BRANCH 14	FILLED COMPLETELY WITH SMOKE AT TIME	6.700 MINUTES
BRANCH 40	FILLED COMPLETELY WITH STENCH AT TIME	6.700 MINUTES
BRANCH 41	FILLED COMPLETELY WITH STENCH AT TIME	6.700 MINUTES
BRANCH 115	FILLED COMPLETELY WITH STENCH AT TIME	6.700 MINUTES
BRANCH 17	FILLED COMPLETELY WITH STENCH AT TIME	6.750 MINUTES
BRANCH 34	FILLED COMPLETELY WITH STENCH AT TIME	6.750 MINUTES
BRANCH 42	FILLED COMPLETELY WITH STENCH AT TIME	6.850 MINUTES
BRANCH 43	FILLED COMPLETELY WITH STENCH AT TIME	6.850 MINUTES
MINER 34	NOTIFIED AT TIME 6.900 BY STENCH	
MINER 35	NOTIFIED AT TIME 6.900 BY STENCH	
BRANCH 35	FILLED COMPLETELY WITH STENCH AT TIME	6.900 MINUTES
BRANCH 36	FILLED COMPLETELY WITH STENCH AT TIME	6.900 MINUTES
BRANCH 105	FILLED COMPLETELY WITH STENCH AT TIME	6.900 MINUTES
MINER 32	NOTIFIED AT TIME 7.000 BY STENCH	
MINER 33	NOTIFIED AT TIME 7.000 BY STENCH	
MINER 114	NOTIFIED AT TIME 7.000 BY SMOKE	
BRANCH 44	FILLED COMPLETELY WITH STENCH AT TIME	7.000 MINUTES
BRANCH 45	FILLED COMPLETELY WITH STENCH AT TIME	7.000 MINUTES
BRANCH 45	FILLED COMPLETELY WITH STENCH AT TIME	7.000 MINUTES
BRANCH 47	FILLED COMPLETELY WITH STENCH AT TIME	7.000 MINUTES
BRANCH 30	FILLED COMPLETELY WITH STENCH AT TIME	7.050 MINUTES
MINER 28	NOTIFIED AT TIME 7.150 BY STENCH	
MINER 29	NOTIFIED AT TIME 7.150 BY STENCH	
MINER 30	NOTIFIED AT TIME 7.150 BY STENCH	
MINER 31	NOTIFIED AT TIME 7.150 BY STENCH	
MINER 40	NOTIFIED AT TIME 7.150 BY STENCH	
MINER 41	NOTIFIED AT TIME 7.150 BY STENCH	
MINER 42	NOTIFIED AT TIME 7.150 BY STENCH	
BRANCH 20	FILLED COMPLETELY WITH STENCH AT TIME	7.150 MINUTES
BRANCH 48	FILLED COMPLETELY WITH STENCH AT TIME	7.200 MINUTES
BRANCH 19	FILLED COMPLETELY WITH STENCH AT TIME	7.450 MINUTES
BRANCH 8	FILLED COMPLETELY WITH STENCH AT TIME	7.500 MINUTES
BRANCH 18	FILLED COMPLETELY WITH STENCH AT TIME	7.550 MINUTES
BRANCH 49	FILLED COMPLETELY WITH STENCH AT TIME	7.600 MINUTES
BRANCH 52	FILLED COMPLETELY WITH STENCH AT TIME	7.650 MINUTES
BRANCH 57	FILLED COMPLETELY WITH SMOKE AT TIME	7.700 MINUTES
BRANCH 10	FILLED COMPLETELY WITH STENCH AT TIME	7.750 MINUTES
BRANCH 50	FILLED COMPLETELY WITH STENCH AT TIME	7.750 MINUTES
MINER 48	NOTIFIED AT TIME 7.800 BY STENCH	
MINER 49	NOTIFIED AT TIME 7.800 BY STENCH	
BRANCH 11	FILLED COMPLETELY WITH STENCH AT TIME	7.800 MINUTES
BRANCH 53	FILLED COMPLETELY WITH STENCH AT TIME	7.800 MINUTES
BRANCH 57	FILLED COMPLETELY WITH STENCH AT TIME	7.800 MINUTES
BRANCH 106	FILLED COMPLETELY WITH STENCH AT TIME	7.800 MINUTES
BRANCH 60	FILLED COMPLETELY WITH STENCH AT TIME	7.850 MINUTES
BRANCH 9	FILLED COMPLETELY WITH STENCH AT TIME	7.900 MINUTES
BRANCH 12	FILLED COMPLETELY WITH STENCH AT TIME	7.900 MINUTES
BRANCH 54	FILLED COMPLETELY WITH STENCH AT TIME	7.900 MINUTES
BRANCH 64	FILLED COMPLETELY WITH STENCH AT TIME	7.900 MINUTES
MINER 58	NOTIFIED AT TIME 7.950 BY STENCH	
MINER 59	NOTIFIED AT TIME 7.950 BY STENCH	
MINER 60	NOTIFIED AT TIME 7.950 BY STENCH	
BRANCH 92	FILLED COMPLETELY WITH SMOKE AT TIME	7.950 MINUTES
MINER 43	NOTIFIED AT TIME 8.000 BY STENCH	
MINER 44	NOTIFIED AT TIME 8.000 BY STENCH	
MINER 50	NOTIFIED AT TIME 8.000 BY STENCH	
MINER 51	NOTIFIED AT TIME 8.000 BY STENCH	
MINER 51	NOTIFIED AT TIME 8.000 BY STENCH	

MINER 63 NOTIFIED AT TIME 8.000 BY STENCH
 MINER 64 NOTIFIED AT TIME 8.000 BY STENCH
 MINER 79 NOTIFIED AT TIME 8.000 BY STENCH
 BRANCH 13 FILLED COMPLETELY WITH STENCH AT TIME 8.000MINUTES
 BRANCH 68 FILLED COMPLETELY WITH STENCH AT TIME 8.000MINUTES
 BRANCH 74 FILLED COMPLETELY WITH STENCH AT TIME 8.000MINUTES
 MINER 67 NOTIFIED AT TIME 8.050 BY STENCH
 MINER 68 NOTIFIED AT TIME 8.050 BY STENCH
 MINER 85 NOTIFIED AT TIME 8.050 BY SMOKE
 MINER 85 NOTIFIED AT TIME 8.050 BY SMOKE
 BRANCH 55 FILLED COMPLETELY WITH STENCH AT TIME 8.050MINUTES
 BRANCH 58 FILLED COMPLETELY WITH STENCH AT TIME 8.050MINUTES
 BRANCH 61 FILLED COMPLETELY WITH STENCH AT TIME 8.050MINUTES
 BRANCH 78 FILLED COMPLETELY WITH STENCH AT TIME 8.050MINUTES
 MINER 45 NOTIFIED AT TIME 8.100 BY STENCH
 MINER 46 NOTIFIED AT TIME 8.100 BY STENCH
 MINER 47 NOTIFIED AT TIME 8.100 BY STENCH
 MINER 75 NOTIFIED AT TIME 8.100 BY STENCH
 MINER 76 NOTIFIED AT TIME 8.100 BY STENCH
 MINER 77 NOTIFIED AT TIME 8.100 BY STENCH
 MINER 78 NOTIFIED AT TIME 8.100 BY STENCH
 BRANCH 64 FILLED COMPLETELY WITH SMOKE AT TIME 8.100 MINUTES
 BRANCH 14 FILLED COMPLETELY WITH STENCH AT TIME 8.100MINUTES
 BRANCH 65 FILLED COMPLETELY WITH STENCH AT TIME 8.100MINUTES
 BRANCH 83 FILLED COMPLETELY WITH STENCH AT TIME 8.100MINUTES
 BRANCH 75 FILLED COMPLETELY WITH SMOKE AT TIME 8.150 MINUTES
 BRANCH 62 FILLED COMPLETELY WITH STENCH AT TIME 8.150MINUTES
 BRANCH 87 FILLED COMPLETELY WITH STENCH AT TIME 8.150MINUTES
 BRANCH 15 FILLED COMPLETELY WITH STENCH AT TIME 8.200MINUTES
 BRANCH 63 FILLED COMPLETELY WITH STENCH AT TIME 8.200MINUTES
 BRANCH 70 FILLED COMPLETELY WITH STENCH AT TIME 8.200MINUTES
 BRANCH 75 FILLED COMPLETELY WITH STENCH AT TIME 8.200MINUTES
 BRANCH 92 FILLED COMPLETELY WITH STENCH AT TIME 8.200MINUTES
 MINER 55 NOTIFIED AT TIME 8.250 BY STENCH
 MINER 56 NOTIFIED AT TIME 8.250 BY STENCH
 MINER 57 NOTIFIED AT TIME 8.250 BY STENCH
 MINER 65 NOTIFIED AT TIME 8.250 BY STENCH
 MINER 66 NOTIFIED AT TIME 8.250 BY STENCH
 MINER 121 NOTIFIED AT TIME 8.250 BY STENCH
 BRANCH 79 FILLED COMPLETELY WITH STENCH AT TIME 8.250MINUTES
 BRANCH 80 FILLED COMPLETELY WITH STENCH AT TIME 8.250MINUTES
 BRANCH 95 FILLED COMPLETELY WITH STENCH AT TIME 8.250MINUTES
 MINER 52 NOTIFIED AT TIME 8.300 BY STENCH
 MINER 53 NOTIFIED AT TIME 8.300 BY STENCH
 MINER 54 NOTIFIED AT TIME 8.300 BY STENCH
 MINER 98 NOTIFIED AT TIME 8.300 BY STENCH
 MINER 99 NOTIFIED AT TIME 8.300 BY STENCH
 MINER 117 NOTIFIED AT TIME 8.300 BY STENCH
 MINER 118 NOTIFIED AT TIME 8.300 BY STENCH
 BRANCH 84 FILLED COMPLETELY WITH SMOKE AT TIME 8.300 MINUTES
 BRANCH 15 FILLED COMPLETELY WITH STENCH AT TIME 8.300MINUTES
 BRANCH 51 FILLED COMPLETELY WITH STENCH AT TIME 8.300MINUTES
 BRANCH 63 FILLED COMPLETELY WITH STENCH AT TIME 8.300MINUTES
 BRANCH 66 FILLED COMPLETELY WITH STENCH AT TIME 8.300MINUTES
 BRANCH 84 FILLED COMPLETELY WITH STENCH AT TIME 8.300MINUTES
 BRANCH 93 FILLED COMPLETELY WITH STENCH AT TIME 8.300MINUTES
 MINER 95 NOTIFIED AT TIME 8.350 BY STENCH
 MINER 96 NOTIFIED AT TIME 8.350 BY STENCH
 MINER 97 NOTIFIED AT TIME 8.350 BY STENCH
 MINER 100 NOTIFIED AT TIME 8.350 BY STENCH
 MINER 101 NOTIFIED AT TIME 8.350 BY STENCH
 MINER 102 NOTIFIED AT TIME 8.350 BY STENCH
 BRANCH 88 FILLED COMPLETELY WITH STENCH AT TIME 8.350MINUTES

BRANCH 101 FILLED COMPLETELY WITH STENCH AT TIME	8.350 MINUTES
MINER 82 NOTIFIED AT TIME	8.400 BY STENCH
MINER 83 NOTIFIED AT TIME	8.400 BY STENCH
MINER 84 NOTIFIED AT TIME	8.400 BY STENCH
MINER 92 NOTIFIED AT TIME	8.400 BY STENCH
MINER 93 NOTIFIED AT TIME	8.400 BY STENCH
MINER 94 NOTIFIED AT TIME	8.400 BY STENCH
MINER 115 NOTIFIED AT TIME	8.400 BY STENCH
MINER 116 NOTIFIED AT TIME	8.400 BY STENCH
MINER 122 NOTIFIED AT TIME	8.400 BY STENCH
MINER 123 NOTIFIED AT TIME	8.400 BY STENCH
BRANCH 71 FILLED COMPLETELY WITH STENCH AT TIME	8.400 MINUTES
BRANCH 72 FILLED COMPLETELY WITH STENCH AT TIME	8.400 MINUTES
BRANCH 75 FILLED COMPLETELY WITH STENCH AT TIME	8.400 MINUTES
BRANCH 93 FILLED COMPLETELY WITH STENCH AT TIME	8.400 MINUTES
MINER 72 NOTIFIED AT TIME	8.450 BY STENCH
MINER 73 NOTIFIED AT TIME	8.450 BY STENCH
MINER 74 NOTIFIED AT TIME	8.450 BY STENCH
MINER 129 NOTIFIED AT TIME	8.450 BY STENCH
MINER 130 NOTIFIED AT TIME	8.450 BY STENCH
BRANCH 55 FILLED COMPLETELY WITH STENCH AT TIME	8.450 MINUTES
BRANCH 81 FILLED COMPLETELY WITH STENCH AT TIME	8.450 MINUTES
BRANCH 96 FILLED COMPLETELY WITH STENCH AT TIME	8.450 MINUTES
BRANCH 107 FILLED COMPLETELY WITH STENCH AT TIME	8.450 MINUTES
BRANCH 110 FILLED COMPLETELY WITH STENCH AT TIME	8.450 MINUTES
MINER 80 NOTIFIED AT TIME	8.500 BY STENCH
MINER 81 NOTIFIED AT TIME	8.500 BY STENCH
MINER 112 NOTIFIED AT TIME	8.500 BY STENCH
MINER 113 NOTIFIED AT TIME	8.500 BY STENCH
BRANCH 53 FILLED COMPLETELY WITH STENCH AT TIME	8.500 MINUTES
BRANCH 99 FILLED COMPLETELY WITH STENCH AT TIME	8.500 MINUTES
BRANCH 102 FILLED COMPLETELY WITH STENCH AT TIME	8.500 MINUTES
BRANCH 113 FILLED COMPLETELY WITH STENCH AT TIME	8.500 MINUTES
BRANCH 114 FILLED COMPLETELY WITH STENCH AT TIME	8.500 MINUTES
MINER 113 NOTIFIED AT TIME	8.550 BY STENCH
MINER 120 NOTIFIED AT TIME	8.550 BY STENCH
MINER 128 NOTIFIED AT TIME	8.550 BY STENCH
MINER 131 NOTIFIED AT TIME	8.550 BY STENCH
MINER 132 NOTIFIED AT TIME	8.550 BY STENCH
BRANCH 67 FILLED COMPLETELY WITH STENCH AT TIME	8.550 MINUTES
BRANCH 85 FILLED COMPLETELY WITH STENCH AT TIME	8.550 MINUTES
BRANCH 85 FILLED COMPLETELY WITH STENCH AT TIME	8.550 MINUTES
BRANCH 91 FILLED COMPLETELY WITH STENCH AT TIME	8.550 MINUTES
BRANCH 108 FILLED COMPLETELY WITH STENCH AT TIME	8.550 MINUTES
MINER 89 NOTIFIED AT TIME	8.600 BY STENCH
MINER 90 NOTIFIED AT TIME	8.600 BY STENCH
MINER 91 NOTIFIED AT TIME	8.600 BY STENCH
BRANCH 22 FILLED COMPLETELY WITH STENCH AT TIME	8.600 MINUTES
BRANCH 73 FILLED COMPLETELY WITH STENCH AT TIME	8.600 MINUTES
BRANCH 100 FILLED COMPLETELY WITH STENCH AT TIME	8.600 MINUTES
BRANCH 103 FILLED COMPLETELY WITH STENCH AT TIME	8.600 MINUTES
BRANCH 109 FILLED COMPLETELY WITH STENCH AT TIME	8.600 MINUTES
MINER 69 NOTIFIED AT TIME	8.650 BY STENCH
MINER 70 NOTIFIED AT TIME	8.650 BY STENCH
MINER 71 NOTIFIED AT TIME	8.650 BY STENCH
MINER 109 NOTIFIED AT TIME	8.650 BY STENCH
MINER 113 NOTIFIED AT TIME	8.650 BY STENCH
MINER 111 NOTIFIED AT TIME	8.650 BY STENCH
MINER 124 NOTIFIED AT TIME	8.650 BY STENCH
MINER 125 NOTIFIED AT TIME	8.650 BY STENCH
MINER 125 NOTIFIED AT TIME	8.650 BY STENCH
MINER 127 NOTIFIED AT TIME	8.650 BY STENCH
BRANCH 23 FILLED COMPLETELY WITH STENCH AT TIME	8.650 MINUTES
BRANCH 77 FILLED COMPLETELY WITH STENCH AT TIME	8.650 MINUTES
MINER 87 NOTIFIED AT TIME	8.700 BY STENCH

BRANCH 24	FILLED COMPLETELY WITH STENCH AT TIME	8.700MINJTES
BRANCH 82	FILLED COMPLETELY WITH STENCH AT TIME	8.700MINJTES
BRANCH 96	FILLED COMPLETELY WITH STENCH AT TIME	8.700MINJTES
MINER 106	NOTIFIED AT TIME 8.750 BY STENCH	
MINER 107	NOTIFIED AT TIME 8.750 BY STENCH	
MINER 108	NOTIFIED AT TIME 8.750 BY STENCH	
BRANCH 25	FILLED COMPLETELY WITH STENCH AT TIME	8.8004MINJTES
BRANCH 27	FILLED COMPLETELY WITH STENCH AT TIME	8.8004MINJTES
BRANCH 97	FILLED COMPLETELY WITH STENCH AT TIME	8.8004MINJTES
MINER 103	NOTIFIED AT TIME 8.850 BY STENCH	
MINER 104	NOTIFIED AT TIME 8.850 BY STENCH	
MINER 105	NOTIFIED AT TIME 8.850 BY STENCH	
BRANCH 29	FILLED COMPLETELY WITH STENCH AT TIME	8.850MINJTES
BRANCH 91	FILLED COMPLETELY WITH STENCH AT TIME	8.8504MINJTES
BRANCH 25	FILLED COMPLETELY WITH STENCH AT TIME	8.9504MINJTES
BRANCH 50	FILLED COMPLETELY WITH SMOKE AT TIME	9.150 MINUTES
BRANCH 21	FILLED COMPLETELY WITH STENCH AT TIME	9.650MINJTES
BRANCH 76	FILLED COMPLETELY WITH SMOKE AT TIME	10.000 MINUTES
BRANCH 85	FILLED COMPLETELY WITH SMOKE AT TIME	10.050 MINUTES
BRANCH 86	FILLED COMPLETELY WITH SMOKE AT TIME	10.200 MINUTES
BRANCH 93	FILLED COMPLETELY WITH SMOKE AT TIME	10.500 MINUTES
BRANCH 9	FILLED COMPLETELY WITH SMOKE AT TIME	11.050 MINUTES
BRANCH 27	FILLED COMPLETELY WITH SMOKE AT TIME	11.100 MINUTES
BRANCH 32	FILLED COMPLETELY WITH SMOKE AT TIME	11.100 MINUTES
BRANCH 106	FILLED COMPLETELY WITH SMOKE AT TIME	11.150 MINUTES
BRANCH 110	FILLED COMPLETELY WITH SMOKE AT TIME	11.200 MINUTES
BRANCH 26	FILLED COMPLETELY WITH SMOKE AT TIME	11.550 MINUTES
BRANCH 15	FILLED COMPLETELY WITH SMOKE AT TIME	11.650 MINUTES
HOIST 2	REACHES NODE 1 WITH 3 MINERS AT TIME	11.850
BRANCH 25	FILLED COMPLETELY WITH SMOKE AT TIME	11.950 MINUTES
BRANCH 77	FILLED COMPLETELY WITH SMOKE AT TIME	12.050 MINUTES
BRANCH 24	FILLED COMPLETELY WITH SMOKE AT TIME	12.350 MINUTES
BRANCH 23	FILLED COMPLETELY WITH SMOKE AT TIME	12.700 MINUTES
MINER 22	EVACUATED AT TIME 12.800 ON NODE 97 TOTAL	1
MINER 23	EVACUATED AT TIME 12.800 ON NODE 97 TOTAL	2
BRANCH 94	FILLED COMPLETELY WITH SMOKE AT TIME	12.900 MINUTES
BRANCH 22	FILLED COMPLETELY WITH SMOKE AT TIME	13.050 MINUTES
BRANCH 104	FILLED COMPLETELY WITH STENCH AT TIME	13.1504MINJTES
BRANCH 28	FILLED COMPLETELY WITH SMOKE AT TIME	13.200 MINUTES
BRANCH 58	FILLED COMPLETELY WITH SMOKE AT TIME	14.000 MINUTES
BRANCH 65	FILLED COMPLETELY WITH SMOKE AT TIME	14.200 MINUTES
MINER 133	EVACUATED AT TIME 15.100 ON NODE 95 TOTAL	3
BRANCH 98	FILLED COMPLETELY WITH SMOKE AT TIME	15.350 MINUTES
BRANCH 87	FILLED COMPLETELY WITH SMOKE AT TIME	16.300 MINUTES
BRANCH 21	FILLED COMPLETELY WITH SMOKE AT TIME	16.400 MINUTES
BRANCH 95	FILLED COMPLETELY WITH SMOKE AT TIME	16.600 MINUTES
BRANCH 20	FILLED COMPLETELY WITH SMOKE AT TIME	16.800 MINUTES
BRANCH 33	FILLED COMPLETELY WITH SMOKE AT TIME	16.800 MINUTES
BRANCH 52	FILLED COMPLETELY WITH SMOKE AT TIME	17.250 MINUTES
BRANCH 37	FILLED COMPLETELY WITH SMOKE AT TIME	17.350 MINUTES
BRANCH 19	FILLED COMPLETELY WITH SMOKE AT TIME	17.450 MINUTES
BRANCH 78	FILLED COMPLETELY WITH SMOKE AT TIME	17.600 MINUTES
BRANCH 89	FILLED COMPLETELY WITH SMOKE AT TIME	18.250 MINUTES
BRANCH 14	FILLED COMPLETELY WITH SMOKE AT TIME	18.450 MINUTES
BRANCH 116	FILLED COMPLETELY WITH SMOKE AT TIME	18.650 MINUTES
BRANCH 80	FILLED COMPLETELY WITH SMOKE AT TIME	19.100 MINUTES
BRANCH 60	FILLED COMPLETELY WITH SMOKE AT TIME	19.150 MINUTES
MINER 7	EVACUATED AT TIME 19.250 ON NODE 95 TOTAL	4
MINER 8	EVACUATED AT TIME 19.250 ON NODE 95 TOTAL	5
MINER 9	EVACUATED AT TIME 19.350 ON NODE 95 TOTAL	6
MINER 10	EVACUATED AT TIME 19.350 ON NODE 95 TOTAL	7
MINER 11	EVACUATED AT TIME 19.350 ON NODE 95 TOTAL	8
MINER 12	EVACUATED AT TIME 19.400 ON NODE 95 TOTAL	9
BRANCH 103	FILLED COMPLETELY WITH SMOKE AT TIME	19.550 MINUTES

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MINER	14	EVACUATED AT TIME	20.000	ON NODE	95	TOTAL	11
MINER	15	EVACUATED AT TIME	20.250	ON NODE	95	TOTAL	12
MINER	16	EVACUATED AT TIME	20.250	ON NODE	95	TOTAL	13
MINER	17	EVACUATED AT TIME	20.250	ON NODE	95	TOTAL	14
MINER	18	EVACUATED AT TIME	20.250	ON NODE	95	TOTAL	15
MINER	19	EVACUATED AT TIME	20.250	ON NODE	95	TOTAL	16
		BRANCH 109	FILLED COMPLETELY WITH SMOKE AT TIME			20.350	MINUTES
		BRANCH 68	FILLED COMPLETELY WITH SMOKE AT TIME			20.400	MINUTES
		BRANCH 66	FILLED COMPLETELY WITH SMOKE AT TIME			20.450	MINUTES
		BRANCH 107	FILLED COMPLETELY WITH SMOKE AT TIME			20.650	MINUTES
		BRANCH 113	FILLED COMPLETELY WITH SMOKE AT TIME			20.650	MINUTES
		BRANCH 16	FILLED COMPLETELY WITH SMOKE AT TIME			21.600	MINUTES
MINER	5	EVACUATED AT TIME	21.900	ON NODE	95	TOTAL	17
MINER	6	EVACUATED AT TIME	21.900	ON NODE	95	TOTAL	18
		BRANCH 111	FILLED COMPLETELY WITH SMOKE AT TIME			22.000	MINUTES
		BRANCH 34	FILLED COMPLETELY WITH SMOKE AT TIME			22.500	MINUTES
		BRANCH 54	FILLED COMPLETELY WITH SMOKE AT TIME			22.500	MINUTES
		BRANCH 51	FILLED COMPLETELY WITH SMOKE AT TIME			22.650	MINUTES
		BRANCH 99	FILLED COMPLETELY WITH SMOKE AT TIME			22.750	MINUTES
		BRANCH 39	FILLED COMPLETELY WITH SMOKE AT TIME			23.050	MINUTES
		BRANCH 103	FILLED COMPLETELY WITH SMOKE AT TIME			23.800	MINUTES
MINER	40	EVACUATED AT TIME	24.850	ON NODE	95	TOTAL	19
MINER	41	EVACUATED AT TIME	24.850	ON NODE	95	TOTAL	20
MINER	42	EVACUATED AT TIME	24.850	ON NODE	95	TOTAL	21
MINER	3	EVACUATED AT TIME	24.950	ON NODE	95	TOTAL	22
MINER	4	EVACUATED AT TIME	24.950	ON NODE	95	TOTAL	23
		BRANCH 59	FILLED COMPLETELY WITH SMOKE AT TIME			25.950	MINUTES
		BRANCH 62	FILLED COMPLETELY WITH SMOKE AT TIME			25.950	MINUTES
		BRANCH 70	FILLED COMPLETELY WITH SMOKE AT TIME			26.700	MINUTES
MINER	1	EVACUATED AT TIME	27.150	ON NODE	95	TOTAL	24
MINER	2	EVACUATED AT TIME	27.150	ON NODE	95	TOTAL	25
		BRANCH 35	FILLED COMPLETELY WITH SMOKE AT TIME			27.300	MINUTES
		BRANCH 67	FILLED COMPLETELY WITH SMOKE AT TIME			27.450	MINUTES
		BRANCH 36	FILLED COMPLETELY WITH SMOKE AT TIME			27.700	MINUTES
		BRANCH 105	FILLED COMPLETELY WITH SMOKE AT TIME			28.100	MINUTES
		BRANCH 41	FILLED COMPLETELY WITH SMOKE AT TIME			29.450	MINUTES
		BRANCH 72	FILLED COMPLETELY WITH SMOKE AT TIME			32.100	MINUTES
		BRANCH 43	FILLED COMPLETELY WITH SMOKE AT TIME			35.150	MINUTES
		BRANCH 53	FILLED COMPLETELY WITH SMOKE AT TIME			37.900	MINUTES
		BRANCH 38	FILLED COMPLETELY WITH SMOKE AT TIME			39.000	MINUTES
		BRANCH 100	FILLED COMPLETELY WITH SMOKE AT TIME			39.400	MINUTES
		BRANCH 45	FILLED COMPLETELY WITH SMOKE AT TIME			40.250	MINUTES
		BRANCH 47	FILLED COMPLETELY WITH SMOKE AT TIME			40.350	MINUTES
		BRANCH 46	FILLED COMPLETELY WITH SMOKE AT TIME			41.900	MINUTES
		BRANCH 96	FILLED COMPLETELY WITH SMOKE AT TIME			41.900	MINUTES
		BRANCH 102	FILLED COMPLETELY WITH SMOKE AT TIME			42.300	MINUTES
		BRANCH 61	FILLED COMPLETELY WITH SMOKE AT TIME			42.450	MINUTES
		BRANCH 88	FILLED COMPLETELY WITH SMOKE AT TIME			42.950	MINUTES
		BRANCH 43	FILLED COMPLETELY WITH SMOKE AT TIME			43.000	MINUTES
		BRANCH 56	FILLED COMPLETELY WITH SMOKE AT TIME			43.300	MINUTES
		BRANCH 55	FILLED COMPLETELY WITH SMOKE AT TIME			43.450	MINUTES
		BRANCH 79	FILLED COMPLETELY WITH SMOKE AT TIME			43.550	MINUTES
		BRANCH 97	FILLED COMPLETELY WITH SMOKE AT TIME			43.900	MINUTES
		BRANCH 81	FILLED COMPLETELY WITH SMOKE AT TIME			44.750	MINUTES
		BRANCH 69	FILLED COMPLETELY WITH SMOKE AT TIME			45.350	MINUTES
HOIST	2	REACHES NODE	1 WITH	4 MINERS AT TIME		46.200	
		BRANCH 93	FILLED COMPLETELY WITH SMOKE AT TIME			46.200	MINUTES
		BRANCH 91	FILLED COMPLETELY WITH SMOKE AT TIME			47.700	MINUTES
		BRANCH 63	FILLED COMPLETELY WITH SMOKE AT TIME			48.250	MINUTES
		BRANCH 82	FILLED COMPLETELY WITH SMOKE AT TIME			49.350	MINUTES
HOIST	1	REACHES NODE	19 WITH	18 MINERS AT TIME		50.950	
		BRANCH 42	FILLED COMPLETELY WITH SMOKE AT TIME			51.100	MINUTES
HOIST	2	REACHES NODE	1 WITH	14 MINERS AT TIME		51.850	

BRANCH 29	FILLED COMPLETELY WITH SMOKE AT TIME	53.100	MINUTES
BRANCH 71	FILLED COMPLETELY WITH SMOKE AT TIME	53.350	MINUTES
BRANCH 115	FILLED COMPLETELY WITH SMOKE AT TIME	53.350	MINUTES
BRANCH 30	FILLED COMPLETELY WITH SMOKE AT TIME	54.150	MINUTES
BRANCH 44	FILLED COMPLETELY WITH SMOKE AT TIME	55.800	MINUTES
BRANCH 73	FILLED COMPLETELY WITH SMOKE AT TIME	58.750	MINUTES
MINER 20	EVACUATED AT TIME	59.200	ON NODE 95 TOTAL 26
MINER 21	EVACUATED AT TIME	59.200	ON NODE 95 TOTAL 27
MINER 24	EVACUATED AT TIME	59.200	ON NODE 95 TOTAL 28
MINER 25	EVACUATED AT TIME	59.200	ON NODE 95 TOTAL 29
HOIST 2	REACHES NODE 1 WITH 18 MINERS AT TIME	59.600	
HOIST 1	REACHES NODE 19 WITH 18 MINERS AT TIME	61.900	

BRANCH 48	FILLED COMPLETELY WITH SMOKE AT TIME	63.650	MINUTES
MINER 25	EVAUATED AT TIME	64.850	ON NODE 95 TOTAL 30
MINER 27	EVAUATED AT TIME	64.850	ON NODE 95 TOTAL 31
MINER 28	EVAUATED AT TIME	64.850	ON NODE 95 TOTAL 32
MINER 29	EVAUATED AT TIME	64.850	ON NODE 95 TOTAL 33
MINER 30	EVAUATED AT TIME	64.850	ON NODE 95 TOTAL 34
MINER 31	EVAUATED AT TIME	64.850	ON NODE 95 TOTAL 35
MINER 32	EVAUATED AT TIME	64.850	ON NODE 95 TOTAL 36
MINER 33	EVAUATED AT TIME	64.850	ON NODE 95 TOTAL 37
MINER 34	EVAUATED AT TIME	64.850	ON NODE 95 TOTAL 38
MINER 35	EVAUATED AT TIME	64.850	ON NODE 95 TOTAL 39
MINER 36	EVAUATED AT TIME	64.850	ON NODE 95 TOTAL 40
MINER 37	EVAUATED AT TIME	64.850	ON NODE 95 TOTAL 41
MINER 38	EVAUATED AT TIME	64.850	ON NODE 95 TOTAL 42
MINER 39	EVAUATED AT TIME	64.850	ON NODE 95 TOTAL 43
MINER 114	DEAD AT TIME	67.100	
	ON BRANCH 19		
	AT DISTANCE	.000	
	FROM NODE 18		

MINER 67 DEAD AT TIME 68.750
ON BRANCH 24
AT DISTANCE .300
FROM NODE 23

MINER 68 DEAD AT TIME 68.750
ON BRANCH 24
AT DISTANCE .000
FROM NODE 23

MINER 50 DEAD AT TIME 68.950
ON BRANCH 23
AT DISTANCE .300
FROM NODE 22

MINER 51 DEAD AT TIME 68.950
ON BRANCH 23
AT DISTANCE .300
FROM NODE 22

MINER 43 DEAD AT TIME 69.550
ON BRANCH 21
AT DISTANCE .300
FROM NODE 20

ON BRANCH 21
AT DISTANCE .000
FROM NODE 20

MINER 66 DEAD AT TIME 70.150
ON BRANCH 24
AT DISTANCE .000
FROM NODE 23

HOIST 2 REACHES NODE 1 WITH 17 MINERS AT TIME 70.450

MINER 79 DEAD AT TIME 70.500
ON BRANCH 24
AT DISTANCE .000
FROM NODE 23

MINER 101 DEAD AT TIME 70.550
ON BRANCH 104
AT DISTANCE 46.300
FROM NODE 1

MINER 102 DEAD AT TIME 70.550
ON BRANCH 104
AT DISTANCE 46.300
FROM NODE 1

MINER 48 DEAD AT TIME 72.200
ON BRANCH 21
AT DISTANCE .000
FROM NODE 20

MINER 49 DEAD AT TIME 72.200
ON BRANCH 21
AT DISTANCE .300
FROM NODE 20

MINER 58 DEAD AT TIME 72.600
ON BRANCH 23
AT DISTANCE .000
FROM NODE 22

MINER 59 DEAD AT TIME 72.600
ON BRANCH 23
AT DISTANCE .000
FROM NODE 22

MINER 60 DEAD AT TIME 72.600
ON BRANCH 23
AT DISTANCE .000
FROM NODE 22

MINER 80 EVACUATED AT TIME 72.600 ON NODE 95 TOTAL 44
MINER 81 EVACUATED AT TIME 72.600 ON NODE 95 TOTAL 45
MINER 82 EVACUATED AT TIME 72.600 ON NODE 95 TOTAL 46
MINER 83 EVACUATED AT TIME 72.600 ON NODE 95 TOTAL 47

MINER	85	EVACUATED	AT TIME	72.600	ON NODE	95	TOTAL	49
MINER	86	EVACUATED	AT TIME	72.600	ON NODE	95	TOTAL	50
MINER	87	EVACUATED	AT TIME	72.600	ON NODE	95	TOTAL	51
MINER	88	EVACUATED	AT TIME	72.600	ON NODE	95	TOTAL	52
MINER	89	EVACUATED	AT TIME	72.600	ON NODE	95	TOTAL	53
MINER	90	EVACUATED	AT TIME	72.600	ON NODE	95	TOTAL	54
MINER	91	EVACUATED	AT TIME	72.600	ON NODE	95	TOTAL	55
MINER	92	EVACUATED	AT TIME	72.600	ON NODE	95	TOTAL	56
MINER	93	EVACUATED	AT TIME	72.600	ON NODE	95	TOTAL	57
MINER	94	EVACUATED	AT TIME	72.600	ON NODE	95	TOTAL	58
MINER	95	EVACUATED	AT TIME	72.600	ON NODE	95	TOTAL	59
MINER	95	EVACUATED	AT TIME	72.600	ON NODE	95	TOTAL	60
MINER	97	EVACUATED	AT TIME	72.600	ON NODE	95	TOTAL	61
HOIST	1	REACHES	NODE	19	WITH	18	MINERS AT TIME	72.850

MINER 65 DEAD AT TIME 72.950
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER116 DEAD AT TIME 72.950
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER117 DEAD AT TIME 72.950
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER118 DEAD AT TIME 72.950
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER119 DEAD AT TIME 72.950
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER120 DEAD AT TIME 72.950
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER121 DEAD AT TIME 72.950
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER122 DEAD AT TIME 72.950
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER123 DEAD AT TIME 72.950
ON BRANCH 20

FROM NODE 19

MINER124 DEAD AT TIME 72.950
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER125 DEAD AT TIME 72.950
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER126 DEAD AT TIME 72.950
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER127 DEAD AT TIME 72.950
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER128 DEAD AT TIME 72.950
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER 61 DEAD AT TIME 73.100
ON BRANCH 23
AT DISTANCE .000
FROM NODE 22

MINER 62 DEAD AT TIME 73.100
ON BRANCH 23
AT DISTANCE .300
FROM NODE 22

MINER 63 DEAD AT TIME 73.100
ON BRANCH 23
AT DISTANCE .300
FROM NODE 22

MINER 64 DEAD AT TIME 73.100
ON BRANCH 23
AT DISTANCE .300
FROM NODE 22

MINER 75 DEAD AT TIME 73.350
ON BRANCH 24
AT DISTANCE .000
FROM NODE 23

MINER 76 DEAD AT TIME 73.350

FROM NODE 23

MINER 77 DEAD AT TIME 73.350
ON BRANCH 24
AT DISTANCE .000
FROM NODE 23

MINER 78 DEAD AT TIME 73.350
ON BRANCH 24
AT DISTANCE .000
FROM NODE 23

MINER129 DEAD AT TIME 73.950
ON BRANCH 20
AT DISTANCE 138.500
FROM NODE 19

MINER130 DEAD AT TIME 73.950
ON BRANCH 20
AT DISTANCE 138.600
FROM NODE 19

MINER 45 DEAD AT TIME 74.450
ON BRANCH 21
AT DISTANCE .000
FROM NODE 20

MINER 46 DEAD AT TIME 74.450
ON BRANCH 21
AT DISTANCE .000
FROM NODE 20

MINER 47 DEAD AT TIME 74.450
ON BRANCH 21
AT DISTANCE .000
FROM NODE 20

MINER131 DEAD AT TIME 74.700
ON BRANCH 20
AT DISTANCE 237.600
FROM NODE 19

MINER132 DEAD AT TIME 74.700
ON BRANCH 20
AT DISTANCE 237.600
FROM NODE 19

MINER 55 DEAD AT TIME 75.450
ON BRANCH 23
AT DISTANCE .000
FROM NODE 22

MINER 56 DEAD AT TIME 75.450

FROM NODE 22

MINER 57 DEAD AT TIME 75.450
ON BRANCH 23
AT DISTANCE .000
FROM NODE 22

MINER 52 DEAD AT TIME 75.800
ON BRANCH 23
AT DISTANCE .000
FROM NODE 22

MINER 53 DEAD AT TIME 75.800
ON BRANCH 23
AT DISTANCE .000
FROM NODE 22

MINER 54 DEAD AT TIME 75.800
ON BRANCH 23
AT DISTANCE .000
FROM NODE 22

MINER 72 DEAD AT TIME 76.600
ON BRANCH 24
AT DISTANCE .000
FROM NODE 23

MINER 73 DEAD AT TIME 76.600
ON BRANCH 24
AT DISTANCE .000
FROM NODE 23

MINER 74 DEAD AT TIME 76.600
ON BRANCH 24
AT DISTANCE .000
FROM NODE 23

HOIST 1 REACHES NODE 19 WITH 3 MINERS AT TIME 82.000

MINER 69 DEAD AT TIME 82.100
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER 70 DEAD AT TIME 82.100
ON BRANCH 20
AT DISTANCE 6.600
FROM NODE 19

MINER 71 DEAD AT TIME 82.100
ON BRANCH 20

MINE C SIMULATION - CASE 8

TOTAL MINERS IN THE MINE	=	133
TOTAL MINERS EVACUATED	=	76
TOTAL MINERS LOST	=	57
EVACUATION TIME	=	83.453 MINUTES

DELAY IN STENCH ACTIVATION	=	5.000 MINUTES
DELAY IN NOTIFYING LAST MINER AFTER STENCH ACTIVATION	=	3.850 MINUTES
TOTAL MINERS NOTIFIED BY STENCH	=	127
TOTAL MINERS NOTIFIED BY SMOKE	=	5

TOTAL MINERS EXPOSED TO SMOKE	=	110
AVERAGE SMOKE EXPOSURE (FOR TOTAL NUMBER OF MINERS)	=	43.974 MINUTES
AVERAGE SMOKE EXPOSURE (FOR MINERS EXPOSED TO SMOKE)	=	53.169 MINUTES
MAXIMUM INDIVIDUAL SMOKE EXPOSURE	=	63.900 MINUTES
MAN MINUTES OF SMOKE EXPOSURE	=	5848.600

MINERS EVACUATED VS TIME
HAS BEEN COMPLETED USING INTEGRATED SOFTWARE SYSTEMS CORP. DISSPLA, CDC6600 DATACENTER VERSION 1.

DATA FOR PLOT

NO. OF CURVES DRAWN 1

HORIZ. AXIS LENGTH 5.0 INS.

VERT. AXIS LENGTH 7.0 INS.

HORIZ. ORIGIN .0 VERT. ORIGIN .0

HORIZ. AXIS LINEAR

STEP SIZE 2.6000E+01 UNITS/INCH

VERT. AXIS LINEAR

STEP SIZE 3.0000E+01 UNITS/INCH

.....
. LOCATION OF CURRENT PHYSICAL ORIGIN .

. X= 2.00 Y= 1.69 INCHES .

. FROM LEFT LOWER CORNER OF PAGE .

.....

DATA FOR PLOT

NO. OF CURVES DRAWN 5

HORIZ. AXIS LENGTH 5.0 INS.

VERT. AXIS LENGTH 7.0 INS.

HORIZ. ORIGIN .0 VERT. ORIGIN-3.1200E+03

HORIZ. AXIS LINEAR

STEP SIZE 2.6000E+01 UNITS/INCH

VERT. AXIS LINEAR

STEP SIZE 4.4571E+02 UNITS/INCH

.....
• LOCATION OF CURRENT PHYSICAL ORIGIN •
• X= 2.00 Y= 1.69 INCHES •
• FROM LEFT LOWER CORNER OF PAGE •
.....

HOIST NO.2

HAS BEEN COMPLETED USING INTEGRATED SOFTWARE SYSTEMS CORP. DISSPLA, CDC6600 DATACENTER VERSION 1.

DATA FOR PLOT

NO. OF CURVES DRAWN 6

HORIZ. AXIS LENGTH 5.1 INS.

VERT. AXIS LENGTH 7.0 INS.

HORIZ. ORIGIN .0 VERT. ORIGIN-3.1200E+03

HORIZ. AXIS LINEAR

STEP SIZE 2.6000E+01 UNITS/INCH

VERT. AXIS LINEAR

STEP SIZE 4.4571E+02 UNITS/INCH

.....
 . LOCATION OF CURRENT PHYSICAL ORIGIN .
 . X= 2.00 Y= 1.69 INCHES .
 . FROM LEFT LOWER CORNER OF PAGE .

***** DISSPLA INTERMEDIATE PLOT FILE POSTPROCESSOR *****

FILE NAME OF INTERMEDIATE PLOT FILE PLTFILE (DEFAULT)

FILE NAME OF OUTPUT TAPE FOR PLOTTER PLOT (DEFAULT)

NO POSTPROCESSOR CONTROL DIRECTIVES.

THE INTERMEDIATE PLOT FILE WAS GENERATED BY RUN W1ABA40 AT 03/30/76 09.21
ALL PLOTS HAVE BEEN WRITTEN ONTO THE PLOTTAPE

..... END OF POSTPROCESSOR

09.19.13.5.WIABA40
 09.19.13.IP 000052 INPUT UNITS USED.
 09.19.13.\$SEQUENCE,1AB.
 09.19.10.\$CHARGE,31691 -950.
 09.19.10.FIRE,CM130000,F200,IP1,P4.
 09.19.12.RFL,120000.
 09.19.13.CM 130000 CM CELLS USED.
 09.19.13.CP 000000.038 CP SEC. JSED.
 09.19.13.IO 000000.600 IO SEC. USED.
 09.19.13.SS 000000.244 SYSTEM SEC. JSED.
 09.19.13.MAP(PART)
 09.19.13.RUN,S.
 09.19.13.FILE OPENED - OUTPUT
 09.19.13.FILE OPENED - LGO
 09.19.27.ATTACH,LFN,DISSPLA.
 09.19.27.SA- CYCLE 01, DISSPLA
 09.19.27.FILE ATTACHED
 09.19.27.COPYLIB,GO,LGO,LFN.
 09.19.28.FILE OPENED - GO
 09.19.29.FILE OPENED - RANSCR
 09.20.12.FILE OPENED - LIBIN3
 09.20.12.FILE OPENED - LIBIN4
 09.20.12.FILE OPENED - LIBIN5
 09.20.13.FILE OPENED - LIBIN6
 09.20.13.CM 120000 CM CELLS USED.
 09.20.13.CP 000009.813 CP SEC. USED.
 09.20.13.IO 000085.000 IO SEC. USED.
 09.20.13.SS 000036.394 SYSTEM SEC. JSED.
 09.20.22.CM 051600 CM CELLS USED.
 09.20.22.CP 000011.087 CP SEC. USED.
 09.20.22.IO 000100.100 IO SEC. USED.
 09.20.22.SS 000040.130 SYSTEM SEC. JSED.
 09.20.22.END COPYLIB
 09.20.22.REWIND,G3.
 09.20.22.RETURN,LFN.
 09.20.22.RFL,130000.
 09.20.22.CM 120000 CM CELLS USED.
 09.20.22.CP 000011.187 CP SEC. JSED.
 09.20.22.IO 000100.700 IO SEC. JSED.
 09.20.22.SS 000040.417 SYSTEM SEC. JSED.
 09.20.22.GO.
 09.21.32.BEGIN OF DISSPLA PLOT GENERATION.
 09.21.32.DISSPLA INTERMEDIATE PLOT FILE IS
 09.21.32. ...PLTFILE...
 09.21.37.FILE OPENED - PLTFILE
 09.21.41.END FIRE
 09.21.41.\$SC DSPL **4565 5762
 09.21.41. 5914 DISSPLA VECTORS GENERATED.
 09.21.41. (
 09.21.41.END OF DISSPLA PLOT GENERATION.
 09.21.41.ATTACH,PLOTTER,DISSPLAPLOTTER.
 09.21.41.SA- CYCLE 01, DISSPLAPLOTTER
 09.21.41.FILE ATTACHED
 09.21.41.REQUEST,PLOT,HI. (RING,NL,I=PLOT)
 09.24.02. VSNPLT124
 09.24.02.INFORM(PLOT,EWA*A)
 09.24.03.FILE OPENED - INFILE
 09.24.03.OP 000004 STORAGE DATA BLOCKS ON FILE INFILE
 09.24.04.EXT 000009 SDB,CY01 INFORMS_IPFILE
 09.24.04.FILE OPENED - PFNFILE
 09.24.04.SET(0) * *
 09.24.04.PLOTTER.

09.24.07.CM 130000 CM CELLS USED.
09.24.07.CP 000052.075 CP SEC. USED.
09.24.07.IO 000112.100 IO SEC. USED.
09.24.07.SS 000095.223 SYSTEM SEC. USED.
09.24.07.MT42 ASSIGNED TO PLOT
09.25.00. VSNPLT124
09.25.10. MT 42 VSN IS PLT124
09.25.25.CM 030400 CM CELLS USED.
09.25.25.CP 000054.832 CP SEC. USED.
09.25.25.IO 000136.838 IO SEC. USED.
09.25.25.SS 000100.347 SYSTEM SEC. USED.
09.25.25.END QQPOST
09.25.25.MT 42 BLKS WRITTEN- 000122
09.25.25.IP 000052 STORAGE DATA BLOCKS ON FILE INPUT
09.25.25.OP 000090 STORAGE DATA BLOCKS ON FILE OUTPUT
09.25.25.CM 130000 CM CELLS USED.
09.25.25.CP 000054.833 CP SEC. USED.
09.25.25.IO 000137.285 IO SEC. USED.
09.25.25.SS 000100.501 SYSTEM SEC. USED.
09.25.25.AC - END OF JOB.



B.6 Listing

The following is a listing of the Mine Evacuation Simulation Program.

09.24.07.CM 130000 CM CELLS USED.
09.24.07.CP 000052.075 CP SEC. JSED.
09.24.07.IO 000112.100 IO SEC. JSED.
09.24.07.SS 000095.223 SYSTEM SEC. JSED.
09.24.07.MT 42 ASSIGNED TO PLOT
09.25.00. VSNPLT124
09.25.10. MT 42 VSN IS PLT124
09.25.25.CM 030400 CM CELLS USED.
09.25.25.CP 000054.832 CP SEC. JSED.
09.25.25.IO 000136.838 IO SEC. JSED.
09.25.25.SS 000100.347 SYSTEM SEC. JSED.
09.25.25.END QQPOST
09.25.25.MT 42 BLKS WRITTEN- 000122
09.25.25.IP 000052 STORAGE DATA BLOCKS ON FILE INPUT
09.25.25.OP 000090 STORAGE DATA BLOCKS ON FILE OUTPUT
09.25.25.CM 130000 CM CELLS USED.
09.25.25.CP 000054.833 CP SEC. USED.
09.25.25.IO 000137.285 IO SEC. JSED.
09.25.25.SS 000100.501 SYSTEM SEC. JSED.
09.25.25.AC - END OF JOB.

PROGRAM FIRE(INPUT,OUTPUT,TAPE5=INPUT,TAPE6=OUTPUT)

C*****

C MNE EVACUATION SIMULATION PROGRAM*****

C*****

C DEVELOPED AT FOSTER MILLER ASSOCIATES, WALTHAM ,MASSACHUSETTS

C BY ASHOK B. BOGHANI TEL.(617)890 3200

C

C

C

```

000003 COMMON/ICOUNT/ICOUNT
000003 COMMON/CMINER/JM(200),XM(200),KM(200),VELM(200),IMINER(200),
1NMT(200),MDE(200),KMAX,MSAFE,MDEAD,TD4(200),KGHOST,KNOTF(200)
2,TEVAC
000003 COMMON/CBRN/I3(200),JB(200),ALB(200),V3(200),IMAX
000003 COMMON/CNODE/IN(200),JN(200),KN(200),LN(200),MN(200),NN(200),
1MNP(200),JMAX,MN2(200),NN2(200),TSWITCH
000003 COMMON/CHOIST/MH(10),LH(10,30),IH(10),VELNH(10),TDELAY(10),JH(10),
1TSTAR(10),NSTAR(10),TMOVE(10),TDEL(10),MINH(10,100),IHOIST(10),
2TWAIT(10),TUP(10),XHST(10),LMAX,XHSTI(10),THSCH(10),TDHD(10),
3THSRH(10),NOPT(10),NODFI(10),IFORCE(10),TDELS(10),TDELFI(10)
4,IOPT(10),MH1(10),MH2(10),XHSTIN(10)
000003 COMMON/TIME/T,TIME,FTIME
000003 COMMON/I0/IWT,IRD,IERROR
000003 COMMON/XYPLT/NPLTM,NPLT(10),PLT(10,500),JPL,TPLSTP,TPLSTR,LIMP,NXT
1,IXT
000003 COMMON/LEV/LEVN(30),LEVA(30,5),XLEP(10,20),LLEP(10,20),XXP(10,40),
1XYP(10,40),INL(10),INX(10),MMAX,XHMAX
000003 COMMON/SMCO/IBFIR,XBFIR,ISCOB(200),XSMOK(200),VENB(200),IMINS(200)
000003 COMMON/SELFR/TSELR(200),TSRMAX
000003 COMMON/DOUB/IDISC,LSLBR,MSLAV(10),MALEV(10),ISLAVE,IMAST,XMAST,
1 MANOO,IFORCD
000003 COMMON/WARN/IBSTN,XBSTN,ISTNB(200),XSTN(200),IMINT(200),VENO(200)
1,TSTEN,TENOT,MNSTEN,MNSMOK
000003 COMMON/TITLE/TITL(8)
000003 DIMENSION XPLOI(1024)
    
```

C*****

C INITIALIZATION

C

```

000003 ICOUNT=1
000004 IWT=6
000005 IRD=5
000006 LIMP=500
000007 IERROR=0
000010 TPAT=10.
000012 TPAS=60.
000013 IDISC=0
000014 ISLAVE=0
000015 IMAST=0
000016 IFORCD=0
000017 INSTRCT=1
    
```

C

C CALL INPUT OUTPUT SUBROUTINE ,PROGIO

```

000020 CALL PROGIO
    
```

C

FIRE

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```
000021 KGHST=KMAX
000023 MSAFE=0
000024 MDEAD=0
000025 XHMAX=0.
000026 TEVAC=0.
000027 TOTSMO=0.
000030 MNSTEN=0
000031 MNSMOK=0
000032 NMSMO=0
000033 TMAXSMO=0.
000034 TENOT=0.
000035 AVSMO=0.
000036 BVSMO=0.

C
000037 DO 60 I=1,IMAX
000040 ISCOR(I)=0
000041 XSMOK(I)=0.
000042 ISTN3(I)=0
000043 XSTN(I)=0.0
000044 VENCI=VENC(I)
000046 IF (ABS(VENCI).LE.0.0001)VENC(I)=VENB(I)
000053 60 CONTINUE

C
000056 DO 50 J=1,JMAX
000057 MNP(J)=0
000060 50 CONTINUE

C
000062 DO 20 K=1,KMAX
000064 NMT(K)=0
000065 IMINER(K)=2
000067 MJE(K)=0
000070 IMINS(K)=0
000071 IMINT(K)=0
000072 TSEFR(K)=0.
000073 KNOTF(K)=0
000074 20 CONTINUE
000076 KNOTF(KMAX)=1

C
000077 DO 10 L=1,LMAX
000101 JH(L)=0
000102 TDEL(L)=0.
000103 TWAIT(L)=0.
000104 XHSTIN(L)=0.0
000105 XHST(L)=0.
000106 IDPT(L)=0
000107 DO 11 LP=1,20
000111 11 LLEP(L,LP)=0
000116 INL(L)=1
000117 INX(L)=1
000121 IFORCE(L)=0
000122 THSRH(L)=XHSTI(L)/VELNH(L)
000124 TDHD(L)=XHSTI(L)/VELNH(L)+THSCH(L)
000127 XHST(L)=XHSTI(L)
000130 IF (NOPT(L).NE.3)GO TO 51
000132 MH2(L)=0
```

FIRE

```

000133      MH1(L)=MH(L)
000135      INDEX=0
000136      MHILI=MH(L)
000137      DO 52 LL=1,MHILI
000141      IF(INDEX.EQ.1)GO TO 52
000143      IF(LH(L,LL).EQ.NODFI(L))INDEX=1
000150      MH2(L)=MH2(L)+1
000152      52 CONTINUE
000155      51 CONTINUE
000155      MHILI=MH(L)
000157      NOODL=LH(L,MHILI)
000162      IF(XHST(L).LE.1.)CALL LEVEL(NOODL,L)
000167      10 CONTINUE

```

C
C

C FIRE AND STENCH SYSTEM DATA REDUCTION

```

000172      IF(IBFIR.EQ.0)GO TO 62
000173      ISCOB(IBFIR)=1
000174      XSMOK(IBFIR)=X3FIR
000176      62 CONTINUE
000176      IF(IBSTN.EQ.0)GO TO 61
000177      ISTNB(IBSTN)=1
000201      XSTN(IBSTN)=X3STN
000202      61 CONTINUE

```

C

C IF NO STENCH OR FIRE ,ASSUME MINERS NOTIFIED AT TIME T=0.

```

000202      IF(IBFIR.NE.0.OR.IBSTN.NE.0)GO TO 65
000211      DO 65 K=1,KMAX
000213      66 KNOTF(K)=1
000217      65 CONTINUE

```

C

C DETERMINE MASTER NODE (DOUBLE DRUM HOIST)

```

000217      IF(ISLAVE.EQ.0)GO TO 13
000220      DO 12 M=1,MMAX
000222      IF(MALEV(ISLAVE).EQ.LEVN(M))GO TO 14
000225      12 CONTINUE
000227      14 DO 15 MM=1,5
000231      MHST=MH(IMAST)
000233      DO 15 LL=1,MHST
000235      IF(LH(IMAST,LL).EQ.LEVA(M,MM))GO TO 15
000243      15 CONTINUE
000247      16 MANOD=LEVA(M,MM)
000253      13 CONTINUE

```

C

C *****

C

DYNAMIC SIMULATION

C

```

000253      T=0.
000254      IXT=0
000255      JXT=1
000256      30 CALL MINEF
000257      CALL HOIST
000260      CALL SMOKE
000261      IF(T.GT.TSTEN)CALL STENCH
000265      IF(IERROR.EQ.1)GO TO 200

```

FIRE

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```

C
C SWITCH MINER INSTRUCTION AFTER T=TSWITCH
000267     IF(T.LT.TSWITCH)GO TO 304
000272     IF(INSTRCT.EQ.0)GO TO 304
000273     DO 305 J=1,JMAX
000274     IF(MN2(J).EQ.0)GO TO 306
000275     MN(J)=MN2(J)
000277     306 IF(NN2(J).EQ.0)GO TO 305
000301     NN(J)=NN2(J)
000302     305 CONTINUE
000305     INSTRCT=0
000306     304 CONTINUE

C
C STORE VARBS FOR PLOT
000306     IF(NPLTM)301,300,301
000307     301 IF(T .LT.TPLSTR) GO TO 300
000312     IF(T .GT.TPLSTP) GO TO 300
000315     IT=JXT-NXT
000317     IF(IT)302,303,302
000320     303 IXT=IXT+1
000322     CALL PSTOPE
000323     JXT=0
000324     302 JXT=JXT+1
000326     300 CONTINUE

C
000326     T=T+DTIME
000330     KTOTAL=MSAFE+4)DEAD

C
C DETERMINE IF THE HOISTMAN SHOULD LEAVE THE POST
000332     IF(INX(LMAX).EQ.1.AND.TWAIT(LMAX).GT.TPAS)IHOIST(LMAX)=1
000347     IF(INX(LMAX).EQ.1.AND.TWAIT(LMAX).GT.TPAS)TDM(KMAX)=0.9*T
000365     IF(INX(LMAX).GT.1.AND.TWAIT(LMAX).GT.TPAT)IHOIST(LMAX)=1
000403     IF(INX(LMAX).GT.1.AND.TWAIT(LMAX).GT.TPAT)TDM(KMAX)=0.9*T
000422     IF(TDELF(LMAX).GT.5000..AND.TDELS(LMAX).GT.5000..AND.IHOIST(LMAX)
000445     1.EQ.1)TDM(KMAX)=0.9*T
000445     IF(TDELF(LMAX).GT.5000..AND.T.GT.TDELS(LMAX).AND.IHOIST(LMAX)
000445     1.EQ.1)TDM(KMAX)=0.9*T

C
000470     IF(T.GE.FTIME)GO TO 40
000473     GO TO 30
000473     40 CONTINUE

C
C
000473     DO 41 K=1,KMAX
000475     IF(TSELFR(K).GT.TMAXSMO)TMAXSMO=TSELFR(K)
000501     IF(TSELFR(K).GT.0.001)NMSMO=NMSMO+1
000506     41 TOTSMO=TOTSMO+TSELFR(K)
000513     AVSMO=TOTSMO/FLOAT(KMAX)
000514     IF(NMSMO.GT.0)BVSMO=TOTSMO/FLOAT(NMSMO)
000520     TENOT=TENOT-TSTEN
000522     WRITE(IWT,42)
000526     WRITE(IWT,71)(TITL(K),K=1,8)
000540     WRITE(IWT,43)KMAX
000546     WRITE(IWT,44)MSAFE
000554     WRITE(IWT,45)4)DEAD

```

FIRE

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```
000562 WRITE(IWT,46)TEVAC
000570 WRITE(IWT,72)
000574 WRITE(IWT,73)TSTEN
000602 WRITE(IWT,74)TENOT
000610 WRITE(IWT,75)MNSTEN
000616 WRITE(IWT,76)MNSMOK
000624 WRITE(IWT,72)
000630 WRITE(IWT,77)MNSMO
000636 WRITE(IWT,78)AVSMO
000644 WRITE(IWT,79)BVSMO
000652 WRITE(IWT,80)MAYSMO
000660 WRITE(IWT,81)TOTSMO
```

C*****

C PLOTTING SECTION

C

```
000666 IF(NPLTM) 101,200,101
000667 101 JPL=IXT
000671 DO 150 IPLN=1,NPLTM
000672 CALL VPLOTS(IP,N)
000673 CALL ENDPL(IPLN)
000675 150 CONTINUE
000700 200 CONTINUE
000700 42 FORMAT(1H1,////////)
000700 43 FORMAT(30X,*TOTAL MINERS IN THE MINE = *,I10)
000700 44 FORMAT(30X,*TOTAL MINERS EVACUATED = *,I10)
000700 45 FORMAT(30X,*TOTAL MINERS LOST = *,I10)
000700 46 FORMAT(30X,*EVACUATION TIME = *,
1F10.3,* MINUTES*)
000700 71 FORMAT(35X,8A13////)
000700 72 FORMAT(//)
000700 73 FORMAT(30X,*DELAY IN STENCH ACTIVATION = *,
1F10.3,* MINUTES*)
000700 74 FORMAT(30X,*DELAY IN NOTIFYING LAST */30X,*MINER AFTER STENCH A
1CTIVATION *,F10.3,* MINUTES*)
000700 75 FORMAT(30X,*TOTAL MINERS NOTIFIED BY STENCH = *,I10)
000700 76 FORMAT(30X,*TOTAL MINERS NOTIFIED BY SMOKE = *,I10)
000700 77 FORMAT(30X,*TOTAL MINERS EXPOSED TO SMOKE = *,I10)
000700 78 FORMAT(30X,*AVERAGE SMOKE EXPOSURE*/30X,
1 *(FOR TOTAL NUMBER OF MINERS) = *,
1F10.3,* MINUTES*)
000700 79 FORMAT(30X,*AVERAGE SMOKE EXPOSURE*/30X,
1 *(FOR MINERS EXPOSED TO SMOKE) = *,
1F10.3,* MINUTES*)
000700 80 FORMAT(30X,*MAXIMUM INDIVIDUAL SMOKE EXPOSURE = *,
1F10.3,* MINUTES*)
000700 81 FORMAT(30X,*MAX MINUTES OF SMOKE EXPOSURE = *,F10.3)
000700 END
```

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```

SUBROUTINE PROG10
C DATA ACQUISITION SUBROUTINE
000002 COMMON/CHINER/JM(200),XM(200),KM(200),VELM(200),IMINER(200),
1NNT(200),MOE(200),KMAX,MSAFE,MOEAD,TOM(200),KGHOST,KNOTF(200)
2,TEVAC
000002 COMMON/CBRN/IB(200),JB(200),ALB(200),VB(200),IMAX
000002 COMMON/CNODE/IV(200),JN(200),KN(200),LN(200),MN(200),NN(200),
1MNP(200),JMAX,MN2(200),NN2(200),TSWITCH
000002 COMMON/CHOIST/MH(10),LH(10,30),IH(10),VELNH(10),TDELAY(10),JH(10),
1TSTAR(10),NSTAR(10),TMOVE(10),TDEL(10),MINH(10,100),IHOIST(10),
2TWAIT(10),TUP(10),XHST(10),LMAX,XHSTI(10),THSCH(10),TDHD(10),
3THSRH(10),NOPT(10),NOOFI(10),IFORGE(10),TDELS(10),TDELF(10)
4,IOPT(10),MH1(10),MH2(10),XHSTIN(10)
000002 COMMON/IO/IWT,IRD,IERROR
000002 COMMON/TIME/T,TIME,FTIME
000002 COMMON/XYPLT/NPLTM,NPLT(10),PLT(10,500),JPL,TPLSTP,TPLSTR,LIMP,NXT
1,IXT
000002 COMMON/LEV/LEVN(30),LEVA(30,5),XLEP(10,20),LLEP(10,20),XYP(10,40),
1XYP(10,40),INL(10),INX(10),MMAX,XHMAX
000002 COMMON/SMCO/IBFIR,XBFIR,ISCOB(200),XS4CK(200),VENB(200),IMINS(200)
000002 COMMON/SELFR/ISELFR(200),TSRMAX
000002 COMMON/DOUB/IDISC,LSLBR,MSLAV(10),MALEV(10),ISLAVE,IMAST,XMAST,
1MANOD,IFORCD
000002 COMMON/WARN/IBSTN,XBSTN,ISTNB(200),XSTN(200),IMINT(200),VENC(200)
1,TSTEN,TENOT,MNSTEN,MNSMOK
000002 COMMON/TITLE/TITL(8)
000002 DIMENSION JPLT(50)
C READING SECTION
000002 READ(IRD,10) (TITL(K),K=1,8)
000014 READ(IRD,1) IMAX
000022 DO 2 I=1,IMAX
000024 2 READ(IRD,3) II,IB(I),JB(I),ALB(I),VB(I),VENB(I),VENC(I)
000050 READ(IRD,11) JMAX,TSWITCH
000057 IF(TSWITCH.LT.0.1)TSWITCH=10000.
000063 DO 4 J=1,JMAX
000065 4 READ(IRD,7) II,MN(J),NN(J),IN(J),JN(J),KN(J),LN(J),MN2(J),NN2(J)
000115 READ(IRD,1) KMAX
000122 DO 5 K=1,KMAX
000124 5 READ(IRD,6) II,JM(K),XM(K),KM(K),TOM(K)
000144 READ(IRD,1) LMAX
000151 DO 8 L=1,LMAX
000153 READ(IRD,53) II,MH(L),IH(L),VELNH(L),TDELAY(L),IHOIST(L),MSLAV(L)
1,MALEV(L)
000176 READ(IRD,54)XHSTI(L),THSCH(L),NOPT(L),NOOFI(L),TDELS(L),TDELF(L)
000216 IF(MSLAV(L).NE.0)ISLAVE=L
000221 IF(MSLAV(L).NE.0)IMAST=MSLAV(ISLAVE)
000225 IF(TDELS(L).LT.0.001)TDELS(L)=10000.
000232 IF(TDELF(L).LT.0.001)TDELF(L)=10000.
000236 MHILI=MH(L)
000240 READ(IRD,10) (LH(L,LL),LL=1,MHILI)
000253 3 CONTINUE
000256 READ(IRD,1) MMAX
000263 DO 20 M=1,MMAX
000265 READ(IRD,21)LEVN(M),(LEVA(M,MH),MH=1,5)

```

```

000301      20 CONTINUE
000304      READ(IRD,30)IB=IR,XBFIR
000313      READ(IRD,35)IBSTN,XBSTN,TSTEN
000325      READ(IRD,31)TSRMAX
000333      READ(IRD,11)DTIME,FTIME
000343      READ(5,9071)(JPLT(K),K=1,40),TPLSTR,TPLSTP
C INPUT PLOT INFORMATION
000361      I=1
000362      DO 61 K=1,40
000364          IF(JPLT(K))62,51,62
000365      62 NPLT(I)=K
000367          I=I+1
000371      61 CONTINUE
000373          NPLTM=I-1
000375          JREG=IFIX((TPLSTP-TPLSTR)/DTIME)
000401          NXT=JREG/LIMP+1
C      WRITING SECTION
000405          WRITE(IWT,100)
000410          WRITE(IWT,103)
000414          WRITE(IWT,102)(TITL(K),K=1,8)
000426          WRITE(IWT,100)
000432          WRITE(IWT,103)
000436          WRITE(IWT,104)
000442          WRITE(IWT,70)
000446          WRITE(IWT,200)
000452          DO 90 I=1,IMAX
000454          WRITE(IWT,80)I,IB(I),JB(I),ALB(I),VB(I),VENB(I),VENC(I)
000475      90 CONTINUE
000500          WRITE(IWT,71)
000503          WRITE(IWT,107)TSWITCH
000511          WRITE(IWT,201)
000515          DO 91 J=1,JMAX
000517          WRITE(IWT,81)J,MN(J),NN(J),IN(J),JN(J),KN(J),LN(J),MN2(J),NN2(J)
000544      91 CONTINUE
000547          WRITE(IWT,72)
000552          WRITE(IWT,202)
000556          DO 92 K=1,KMAX
000560          WRITE(IWT,82)K,JM(K),XM(K),KM(K),TDM(K)
000575      92 CONTINUE
000600          WRITE(IWT,73)
000603          WRITE(IWT,203)
000607          WRITE(IWT,204)
000613          WRITE(IWT,205)
000617          DO 93 L=1,LMAX
000621          WRITE(IWT,83)L,MH(L),IH(L),VELNH(L),TDELAY(L)
1, IHOIST(L),MSLAV(L),MALEV(L)
000644          WRITE(IWT,832)XHSTI(L),THSCH(L),NOPT(L),NOPTI(L),TDELS(L),TDELF(L)
000664          MHILI=MH(L)
000666          WRITE(IWT,831)(LH(L,LL),LL=1,MHILI)
000702          WRITE(IWT,105)
000706      93 CONTINUE
000711          WRITE(IWT,74)
000714          WRITE(IWT,206)
000720          DO 94 M=1,MMAX
000722          WRITE(IWT,84)LEVN(M),(LEVA(M,MM),MM=1,5)

```

```

000736 94 CONTINUE
000741 WRITE(IWT,75)
000744 WRITE(IWT,207)
000750 WRITE(IWT,85)I3FIR,XBFIR
000760 WRITE(IWT,95)
000764 WRITE(IWT,208)
000770 WRITE(IWT,851)IBSTN,XBSTN,TSTEN
001002 WRITE(IWT,76)
001006 WRITE(IWT,209)
001012 WRITE(IWT,86)TSRMAX
001020 WRITE(IWT,100)
001024 WRITE(IWT,103)
001030 WRITE(IWT,106)
001034 WRITE(IWT,100)
001040 WRITE(IWT,301)
001044 1 FORMAT(I10)
001044 3 FORMAT(3I10,4F10.3)
001044 6 FORMAT(2I10,F10.3,I10,F10.3)
001044 7 FORMAT(7I10,2I5)
001044 10 FORMAT(8I10)
001044 11 FORMAT(2F10.3)
001044 21 FORMAT(6I10)
001044 30 FORMAT(I10,F10.3)
001044 31 FJRMAT(F10.3)
001044 35 FORMAT(I10,2F10.3)
001044 53 FORMAT(3I10,2F10.3,3I10)
001044 54 FORMAT(2F10.3,2I10,2F10.3)
001044 70 FORMAT(10X,*BRANCHES*///)
001044 71 FORMAT(10X,*NOJES*///)
001044 72 FORMAT(10X,*MINERS*///)
001044 73 FORMAT(10X,*HOISTS*///)
001044 74 FORMAT(10X,*MINE LEVELS*///)
001044 75 FORMAT(10X,*FIRE POSITION*///)
001044 76 FORMAT(10X,*SELF RESCUER*///)
001044 80 FORMAT(10X,3I10,4F10.3)
001044 81 FJRMAT(10X,7I10,2I5)
001044 82 FORMAT(10X,2I10,F10.3,I10,F10.3)
001044 83 FORMAT(10X,3I10,2F10.3,3I10)
001044 84 FORMAT(10X,6I10)
001044 85 FORMAT(10X,I10,F10.3)
001044 86 FORMAT(10X,F10.3)
001044 95 FORMAT(10X,*STENCH WARNING SYSTEM*///)
001044 100 FORMAT(1H1)
001044 101 FORMAT(8A10)
001044 102 FORMAT(30X,8A10///)
001044 103 FORMAT(//////////)
001044 104 FORMAT(50X,*INPUT DATA*////)
001044 105 FORMAT(//)
001044 106 FORMAT(50X,*OUTPUT DATA*////////)
001044 107 FORMAT(15X,*TSWITCH = *,F10.3)
001044 111 FORMAT(I10,F10.3)
001044 200 FORMAT(10X,* I IB(I) JB(I) ALB(I) VB(I) V
1END(I) VENC(I) */)
001044 201 FORMAT(10X,* J MN(J) NN(J) IN(J) ON(J)
1 KN(J) LN(J) MN2(J) NN2(J)*/)

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```
001044 202 FORMAT(10X,*          K          JM(K)   XM(K)      KM(K)   TDH(K)*//)
001044 203 FORMAT(10X,*          L          MH(L)   IH(L)   VELNH(L) TDELAY(L) IH
10IST(L) MSLAV(L) MALEV(L)*//)
001044 204 FORMAT(10X,* X4STI(L) THSCH(L)   NOPT(L)  NODFI(L) TDELS(L) TD
1ELF(L)*//)
001044 205 FORMAT(10X,*          LH(L,LL),LL=1,MH(L)...*//)
001044 206 FORMAT(10X,*          LEVN(M)   LEVA(M,MM),MM=1,5...*//)
001044 207 FORMAT(10X,*          IBFIR   XBFIR*)
001044 208 FORMAT(10X,*          IBSTN   XBSTN   TSTEN*)
001044 209 FORMAT(10X,*          TSRMAX*)
001044 301 FORMAT(30X,* CHRONOLOGICAL EVENTS*//)
001044 831 FORMAT(10X,8I10)
001044 832 FORMAT(10X,2F10.3,2I10,2F10.3)
001044 851 FORMAT(10X,I10,2F10.3)
001044 9071 FORMAT(40I1,2F10.3)
001044      RETURN
001045      END
```

```

SUBROUTINE HOIST
C HOIST PROPAGATION SUBROUTINE
000002 COMMON/ICOUNT/ICOUNT
000002 COMMON/CMINER/JM(200),XM(200),KM(200),VELM(200),IMINER(200),
1NMT(200),MDE(200),KMAX,MSAFE,MDEAD,TOM(200),KGHOST,KNOTF(200)
2,TEVAC
000002 COMMON/CBRN/IB(200),JB(200),ALB(200),VB(200),IMAX
000002 COMMON/CNODE/IN(200),JN(200),KN(200),LN(200),MN(200),NN(200),
1MNP(200),JMAX,MN2(200),NN2(200),TSWITCH
000002 COMMON/CHOIST/MH(10),LH(10,30),IH(10),VELNH(10),TDELAY(10),JH(10),
1TSTAR(10),NSTAR(10),TMOVE(10),TDEL(10),MINH(10,100),IHOIST(10),
2TWAIT(10),TUP(10),XHST(10),LMAX,XHSTI(10),THSCH(10),TDHD(10),
3THSRH(10),NOPT(10),MODFI(10),IFORCE(10),TDELS(10),TDELFI(10)
4,IOPT(10),MH1(10),MH2(10),XHSTIN(10)
000002 COMMON/IO/IWT,IRD,IERROR
000002 COMMON/TIME/T,DTIME,FTIME
000002 COMMON/LEV/LEVN(30),LEVA(30,5),XLEP(10,20),LLEP(10,20),XXP(10,40),
1XYP(10,40),INL(10),INX(10),MMAX,XHMAX
000002 COMMON/DOUB/IDISC,LSLBR,MSLAV(10),MALEV(10),ISLAVE,IMAST,XMAST,
1MANOD,IFORCD
000002 DIMENSION LGHOST(10)
000002 TPAR=7.
000004 DO 20 L=1,LMAX

C
C DELAY IN GETTING HOIST OPERATIONAL
000005 IF(T.LT.THSRH(L))GO TO 8
000010 IF(T.LT.TDHD(L))GO TO 9

C
C THE STATUS OF HOIST (IHOIST(L)) DETERMINES WHICH
C PART OF THE SUBROUTINE WILL BE EXECUTED
000012 LHOST=IHOIST(L)
000013 GO TO (1,2,3,4,5,6,7,7,7,7),LHOST
C*****
C...1 HOIST INOPERATIVE
C
000030 1 XX=0.99*DTIME
000032 IF(T.LT.XX)WRITE(IWT,11)L
000042 11 FORMAT(5X,'HOIST NO. ',5X,I2,' INOPERATIVE*')

C
C HOIST INOPERATIVE ONLY FOR A LENGTH OF TIME
000042 IF(TOM(KMAX).LT.T.AND.L.EQ.LMAX)GO TO 20
000055 IF(T.GT.TDELFI(L))IHOIST(L)=2
000061 IF(T.GT.TDELFI(L))WRITE(IWT,12)L,T
000073 12 FORMAT(5X,'HOIST NO. ',I9,' BACK IN OPERATION AT TIME ',F10.3/)
000073 GO TO 20
C*****
C...2 HOIST WAITING AT TOP
C
000074 2 IF(TWAIT(L)-TDEL(L))22,21,21
000077 22 TWAIT(L)=TWAIT(L)+DTIME

C
C HOIST INOPERATIVE FOR A LENGTH OF TIME
000102 IF(T.GT.TDELS(L).AND.T.LT.TDELFI(L))IHOIST(L)=1
000118 IF(T.GT.TDELS(L).AND.T.LT.TDELFI(L))WRITE(IWT,205)L,T

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000136 255 FORMAT(5X, *HOIST NO. *,I5,* STOPS OPERATING AT TIME*,F10.3/)
000136 IF(T.GT.TDELS(L).AND .T.LT.TDELF(L))GO TO 20
C
000150 YY=2.*DTIME
000152 IF(TWAIT(L).GT.YY)GO TO 20
000156 NSTAR(L)=0
000157 IF(IOPT(L).NE.1)GO TO 281
000161 IF(XHST(L).GT.XHSTIN(L))XHSTIN(L)=XHST(L)
000165 XHST(L)=XHSTIN(L)
000167 GO TO 282
000170 281 XHST(L)=0.
000172 282 CONTINUE
000172 TMOVE(L)=0.
000174 JH(L)=0
000175 LGHOST(L)=0
000176 IHILI=IH(L)
000177 DO 28 I=1,IHILI
000201 28 MINH(L,I)=0
000206 GO TO 20
C
C FORCE HOIST TO FIRE NODE IF OPTION2 IS USED
000207 21 IF(NOPT(L).NE.2)GO TO 221
000212 NODFIL=NODFI(L)
000213 IF(MNP(NODFIL).NE.0)NSTAR(L)=NODFIL
000215 IF(MNP(NODFIL).NE.0)IFORC(L)=1
000221 IF(MNP(NODFIL).NE.0)GO TO 211
C
C FORCE MAIN HOIST TO MASTER LEVEL, IF MINERS IN CLUTCHED HOIST
000223 221 IF(ISLAVE.EQ.0)GO TO 212
000224 IF(L.EQ.IMAST.AND.JH(ISLAVE).NE.0)NSTAR(L)=MANOD
000235 IF(L.EQ.IMAST.AND.JH(ISLAVE).NE.0)IFORC(L)=1
000246 IF(L.EQ.IMAST.AND.JH(ISLAVE).NE.0)GO TO 211
C
C SEARCH FOR NODE WHERE MINERS ARE WAITING , I.E. MNP NONZERO
000256 212 LL=1
000257 TWAIT(L)=TWAIT(L)+DTIME
C
C DETERMINE IF HOIST SHOULD STOP THE INTERMEDIATE HAUL,
C IF OPTION 3 IS USED
000262 IF(IOPT(L).EQ.1.AND.TWAIT(L).GT.TPAR)GO TO 231
000274 GO TO 232
000275 231 IOPT(L)=2
000277 MH(L)=MH1(L)
000301 NSTAR(L)=NODFI(L)
000302 TWAIT(L)=0.
000303 TMOVE(L)=0.
000304 IHOIST(L)=4
000306 GO TO 4
000306 232 CONTINUE
C
C
000309 25 IF(LL.GE.MH(L))GO TO 20
000311 MMM=LH(L,LL)
000314 IF(IFORC.EQ.1.AND.MMM.EQ.MANOD.AND.L.EQ.IMAST)GO TO 20
000331 IF(MNP(MMM))27,27,26

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HOIST

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000333 27 LL=LL+1
000335 GO TO 25
000335 26 IF(NSTAR(L).EQ.MMM)GO TO 20
C
000340 NSTAR(L)=MMM
000341 211 IHOIST(L)=3
000343 TTRAV=TMOVE(L)
000345 TMOVE(L)=0.
000346 NODEA=NSTAR(L)
000347 MHILI=MH(L)
000351 NODEB=LH(L,MHILI)
C CALCULATE TIME REQUIRED TO REACH TARGET NODE
000354 CALL TSTAR(L,NODEA,NODEB,TTRAV)
C
000357 GO TO 20
C*****
C...3 HOIST HEADING DOWN
C
000360 3 TMOVE(L)=TMOVE(L)+DTIME
000363 XHST(L)=XHST(L)+VELNH(L)*DTIME
000366 IF(TMOVE(L).LT.TSTAR(L).AND.IFORCE(L).EQ.1)GO TO 20
000400 IF(TMOVE(L).LT.TSTAR(L))GO TO 212
000403 TMOVE(L)=0.
000404 IHOIST(L)=4
000406 TWAIT(L)=0.
000407 GO TO 20
C*****
C...4 HOIST WAITING AT TARGET NODE
C
000407 4 XX=0.99*DTIME
000411 IF(TWAIT(L).GE.XX)GO TO 41
000414 IF(IFORCE(L).EQ.1)IFORCE(L)=0
000417 NODDL=NSTAR(L)
C
C DETERMINE IF INTERMEDIATE HAUL SHOULD COMMENCE,
C IF OPTION 3 IS USED
000421 IF(NOPT(L).EQ.3.AND.IOPT(L).EQ.0)GO TO 450
000430 GO TO 422
000431 450 MH2L=MH2(L)
000433 DO 423 LL=1,MH2L
000435 IF(NODDL.EQ.LH(L,LL))GO TO 424
000441 423 CONTINUE
000443 GO TO 422
000444 424 IOPT(L)=1
000446 MH(L)=MH2(L)
000450 IF(LL.NE.MH2L)GO TO 422
000452 IHOIST(L)=2
000453 TWAIT(L)=0.
000454 TDEL(L)=0.
000455 GO TO 20
000456 422 CONTINUE
C
C STORE INFORMATION OF THE STOP
000456 CALL LEVEL(NDDL,L)
000460 CALL XSTAR(L)
```

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C
C CLUTCHED(SLAVE) HOIST AT TOP LEVEL, IF MAIN (MASTER) HOIST IS AT
C MASTER LEVEL-MALEV(L)
000462 IF(ISLAVE.EQ.0)GO TO 421
000463 IF(NOODL.EQ.MANOD.AND.L.EQ.IMAST.AND.IHOIST(ISLAVE).EQ.8)
1IHOIST(ISLAVE)=10
000502 421 CONTINUE
C
000502 IF(XHMAX.LE.XHST(L))XHMAX=XHST(L)
000507 TDEL(L)=0.
000511 K=1
000512 43 IF(NMT(K).EQ.NSTAR(L).AND.IMINER(K).NE.1)GO TO 42
000523 44 IF(K.GE.KMAX)GO TO 41
000526 K=K+1
000527 GO TO 43
C
000530 C DISTINGUISH MINERS ALREADY IN HOIST
000533 42 IF (IMINER(K)-6) 46, 47, 46
000535 47 IMINER(K)=4
000536 K=K+1
GO TO 43
C
000537 46 TDEL(L)=TDELAY(L)/FLOAT(IH(L))+TDEL(L)
000543 JH(L)=JH(L)+1
000545 NSTARL=NSTAR(L)
000547 MNP(NSTARL)=MNP(NSTARL)-1
000551 JHILI=JH(L)
000553 MINH(L,JHILI)=<
000556 MDE(K)=2
000557 IF(JH(L).EQ.IH(L))GO TO 41
000561 GO TO 44
000562 41 TWAIT(L)=TWAIT(L)+DIME
000565 IF(TWAIT(L).LT.TDEL(L))GO TO 20
000567 IHOIST(L)=5
000571 TWAIT(L)=0.
000572 TUP(L)=0.
000573 IF(MINH(L,1).NE.0)GO TO 49
C
000574 C CREATE A GHOST IF THE LONE MINER DIES BEFORE HOIST ARRIVES
000575 KGHOST=KGHOST+1
000576 MINH(L,1)=KGHOST
000577 JH(L)=JH(L)+1
000600 MDE(KGHOST)=2
000602 NMT(KGHOST)=NSTAR(L)
000603 NMTK=NMT(KGHOST)
000605 NNNN=NN(NMTK)
000607 GO TO (481,482,483,484),NNNN
000616 481 JM(KGHOST)=IN(NMTK)
000621 GO TO 48
000621 482 JM(KGHOST)=JN(NMTK)
000624 GO TO 48
000624 483 JM(KGHOST)=KN(NMTK)
000627 GO TO 48
000627 484 JM(KGHOST)=LN(NMTK)
000632 48 JIMKI=JM(KGHOST)

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000634      XM(KGHOST)=0.
000635      KNOTF(KGHOST)=1
000637      KM(KGHOST)=1
000640      IF (IB (JIMKI).EQ.1.NMTK) KM(KGHOST)=0
000644      IF (L.EQ.IMAST) IDISC=1
000647      LGHOST(L)=LGHOST(L)+1
C
C
000651      49 JHILI=JH(L)
000653      DO 49 I=1,JHILI
000655      K=MINH(L,I)
000660      IMINER(K)=5
000662      IF (IOPT(L).EQ.1) IMINER(K)=8
000666      45 CONTINUE
000671      GO TO 20
C*****
C...5 HOIST HEADING TO TOP
C
000671      5 IF (JH(L).LT.IH(L)) GO TO 53
000674      52 TUP(L)=TUP(L)+DTIME
000677      XHST(L)=XHST(L)-VELNH(L)*DTIME
000702      MHILI=MH(L)
000704      K=MINH(L,1)
000705      IF (LH(L,MHILI).NE.NMT(K)) GO TO 20
000711      IHOIST(L)=2
000713      JHILI=JH(L)-LGHOST(L)
000715      WRITE (IWT,522) L,LH(L,MHILI),JHILI,T
000732      522 FORMAT (5X,'HOIST *,I5,* REACHES NODE *,I5,* WITH *,I5,* MINERS AT
          1TIME *,F10.3/)
          IF (ISLAVE.EQ.0) GO TO 521
          IF (L.EQ.IMAST.AND.IHOIST(ISLAVE).EQ.8) IHOIST(ISLAVE)=9
000745      521 CONTINUE
          TUP(L)=0.
          TWAIT(L)=0.
          TDEL(L)=TDELAY(L)*FLOAT (JH(L))/FLOAT (IH(L))
          JHILI=JH(L)
          DO 59 I=1,JHILI
          K=MINH(L,I)
          IF (IMINER(K).EQ.3) IMINER(K)=4
          NODFIL=NODFI(L)
          IF (IMINER(K).EQ.4) MNP(NODFIL)=MNP(NODFIL)+1
          IF (IMINER(K).NE.3.AND.IMINER(K).NE.4) IMINER(K)=2
          IF (IMINER(K).NE.3) MDE(K)=0
001014      59 CONTINUE
          GO TO 20
C
C LOOK FOR OTHER MINERS IF HOIST HAS ROOM WHILE GOING UP
001017      53 MFM=MINH(L,1)
          LL=0
          54 LL=LL+1
          IF (LL.GT.MH(L)) WRITE (IWT,55)
          IF (LL.GT.MH(L)) IERROR=1
          IF (LL.GT.MH(L)) RETURN
          55 FORMAT (10X'ERROR IN MINER SEARCH WHILE GOING UP ROUTINE*)
          IF (LH(L,LL).NE.NMT(MFM)) GO TO 54

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001046      LL=LL+1
001047      56 IF (LL.GE.MH(L)) GO TO 52
001052      MMM=LH(L,LL)
001055      IF (MNP(MMM)) 57, 58, 57
001056      58 LL=LL+1
001060      GO TO 56
001060      57 TMOVE(L)=0.
001062      NSTAR(L)=MMM
001063      IHOIST(L)=6

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C*****
C...6 HOIST HEADING JP TO A TARGET NODE
C

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001065      6 TMOVE(L)=TMOVE(L)+DTIME
001070      XHST(L)=XHST(L)-VELNH(L)*DTIME
001073      K=MINH(L,1)
001075      IF (NSTAR(L).NE.NMT(K)) GO TO 20
001077      TMOVE(L)=0.
001100      IHOIST(L)=4
001101      TWAIT(L)=0.
001102      JHILI=JH(L)
001104      DO 61 I=1,JHILI
001105      K=MINH(L,I)
001110      61 IMINER(K)=6
001114      GO TO 20

```

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C*****
C...7,8,9,10 CLUTCH(SLAVE) HOIST IN A DOUBLE DRUM
C

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001115      7 CALL DDRUM
001116      GO TO 20

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C
C

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001117      8 XHST(L)=XHST(L)-VELNH(L)*DTIME
001123      GO TO 20
001124      9 XHST(L)=0.0
001126      IF (ICOUNT.GT.1) GO TO 20
001131      MHILI=MH(L)
001132      NODDL=LH(L,MHILI)
001135      CALL LEVEL(NODD)L,L)
001137      ICOUNT=2
001140      20 CONTINUE

```

```

C
C

```

```

001143      RETURN
001143      END

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SUBROUTINE MINER
C MINER PROPAGATION SUBROUTINE
000002 COMMON/CMINER/JM(200),XM(200),KM(200),VELM(200),IMINER(200),
1NMT(200),MDE(200),KMAX,MSAFE,MDEAD,TDM(200),KGHOST,KNOTF(200)
2,TEVAC
000002 COMMON/CBRN/IB(200),JB(200),ALB(200),VB(200),IMAX
000002 COMMON/CNODE/IN(200),JN(200),KN(200),LN(200),MN(200),NN(200),
1MNP(200),JMAX,MN2(200),NN2(200),TSWITCH
000002 COMMON/CHOIST/MH(10),LH(10,30),IH(10),VELNH(10),TDELAY(10),JH(10),
1TSTAR(10),NSTAR(10),TMOVE(10),TDEL(10),MINH(10,100),IHOIST(10),
2TWAIT(10),TUP(10),XHST(10),LMAX,XHSTI(10),THSCH(10),TQHD(10),
3THSRH(10),NOPT(10),NODFI(10),IFORCE(10),TDELS(10),TDEL(10)
4,IOPT(10),MH1(10),MH2(10),XHSTIN(10)
000002 COMMON/IO/IWT,IRD,IERROR
000002 COMMON/TIME/T,OTIME,FTIME
000002 COMMON/LEV/LEVN(30),LEVA(30,5),XLEP(10,20),LLEP(10,20),XXP(10,40),
1XYP(10,40),INL(10),INX(10),MMAX,XHMAX
000002 COMMON/SMOQ/IBFIR,XBFIR,ISCOB(200),XS4OK(200),VENB(200),IMINS(200)
000002 COMMON/SELFR/TSELR(200),TSRMAX
000002 COMMON/WARN/IBSTN,XBSTN,ISTNB(200),XSTN(200),IMINT(200),VENO(200)
1,TSTEN,TENOT,MNSTEN,MNSMOK
000002 DO 20 K=1,KGHOST
C
C CHECK IF MINER NOTIFIED OF THE FIRE
000004 IF(KNOTF(K).EQ.1)GO TO 12
000006 CALL MSMOK(K)
000010 CALL MSTNCH(K)
000012 IF(IMINS(K).EQ.1.OR.IMINT(K).EQ.1)KNOTF(K)=1
000024 IF(IMINS(K).EQ.1)WRITE(IWT,13)K,T
000036 IF(IMINS(K).EQ.1)MNSMOK=MNSMOK+1
000042 IF(IMINT(K).EQ.1)WRITE(IWT,14)K,T
000053 IF(IMINT(K).EQ.1)TENOT=T
000057 IF(IMINT(K).EQ.1)MNSTEN=MNSTEN+1
000062 13 FORMAT(10X,*MINER *,I3,* NOTIFIED AT TIME*,F10.3,* BY SMOKE*)
000062 14 FORMAT(10X,*MINER *,I3,* NOTIFIED AT TIME*,F10.3,* BY STENCH*)
000062 IF(IMINS(K).EQ.1.OR.IMINT(K).EQ.1)TDM(K)=TDM(K)+T
000075 GO TO 20
000076 12 CONTINUE
C
C
C DELAY BEFORE MINER COMMENCES PROPAGATION
000076 IF(K.EQ.KMAX.AND.TDM(K).GE.T)GO TO 20
000111 IF(TDM(K).GE.T)GO TO 4
C
C STATUS OF THE MINER (IMINER(K)) DETERMINES WHICH PART
C OF THE SUBROUTINE WILL BE EXECUTED
000114 KMINER=IMINER(K)
000115 GO TO (1,2,3,4,2,2,7,2),KMINER
C*****
C...1 MINER DEAD
C
000130 1 JMIKI=JM(K)
000132 IJB=IB(JMIKI)
000134 IF(KM(K).EQ.1)IJB=JB(JMIKI)

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000140      IF(MDE(K).EQ.1)WRITE(IWT,11)K,T,JM(K),XM(K),IJB
000157      11 FORMAT(10X,*MINER*,I3,* DEAD AT TIME*,F10.3,/,15X,*ON BRANCH*,I3,/,
          1,15X,*AT DISTANCE*,F10.3,/,15X,*FROM NODE*,I3//)
000157      IF(MDE(K).EQ.1)MDEAD=MDEAD+1
000163      MDE(K)=0
000165      NMT(K)=0
000166      GO TO 20
C*****
C...2,5,6,8 MINER TRAVELLING
C  2  MINER WALKING
C  5,6 MINER RIDING HOIST
C  8  MINER IN INTERMEDIATE HAUL
C
000166      2 I=JM(K)
000170      VELM(K)=VB(I)
C
C DETERMINE IF MINER IN SMOKEY REGION
000172      CALL MSMOK(K)
C
000174      IF(IMINS(K).EQ.1.AND.IMINER(K).EQ.2)VELM(K)=0.5*VELM(K)
C
C MINER DIES IF SELF RESCUER USE EXCEEDS TIME LIMIT
000210      IF(IMINS(K).EQ.1)TSELFR(K)=TSELFR(K)+DTIME
000215      IF(TSELFR(K).GT.TSRMAX.AND.MDE(K).NE.2)IMINER(K)=1
000232      IF(TSELFR(K).GT.TSRMAX.AND.K.LE.KMAX.AND.MDE(K).NE.2)MDE(K)=1
C
000255      XM(K)=VELM(K)*DTIME+XM(K)
000261      XX=0.99*DTIME
000262      IF(T.LT.XX)XM(K)=XM(K)-VELM(K)*DTIME
000270      IF(IMINER(K).EQ.6)XM(K)=XM(K)-VELM(K)*DTIME
000276      IF(XM(K).LT.ALB(I))GO TO 20
000302      JMIKI=JM(K)
000303      NMT(K)=IB(JMIKI)
000305      IF(KM(K).EQ.0)NMT(K)=JB(JMIKI)
000310      NMTK=NMT(K)
000312      IF(MN(NMTK).EQ.2)GO TO 25
000314      NNNN=NN(NMTK)
C
C DECISION ON BRANCH TO TAKE AT A NODE
000316      GO TO (21,22,23,24),NNNN
000325      21 JM(K)=IN(NMTK)
000330      GO TO 26
000330      22 JH(K)=JN(NMTK)
000333      GO TO 26
000333      23 JK(K)=KN(NMTK)
000336      GO TO 26
000336      24 JL(K)=LN(NMTK)
000341      GO TO 26
000341      25 IMINER(K)=3
000343      IF(K.LE.KMAX)MDE(K)=1
000347      GO TO 3
C
000350      26 KM(K)=1
000352      JMIKI=JM(K)
000354      IF(IB(JMIKI).EQ.NMTK)KM(K)=0

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000357 XM(K)=0.
000361 IF(IMINER(K).EQ.5.OR.IMINER(K).EQ.8)GO TO 20
000370 IF(MN(NMTK).EQ.3)GO TO 27
000372 GO TO 20
000373 27 IMINER(K)=4
000375 MNP(NMTK)=MNP(NMTK)+1
000400 GO TO 20
C*****
C...3 MINER SAFE
C
000400 3 IF(MDE(K).EQ.1)MSAFE=MSAFE+1
000404 IF(MDE(K).EQ.1)WRITE(IWT,31)K,T,NMT(K),MSAFE
000422 31 FORMAT(10X,*MINER *,I3,* EVACUATED AT TIME *,F10.3,* ON NODE *,
1I3,* TOTAL *,I5)
000422 IF(MDE(K).EQ.1)TEVAC=T
000426 MDE(K)=0
000430 GO TO 20
C*****
C...4 MINER WAITING FOR HOIST
C
C DETERMINE IF MINER IN SMOKEY REGION
000430 4 CALL MSMOK(K)
C
C MINER DIES IF SELF RESCUER USE EXCEEDS TIME LIMIT
000432 IF(IMINS(K).EQ.1)TSELFR(K)=TSELFR(K)+DTIME
000437 IF(TSELFR(K).GT.TSRMAX.AND.IMINER(K).EQ.4)NMTK=NMT(K)
000454 IF(TSELFR(K).GT.TSRMAX.AND.IMINER(K).EQ.4.AND.MDE(K).NE.2)
1MNP(NMTK)=MNP(NMTK)-1
000477 IF(TSELFR(K).GT.TSRMAX.AND.MDE(K).NE.2)IMINER(K)=1
000514 IF(TSELFR(K).GT.TSRMAX.AND.K.LE.KMAX.AND.MDE(K).NE.2)MDE(K)=1
C
C INSTRUCTION SWITCH
000537 NMTK=NMT(K)
000541 JIMKI=JM(K)
000543 IF(MN(NMTK).NE.3.AND.IMINER(K).EQ.4)X4(K)=ALB(JIMKI)-XM(K)
000556 IF(MN(NMTK).NE.3.AND.IMINER(K).EQ.4)K4(K)=1-K4(K)
000572 IF(MN(NMTK).NE.3.AND.IMINER(K).EQ.4)IMINER(K)=2
000605 GO TO 20
C*****
C...7 MINER RIDING IN THE SLAVE (CLUTCHED) HOIST
C
000606 7 NMTK=NMT(K)
000610 JIMKI=JM(K)
000612 IF(T.GT.TSWITCH.AND.IHOIST(IMAST).EQ.1)XM(K)=ALB(JIMKI)-XM(K)
000627 IF(T.GT.TSWITCH.AND.IHOIST(IMAST).EQ.1)K4(K)=1-K4(K)
000644 IF(T.GT.TSWITCH.AND.IHOIST(IMAST).EQ.1)IMINER(K)=2
C
C
000660 20 CONTINUE
000663 RETURN
000663 END
```

```

SUBROUTINE SMOKE
C SMOKE PROPAGATION SUBROUTINE
000002 COMMON/SMCO/IBFIR,XBFIR,ISCOB(200),XS4JK(200),VENB(200),IMINS(200)
000002 COMMON/CNODE/IN(200),JN(200),KN(200),LN(200),MN(200),NN(200),
1MNP(200),JMAX,4N2(200),NN2(200),TSWITCH
000002 COMMON/CBRN/IB(200),JB(200),ALB(200),V3(200),IMAX
000002 COMMON/IO/IWT,IRD,IERROR
000002 COMMON/TIME/T,TIME,FTIME
C
C ISCOB(I) INDICATES SMOKE STATUS OF I TH BRANCH
C =0 BRANCH CLEAR OF SMOKE
C =1 BRANCH PARTLY SMOKE FILLED
C =2 BRANCH COMPLETELY SMOKE FILLED
C
000002 DO 20 I=1,IMAX
000004 IF(ISCOB(I).NE.1)GO TO 20
000006 XSMOK(I)=XSMOK(I)+ABS(VENB(I))*DTIME
000012 IF(XSMOK(I).LT.ALB(I))GO TO 20
000015 IF(I.NE.IBFIR)ISCOB(I)=2
000020 IF(I.NE.IBFIR)WRITE(IWT,21)I,T
000031 21 FORMAT(20X,'BRANCH ',I3,' FILLED COMPLETELY WITH SMOKE AT TIME',
1F10.3,' MINUTES')
000031 JFIR=JB(I)
000033 IF(VENB(I).LT.1.0)JFIR=IB(I)
000036 DO 30 JJ=1,4
000040 GO TO(1,2,3,4),JJ
000047 1 IBRF=IN(JFIR)
000051 GO TO 5
000052 2 IBRF=JN(JFIR)
000054 GO TO 5
000056 3 IBRF=KN(JFIR)
000057 GO TO 5
000060 4 IBRF=LN(JFIR)
000062 5 IF(IBRF.EQ.0)GO TO 20
000063 IF(IB(IFRF).EQ.JFIR.AND.VENB(IBRF).GE.0.0)GO TO 10
000074 IF(JB(IBRF).EQ.JFIR.AND.VENB(IBRF).LT.0.0)GO TO 10
000105 GO TO 30
000106 10 IF(ISCOB(IBRF).NE.2)ISCOB(IBRF)=1
000112 30 CONTINUE
000114 20 CONTINUE
C
C
000117 RETURN
000117 END

```

```

SUBROUTINE STENCH
C STENCH PROPAGATION SUBROUTINE
000002 COMMON/SMCJ/IBFIR,XBFIR,ISCOB(200),XS40K(200),VENB(200),IMINS(200)
000002 COMMON/CNODE/IN(200),JN(200),KN(200),LN(200),MN(200),NN(200),
1MNP(200),JMAX,MN2(200),NN2(200),TSWITCH
000002 COMMON/CBRN/IB(200),JB(200),ALB(200),V3(200),IMAX
000002 COMMON/IO/IWT,IRD,IERROR
000002 COMMON/TIME/T,DTIME,FTIME
000002 COMMON/WARN/IBSTN,XBSTN,ISTNB(200),XSTN(200),IMINT(200),VENC(200)
1,TSTEN,TENDT,MNSTEN,MNSMOK
C
C ISTNB(I) INDICATES STENCH STATUS OF I TH BRANCH
C =0 BRANCH CLEAR OF STENCH
C =1 BRANCH PARTLY STENCH FILLED
C =2 BRANCH COMPLETELY STENCH FILLED
C
000002 DO 20 I=1,IMAX
000004 IF(ISTNB(I).NE.1)GO TO 20
000006 XSTN(I)=XSTN(I)+ABS(VENC(I))*DTIME
000012 IF(XSTN(I).LT.ALB(I))GO TO 20
000015 IF(I.NE.IBSTN)ISTNB(I)=2
000020 IF(I.NE.IBSTN)WRITE(IWT,21)I,T
000031 21 FORMAT(15X,'BRANCH ',I3,' FILLED COMPLETELY WITH STENCH AT TIME*,
1F10.3,'MINUTES*')
000031 JSTN=JB(I)
000033 IF(VENC(I).LT.0.0)JSTN=IB(I)
000036 DO 30 JJ=1,4
000040 GO TO(1,2,3,4),JJ
000047 1 IBRS=IN(JSTN)
000051 GO TO 5
000052 2 IBRS=JN(JSTN)
000054 GO TO 5
000055 3 IBRS=KN(JSTN)
000057 GO TO 5
000060 4 IBRS=LN(JSTN)
000062 5 IF(IBRS.EQ.0)GO TO 20
000063 IF(IB(IBRS).EQ.JSTN.AND.VENC(IBRS).GE.0.0) GO TO 10
000074 IF(JB(IBRS).EQ.JSTN.AND.VENC(IBRS).LT.0.0) GO TO 10
000105 GO TO 30
000106 10 IF(ISTNB(IBRS).NE.2)ISTNB(IBRS)=1
000112 30 CONTINUE
000114 20 CONTINUE
C
C
000117 RETURN
000117 END

```

```

SUBROUTINE MSMJK(K)
C SUBROUTINE TO DETERMINE IF MINER IS IN SMOKEY REGION
000003 COMMON/SMCO/I3FIR,XBFIR,ISCOB(200),XSMJK(200),VENB(200),IMINS(200)
000003 COMMON/CMINER/JM(200),XM(200),KM(200),VELM(200),IMINER(200),
1NMT(200),MDE(200),KMAX,MSAFE,MDEAD,TD1(200),KGHOST,KNOTF(200)
2,TEVAC
000003 COMMON/CBRN/I3(200),JB(200),ALB(200),V3(200),IMAX
C
C IMINS(K)=0 INDICATES THE K TH MINER OUT OF SMOKEY REGION
C IMINS(K)=1 INDICATES THE MINER IN THE SMOKEY REGION
C
000003 JIMKI=JM(K)
000004 IF(ISCOB(JIMKI).EQ.0)GO TO 11
000006 IF(ISCOB(JIMKI).EQ.2)IMINS(K)=1
000012 IF(ISCOB(JIMKI).EQ.2)RETURN
000014 IF(KM(K).EQ.0.AND.VENB(JIMKI).GE.0.0)GO TO 10
000025 IF(KM(K).EQ.1.AND.VENB(JIMKI).LT.0.0)GO TO 10
000037 XXX=XM(K)+XSMJK(JIMKI)
000041 IF(XXX.LE.ALB(JIMKI))GO TO 11
000044 XXY=XM(K)+XBFIR
000046 IF(JIMKI.EQ.I3FIR.AND.XXY.GE.ALB(JIMKI))GO TO 11
000060 IMINS(K)=1
000062 RETURN
000062 10 IF(XM(K).GE.XSMJK(JIMKI))GO TO 11
000066 IF(JIMKI.EQ.I3FIR.AND.XM(K).LE.XBFIR)GO TO 11
000077 IMINS(K)=1
000101 RETURN
000101 11 IMINS(K)=0
000103 RETURN
000103 END

```

SUBROUTINE XSTAR(L)

C HOIST STOP INFORMATION STORE SUBROUTINE

```

000003 COMMON/LEV/LEVN(30),LEVA(30,5),XLEP(10,20),LLEP(10,20),XXP(10,40),
1XYP(10,40),INL(10),INX(10),MMAX,XHMAX
000003 COMMON/CHOIST/MH(10),LH(10,30),IH(10),VELNH(10),TDELAY(10),JH(10),
1TSTAR(10),NSTAR(10),TMOVE(10),TDEL(10),MINH(10,100),IHOIST(10),
2TWAIT(10),TUP(10),XHST(10),LMAX,XHSTI(10),THSCH(10),TOHO(10),
3THSRH(10),NOPT(10),NODFI(10),IFORCE(10),TDELS(10),TDELF(10)
4,IOPT(10),MH1(10),MH2(10),XHSTIN(10)
000003 COMMON/TIME/T,DTIME,FTIME
000003 INXI=INX(L)
000005 XXP(L,INXI)=T
000010 XYP(L,INXI)=-XHST(L)
000013 INX(L)=INX(L)+1
000014 RETURN
000015 END
    
```

```

SUBROUTINE LEVEL(NOODL,L)
C HOIST STOP LEVEL INFORMATION STORE SUBROUTINE
00005 COMMON/LEV/LEVN(30),LEVA(30,5),XLEP(10,20),LLEP(10,20),XXP(10,40),
1XYP(10,40),INL(10),INX(10),MMAX,XHMAX
00005 COMMON/CHOIST/MH(10),LH(10,30),IH(10),VELNH(10),TDELAY(10),JH(10),
1TSTAR(10),NSTAR(10),TMOVE(10),TDEL(10),MINH(10,100),IHOIST(10),
2TWAIT(10),TUP(10),XHST(10),LMAX,XHSTI(10),THSCH(10),TDHD(10),
3THSRH(10),NOPT(10),NODFI(10),IFORCE(10),TOELS(10),TOELF(10)
4,IOPT(10),MH1(10),MH2(10),XHSTIN(10)
00005 COMMON/DOUB/DOISC,LSLBR,MSLAV(10),MALEV(10),ISLAVE,IMAST,XMAST,
1 MANOD,IFORCD
00005 COMMON/TIME/T,TIME,FTIME
00005 COMMON/IO/IWT,IRD,IERROR
00005 DO 10 M=1,MMAX
00006 DO 10 MM=1,5
00007 IF(LEVA(M,MM).EQ.NOODL)GO TO 20
00012 10 CONTINUE
00017 20 IDEN=LEVN(M)
00021 INLL=INL(L)
00023 DO 30 I=1,INLL
00024 IF(IDEN.EQ.LLEP(L,I))RETURN
00030 30 CONTINUE
00033 LLEP(L,INLL)=IDEN
00036 XLEP(L,INLL)=-XHST(L)
00041 INL(L)=INL(L)+1
C CLUTCHED(SLAVE) HOIST IS FIRST CLUTCHED WHEN MASTER HOIST
C REACHES THE MASTER LEVEL
00043 IF(ISLAVE.EQ.0)GO TO 31
00044 IF(IHOIST(ISLAVE).EQ.1)GO TO 31
00046 IF(NOPT(IMAST).EQ.3.AND.IOPT(IMAST).NE.2)GO TO 31
00056 IF(L.EQ.IMAST.AND.IDEN.EQ.MALEV(ISLAVE))IHOIST(ISLAVE)=8
00070 IF(L.EQ.IMAST.AND.IDEN.EQ.MALEV(IMAST))XMAST=XHST(IMAST)
00102 IF(L.EQ.IMAST.AND.IDEN.EQ.MALEV(ISLAVE))WRITE(IWT,32)T
00122 32 FORMAT(5X,*SLAVE HOIST CLUTCHED IN AT TIME*,F10.3)
00122 31 CONTINUE
00122 RETURN
00123 END

```

SUBROUTINE DORJM

C SUBROUTINE TO CALCULATE MOTION OF THE SLAVE HOIST (CLUTCHED HOIST)
C IN A DOUBLE DRUM

```

000002 COMMON/CHINER/JM(200),XM(200),KM(200),VELM(200),IMINER(200),
1NMT(200),MDE(200),KMAX,MSAFE,MDEAD,TDM(200),KGHOST,KNOTF(200)
2,TEVAC
000002 COMMON/CBRN/IB(200),JB(200),ALB(200),VB(200),IMAX
000002 COMMON/CNODE/IN(200),JN(200),KN(200),LN(200),MN(200),NN(200),
1MNP(200),JMAX,MN2(200),NN2(200),TSWITCH
000002 COMMON/CHUIST/MH(10),LH(10,30),IH(10),VELNH(10),TDELAY(10),JH(10),
1TSTAR(10),NSTAR(10),TMOVE(10),TDEL(10),MINH(10,100),IHOIST(10),
2TWAIT(10),TUP(10),XHST(10),LMAX,XHSTI(10),THSCH(10),TDHD(10),
3THSRH(10),NOPT(10),NODFI(10),IFORCE(10),TDELS(10),TDELFI(10)
4,IOPT(10),MH1(10),MH2(10),XHSTIN(10)
000002 COMMON/IO/IWT,IRD,IERRR
000002 COMMON/TIME/T,JTIME,FTIME
000002 COMMON/LEV/LEVN(30),LEVA(30,5),XLEP(10,20),LLEP(10,20),XYP(10,40),
1XYP(10,40),INL(10),INX(10),MMAX,XHMAX
000002 COMMON/DOUB/IDISC,LSLBR,MSLAV(10),MALEV(10),ISLAVE,IMAST,XMAST,
1 MANOD,IFORCD
000002 L=ISLAVE
000004 LHOST=IHOIST(L)
000006 GO TO(1,1,1,1,1,1,1,7,8,9,10),LHOST

```

C*****

C...7 UNCLUTCHED SLAVE HOIST

```

C
7 CONTINUE
GO TO 1

```

C*****

C...8 CLUTCHED SLAVE HOIST

```

C
8 XHST(L)=XMAST-XHST(IMAST)
IF(NSTAR(IMAST).EQ.MANOD)GO TO 1
IF(XHST(L).LE.0.0)XHST(L)=0.0
IF(XHST(L).LE.0.0)IHOIST(L)=10
GO TO 1

```

C*****

C...9 MINERS PICKED JP BY SLAVE HOIST

```

C
9 IHOIST(L)=8
NOODL=MANOD
CALL LEVEL(NOODL,L)
CALL XSTAR(L)
IF(XHMAX.LE.XHST(L))XHMAX=XHST(L)
K=1
43 IF(NMT(K).EQ.MANOD.AND.IMINER(K).NE.1)GO TO 46
44 IF(K.GE.KMAX)GO TO 41
K=K+1
GO TO 43
46 JH(L)=JH(L)+1
MNP(MANOD)=MNP(MANOD)-1
JHILI=JH(L)
MINH(L,JHILI)=K
IF(JH(L).EQ.IH(L))GO TO 41

```


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```
000111      GO TO 44
000111      41 IF(JH(L).EQ.0)IHOIST(L)=7
000114      IF(JH(L).EQ.0)WRITE(IWT,+10)T
000123      410 FORMAT( 5X,*NO MINERS WAITING FOR SLAVE HOIST*/ 5X,*SLAVE HOIST DE
1CLUTCHED AT TIME*,F10.3)
000123      IF(JH(L).EQ.0)GO TO 1
000125      JHILI=JH(L)
000126      DO 45 I=1,JHILI
000130      K=MINH(L,I)
000133      NMT(K)=0
000135      45 IMINER(K)=7
000140      GO TO 1
C*****
C...10 MINERS DISCHARGED BY SLAVE HOIST
C
000141      10 IHOIST(L)=8
000143      IF(IDISC.EQ.1)IHOIST(L)=7
000147      IF(IDISC.EQ.1)WRITE(IWT,51)T
000156      51 FORMAT( 5X,*MASTER HOIST FINDS NO MINERS*/ 5X,*SLAVE HOIST DECLUTC
1HED AT TIME*,F10.3)
000156      IF(JH(L).EQ.0.AND.IHOIST(IMAST).EQ.3.AND.NSTAR(IMAST).NE.MANOD)
1IHOIST(L)=7
000175      IF(JH(L).EQ.0.AND.IHOIST(IMAST).EQ.3.AND.NSTAR(IMAST).NE.MANOD)
1WRITE(IWT,52)T
000220      52 FORMAT( 5X,*MASTER HOIST GOES BELOW MASTER LEVEL*/ 5X,*SLAVE HOIST
1DECLUTCHED AT TIME*,F10.3)
000220      IF(JH(L).EQ.0)GO TO 1
000222      IFORCD=0
000223      JHILI=JH(L)
000224      MHILI=MH(L)
000226      WRITE(IWT,522)_,LH(L,MHILI),JH(L),T
000243      522 FORMAT(5X,*HOIST *,I5,* REACHES NODE *,I5,* WITH *,I5,* MINERS AT
1TIME *,F10.3/)
000243      MHILI1=MHILI-1
000245      NODEA=LH(L,MHILI1)
000251      NODEB=LH(L,MHILI)
000254      TTRAV=0.
000255      CALL TSTARC(L,NODEA,NODEB,TTRAV)
000260      NMTK=LH(L,MHILI)
000264      KMKM=1
000265      IF(JB(LSLBR).EQ.NMTK)KMKM=0
000270      DO 59 I=1,JHILI
000272      K=MINH(L,I)
000275      IMINER(K)=2
000277      JM(K)=LSLBR
000301      XM(K)=ALB(LSLBR)
000302      KM(K)=KMKM
000304      59 CONTINUE
000306      JH(L)=0
000307      1 CONTINUE
C
C
000307      RETURN
000310      END
```

APPENDIX C

HOISTING SYSTEMS - AVAILABLE EQUIPMENT

C.1 Introduction

A survey has been made of available hoisting equipment which has applications for use in metal and non-metal mine emergency escape hoist systems. The information was gathered from a number of sources, including representatives in the USBM and MESA, mine operators, personal visits and telephone interviews with manufacturers, field visits to inspect equipment, advertisements, catalogues and indices of manufacturers. Wherever possible, technical specifications and prices were checked out with the manufacturer, or supplier.

The sections on individual sub-systems and components, such as automatic control systems, winches and controls, are not intended to be all encompassing surveys. Rather a reasonable number of representative units in each category are discussed. The sample is large enough to provide a general picture of the kind of equipment available, including the abilities and limitations and a reasonable price range.

The survey has been divided into six categories:

1. Complete Hoisting Systems
 - A. Above ground installations
 - B. Below ground installations
2. Hoist Assemblies (Man-rated)
3. Hoists (not Man-rated)

4. Safety Equipment and Control Devices
5. Automatic Control Equipment
6. Emergency Rescue Hoists

Discussion and detailed specifications of the equipment is presented in the following sections. Figures 38 and 39 (following the hoisting system surveys) show typical layout arrangements for electric and air hoisting systems.

C.2 Complete Hoisting Systems

A. Above Ground Installations

A total of seven companies were identified who supply complete emergency escape hoist units for above ground installations. The units have been designed predominately to meet the needs of coal mine operators to satisfy the requirements of the Coal Mine Health and Safety Act of 1969. The seven companies are as follows:

1. Dover Conveyor and Equipment Co.
2. Coeur d'Alenes Co.
3. Connellsville Corp.
4. Scott Midland
5. W. W. Williams Co.
6. Equipment Corporation of America
7. Timberland Ellicott

Table VIII contains detailed specifications and price information on each of these units.

The units have a number of similarities:

TABLE VIII - SUMMARY OF BASIC FEATURES OF COMMERCIALY AVAILABLE HOIST SYSTEMS
FOR ABOVE GROUND INSTALLATIONS

Manu- facturer	Cost \$	Capacity	Maximum Service Depth	Running Speed	Braking	Power Supply and Drive Train	Auto- matic Controls	Height of Head- sheave	Safety Features	Boom Type
Dover Conveyor and Equipment Co. Box 424, Dover, Ohio 44622 (216) 364-8861	26,000 F. O. B. Dover	4 Men 1500 lb. Line pull	500 ft. (STD) 1000 ft. (MAX)	100 fpm and 40 fpm, 150 fpm optional	Spring set Motor Brake Spring set Drum Brake	Electric Motor 10 HP, 230 VAC/ 3/60, Direct Drive Propane Engine Generator	No	20 ft.	Linear Footage Counter limit switches on hoist and boom for over and rotate on under travel. Over Pivot travel switch on and track boom. Rope overlap switch. Drum over speed switch.	Fixed Angle Boom. Hoist rotate on Pivot and track
Coeur D'Alenes Co. Canyon Avenue Wallace, Idaho 83873 (208)752-1283	25,000 F. O. B. Spokane, WA.	8 Men 4000 lb. Line pull	1200 ft.	150 fpm 300 fpm	Spring set Motor Brake Gravity set Drum Brake	Electric Motor 40 HP, 460 V/3/60 Direct Drive Worm Drive	Yes Option Available For \$3500	15 ft.	Overspeed, over travel, undertravel Worm drive. Dial boom rotate depth indicator	Fixed angle boom. Hoist on pivot and track
Scott-Midland 11099, Broadway Alden, N. Y. 14004 (716) 685-3131	22,000 - 29,000 Less Cage	3000 lb. Line pull	1100 ft.	125-215 fpm	Spring Set Hydraulic Release, Counter flow braking	Gasoline Diesel or propane engine, Fluid torque converter, Worm drive	No	13 ft.	Simplex cont- roller, for over speed. Over and under travel and depth indication, Worm drive	Fixed frame with electric motor pull- back from shaft.
Equipment Corp. of America, Groveton, PA (412) 331-2000	26,000 - 32,000 F. O. B. Pittsburgh	3000 - 5000 lb. Line pull	400 ft. to 1000 ft.	300 fpm	Manually set drum brake, Spring set motor brake. Electrically released	Gasoline, diesel or propane engine fluid torque converter, Worm drive	No	20-30 ft.	Simplex cont- roller for over- speed over and undertravel and depth indication	Rotating stiff-legged derrick
W. W. Williams Co. Warrendale, PA. (412) 776-3676	35,000 - 38,000	4 Men 3000 lb. Line pull	900 ft.	400 fpm	Spring set hydraulic re- lease brake on drive shaft, Counterflow braking	Electric motor 50 HP, 230/400 VAC, gasoline diesel or propane engine.	No	55 ft (MAX)	Linear footage counter. Limit switches for over and under- travel.	Galion P150 Pedestal Crane
Timberland-Ellicott P. O. Box 490 Woodstock, Ontario, Canada (519) 537-6262		4000 lb. Line pull	1700 ft.	100 fpm 300 fpm	Dual braking	Electric motor 40 HP, 440/3/60	Semi- automatic	30 ft. (MAX) Boom length	Automatic level winding overspeed, depth indicator top limit switch semi-automatic sequencing.	Rotating boom.

1. Cost of units is in the \$22,000 to \$38,000 price range, plus installation. One of the units, Connellsville, quote an approximate installation cost of \$7500.
2. All of the units are designed for a free-hanging cage which is lowered into a large cross-sectioned, vertical ventilation shaft. This precludes the need for cage guidance.
3. All the units are designed such that the cage can be swung away from the shaft collar. This prevents damage to the unit should the shaft vent an explosion. This need increases both system complexity and cost.
4. All the units can be modified for below ground installation. They all include the basic prerequisites for a below ground system, namely a drive system, a hoist, safety equipment and controls. Basic modifications would include a simplified headsheave support system and redesign of the cage to interface with a guidance system.
5. Cage capacity of 4 to 8 men and safe line pull capabilities from 2000 lb to 5000 lb.
6. Standard complement of safety features including overspeed, overtravel and undertravel and normally on brakes (brakes set automatically, by spring or gravity if power is lost).

It should be noted that there are several major categories in which the units differ.

1. Size and type of boom; a multitude of different types of boom are available. Two of the seven units, Connellsville and Williams have booms large enough to permit swinging the cage over a fan housing, another, Scott-Midland can be totally enclosed with a fan housing extension; the other units can be easily factory-modified to provide this capability.

2. Power supply and drive train: three of the units require 220 or 440 volt power for electric motors. One of these units, Dover, includes a propane engine generator for standby use. The remaining four units employ an internal combustion engine, gasoline, diesel or propane powered, and can be delivered with electric motor drives. Three units have a direct drive to the hoist drum; the other four utilize a hydraulic transmission or torque converter.

3. Automatic controls: 2 of the seven units permit a man on the shaft bottom to activate the system with no hoist operator in attendance.

The specifications for each of the seven units are for a "standard" system. However, all of the companies have indicated a willingness to modify their equipment for a specific application. Questions of this nature should be addressed to the company involved.

B. Below Ground Installations

Two commercially available systems have been identified as directly applicable for installation underground as emergency escape hoist systems. A third system, currently being designed under USBM contract, for an underground man and supply application is included for reference. None of these systems however, have been designed specifically for the emergency escape hoist application. A detailed description of each system is presented in the following paragraphs:

1. Alimak Universal Hoist 0-500

Supplier

Raise Equipment
5250 Broadway
Denver, Colorado 80216
303-572-1504

Description

The U-500 system has the drive unit mounted to the travelling cage. The cage and drive units engage a shaft mounted guide channel and rack assembly which is mounted within the shaft. System travel is controlled from within the cage and call stations can be provided at the top and bottom landings. The unit may be installed in vertical or inclined shafts and can be powered from an electric, pneumatic or diesel source.

Specification

Travel Distance

Air powered 500 ft. max.
Electric powered 2000 ft. max.
Diesel powered 2000 ft. plus.

Travel Speed

Electric powered: 88-153 FPM

Cage Size

Cross-section: 3.28 ft. x 4.92 ft. to
3.28 ft. x 8.20 ft.

Cage Capacity

1200 lb., 5 men to 2200 lb., 12 men

Minimum Shaft

4.25 ft. x 5.75 ft.

Drive System

Rack and pinion drive with pinion permanently engaged in gear rack. Single or dual motor-brake with worm gear reducer. 2 x 10 HP motors.

Safety Control

Overspeed, driven directly off rack, is sensed centrifigally and positively screws a cone brake into operation. Each drive motor includes a spring-set power released disc brake. Top and bottom limit switches are cage mounted and operated by guide rail mounted limit cams. Top and bottom buffers are fitted to guide rails. Station entrance includes electrical or mechanical interlocks.

Miscellaneous

Rail and rack can be mounted on foot-wall or hanging wall, cage is positioned vertically in either case. Guide rail can be used as a ladder. Cage can descend by gravity to bottom station in the event of power failure. Hoist can be automated. System does not include communications.

Cost

300 ft. 2 station 3 ft. x 4 ft. cage, approx.
\$65,000.

2. Heede 4000

Supplier

Raise Equipment
5250 Broadway
Denver, Colorado 80216
303-572-1504

Description

The Heede 4000 is a self-contained tower mounted system. The cage locates to the outside of the tower and the drive system is positioned at the top of the tower. The cage is supported by 5 wire ropes which pass over the friction drive drum to a counter weight.

Cage and counterweight guides are tower mounted. The support tower includes an enclosed ladderway with landings at 10 ft. intervals.

Specification

Travel Distance

1000 ft. standard maximum, longer lifts are available.

Travel Speed

350 FPM

Cage Size

3' 10 1/2" x 6' x 7' inside. Custom sizes available.

Cage Capacity

4000 lbs. or 12 men.

Tower

Welded tubular steel in 10 ft. sections with a 4' 2" x 3' 6 1/2" cross-section. Tower is attached to shaft wall at 60' intervals. Tower includes an enclosed ladderway.

Drive System

30/10 HP, 440 v. AC 3 phase motor directly coupled to a worm gear reducer which drives the main Traction Sheave.

Safety Control

Rope equalizers provides equal tension on all 5 ropes. Broken or slack rope tension shuts down system. Spring set power released drum brake. Gravity operated brake on traction sheave, landing and cage door interlocks. Overspeed sensor initiates automatic catching device. Terminal

limit switches. Emergency stop control in cage. Operation is automatic, cage responds to calls from each landing.

Miscellaneous

Cage can be maintained level to inclinations of 40° from normal. System does not include communications.

Cost

Approximately \$25,000 for 500 ft. automated.

3. Man and Supply Hoist

This hoist system is currently being developed by Foster-Miller Associates under USBM Contract No. H0252068. The unit will be installed and tested underground during the latter part of 1976.

Description

The system has been designed as a stope service hoist and can operate in undulating raises. The hoist is attached to the cage and the assembly climb two stationary wire ropes which extend the full length of the raise. The system can be operated from within the cage and also from a maximum of four remote control station.

Specification

Travel Distance

300 ft. standard, 700 ft. with minor modifications.

Travel Speed

50/30 FPM.

Capacity

2000 lb. man-rated, 4000 lb., materials.

Minimum Shaft

5 ft. diameter.

Ropes

Two 7/16 diameter.

Drive System

7 1/2 HP 440/3/60 1800/1200 rpm electric motor driving two traction drums through an 72:1 gear and differential reducer.

Brakes

Spring set, power-released electric motor brake. Wedge type rope brake initiated centrifigally by the overspeed sensor.

Safety Controls

"Deadman" type operating lever in the cage. Safety interlocks on cage doors. Emergency stop at all control station. Overspeed braking. Top and bottom travel and overtravel limit switches. Depth indicator in the cage and at all control stations. Overload sensors monitoring rope tension.

Miscellaneous

Power and control umbilical cable is free hanging in the raise and is tensioned and spooled at the top of the cage assembly. The cage includes an electrically powered materials handling hoist.

C.3 Hoist Assemblies (Man-rated)

A total of nine companies were identified who manufacture and supply man-rated hoisting equipment suitable for below ground installations.

1. The Coeur d'Alenes Company

2. Rexnord/Nordberg
3. Card Corporation
4. Mine Systems, Inc.
5. John T. Hepburn Ltd.
6. Lakeshore Inc.
7. Timberland Ellicott
8. Raise Equipment
9. Beebe Bros.

Many of the companies surveyed produce a wide range of equipment and tailor their equipment to meet the individual users needs. The descriptions of the equipment available are presented in the following paragraphs and indicate the range of hoists available from each manufacturer.

1. Emergency Escape Hoist C 2514

Supplier

The Coeur d'Alenes Company
Wallace, Idaho 83873
208-752-1151

Capacity

3000 lb. line pull at 150 FPM

Drum

30" diameter sized for 3/4" wire rope.

Drive

15 HP electric motor driving a 90:1 helical worm reducer.

Brakes

Gravity set drum brake hydraulically released by hydraulic pressure provided by an integral pump. Stearns spring set power released motor brake.

Controls

Overspeed protection by Euclid overspeed switch directly driven off drum. Undertravel and overtravel limits set on indicator dial and cam arrangement directly driven off drum.

Cost \$16,000 to \$18,000

2. Rexnord Escape Hoist

Supplier Rexnord
Process Machinery Division
P. O. Box 383
Milwaukee, Wisconsin 53201
414-744-2345

Capacity 3810 lb. line pull at 100 FPM

Drum 36 in. drum x 18 in. wide for 3/4" non-rotating wire rope. Active drum capacity 300 ft.

Drive 15-20 HP hydraulic or air motor direct coupled to drum shaft.

Brakes One drum brake and one motor coupling brake rated at 8572 ft. lbs.

Controls Simplex controller with 36" dial indicator for depth indication and providing overspeed and overtravel control.

Cost \$30,000

3. Nordberg Friction Hoist

Supplier Nordberg
Division of Rex Chainbelt Inc.
P. O. Box 383
Milwaukee, Wisconsin 53201
414-744-2345

Capacity 5500 lb. at 580 FPM

Drum Friction wheel 5 ft. diameter for four 5/8" diameter ropes.

Brakes Thruster type motor brake and main service brake which is pressure applied with gravity back-up for accurate repetitive stopping.

Controls Automatic, semi-automatic and manual types available. Controls may be operated from cage or level location. Overspeed and overtravel controls.

Miscellaneous Unit can be converted to unbalanced drum hoist.

Cost Refer to factory.

4. Card Hydrostatic Hoist

Supplier Card Corporation
P.O. Box 117
Denver, Colorado 80201
303-534-6351

Capacity 3500-9000 lb. line pull.

Drum Drum diameter and face from 20" x 20" to 42" x 42".

Drive Gasoline or diesel engine, or electric or air motor driving a variable displacement axial pump, driving a fixed displacement axial piston motor. Motor drives hoist drum via a speed reduction unit.

Brakes Gravity set, hydraulic release post brake acting on the drum. Spring set, magnetically released motor brake coupled between the hydraulic motor

and the gear reducer. Regenerative braking in closed loop hydraulic system.

Controls

Overspeed, overtravel, undertravel, phase reversal, low voltage, cage and shaft gate interlocks, slack rope sensor.

Miscellaneous

Unit can be purchased fully automatic, semi-automatic or manual. Control can be remote or from within the cage.

Cost

Refer to factory.

5. Hydrostatic Mine Hoist

Supplier

Mine Systems Inc.
4424 Vine Street
Denver, Colorado 80216
303-893-1232

Capacity

1500 lb. - 25,000 lb. line pull, 500 - 700 FPM.

Drum

Drum diameter and face 18" x 18" to 84" x 60".

Drive

Diesel engine or electric motor 5 - 300 HP driving a variable closed loop hydrostatic drive either directly to the drum via a high torque - low speed hydraulic motor or via a gear reduction to the motor.

Brakes

Post type drum brake, gravity set and hydraulically released. Hydraulic motor mounted spring set hydraulically released band brake or a motor coupling brake on the electric motor. Regenerative braking in the closed loop hydraulic system. Counter-torque braking by a valve connected to the hoist motor pressure port.

Controls Overspeed, overtravel, undertravel, overtorque, low oil, phase reversal, oil line failure slack rope.

Miscellaneous Manual or semi-automatic control is available.

Cost Refer to factory.

6. Hepburn Mine Hoist

Supplier John T. Hepburn Ltd.
914 Dupont Street
Toronto, Canada
416-534-8871

Capacity Drum hoists: 6000 lb. to 60,000 lb. line pull.
Friction hoists: 4000 lb. to 60,000 lb. payload.

Drum Drum diameter and face from 36" x 24" to 140" x 72". Wheel diameter from 40" to 192".

Drive One or two drive motors through single or double reduction gearing. Expanding jaw or friction clutch.

Brakes Post, caliper, pinion, and disc brakes available.

Controls Manual or remote controls and full range of safety controls.

Cost \$100,000 plus. Smaller units would require special design.

7. Lake Shore Mine Hoists

Supplier Lake Shore, Inc.
Iron Mountain/Kingsford,
Michigan 49801
906-774-1500

Small Single
Drum Hoists

AC controlled for manual operation. Disc type motor brake, manual braking brake, dial depth indicator.

Large Drum
Hoists

Single or double drum construction, post type brakes, manual or automatic operation, Lilly Controller.

Single Rope
Friction Hoists

Head frame mounted for balanced auxiliary man hoisting. Post brake motor coupling brake and Lilly Controller.

Multi-Rope
Friction Hoists

Ground mounted, 9 ropes, post brake auxiliary motor coupling brake, Lilly Controller, automatic or manual control.

8. Timberland Ellicott Escape Hoist

Supplier

Western States Machinery Co.
P. O. Box 2224
Grand Junction, Colorado 81501
303-242-1983

Capacity

15,000 lb. line pull at 400 FPM.

Drum

Drum diameter and face 43" x 31".

Drive

250 HP, 1800 rpm 440/3/60 electric motor drives a reversing hydraulic pump and two hydraulic motors through a gear reduction.

Brakes

Band brake on drum, spring set hydraulic release. Band brake on intermediate drive shaft, manually operated.

Controls Simplex controller driven off the drum providing overspeed, overtravel, undertravel and depth indication.

Miscellaneous Two speed hydraulic motors and controls are available.

Cost Refer to supplier.

9. Alimak Winches EPG 1-4

Supplier Raise Equipment
5250 Broadway
Denver, Colorado 80216
303-572-1504

Capacity 2000 lb. to 8000 lb. line pull.

Drive From one (EPG-1) to four (EPG-4) electric motors are used depending on the capacity and either one or two worm gear reducers transmit the power to the drum.

Brakes Spring set disc brakes on each motor and an electro-hydraulic band brake operates on the drum.

Controls Overtravel and undertravel is sensed by a spindle limit switch. An overspeed sensing device sets the safety brake. Level winding and wire climbing guard ensures correct rope winding. Unit does not include depth indication.

Cost Refer to supplier.

10. Alimak Winches HPG - 3000

Supplier

Raise Equipment
5250 Broadway
Denver, Colorado 80216
303-572-1504

Capacity

2000 lb. to 13,000 lb. at 60 - 120 FPM.

Drive

Air or electric driven hydraulic pump powers one or two radial piston motors which drive the drum.

Brakes

Two spring set, hydraulically released band brakes on the drum.

Controls

Overtravel and undertravel controlled by a spindle limit switch. Overspeed sensor, wire climbing sensor. The unit does not include depth indication.

Miscellaneous

The system comprises two packages, the Power Pack and the winch for easy transport. Unit can be controlled at the winch or remotely.

Cost

Approximately \$77,000.

11. Beebe Bros.

Supplier

Beebe Bros., Inc.
2724 Sixth Avenue S.
Seattle, Washington 98134
206-624-0466

Capacity

3000 lb. line pull at 120 FPM.

Drum Capacity

1050 ft. of 5/8" diameter rope.

<u>Drive</u>	Air motor drive through two pairs of reduction gearing to hoist drum.
<u>Brakes</u>	Two band brakes acting on the hoist drum. One is manually set, the other is spring set, air released. The manual control valve pneumatically locks the drive motor when lever control is in the off position.
<u>Controls</u>	Manual up-off-down throttle lever. Top and bottom travel limit switches are activated by drum rotation. Overspeed sensor shuts off air supply.
<u>Cost</u>	Approximately \$6000.

C.4 Hoist Assemblies (not man-rated)

A large number of manufacturers supply materials handling winches. These units are predominately electric powered while a limited number of vendors supply air powered equipment. Air powered units are currently used extensively for underground materials handling purposes. Suppliers of materials handling equipment normally include a disclaimer statement in their published literature which clearly states that the equipment "is not designed or suitable for lifting or lowering persons." This category of commercially available equipment can be adequate for emergency man hoisting provided that its' capacity is suitably derated and provided also that the necessary safety features are incorporated. Section C.5 details the equipment which could be added to a commercial materials hoist to meet these needs.

Four commercially available hoist assemblies, two electric and two pneumatic are discussed in the following paragraphs. This equipment is typical of what is commercially available and three of the units are currently used extensively in mining applications. Each hoist description includes a remarks paragraph which identifies the additional equipment each hoist would require for emergency hoist use.

1. Beebe Air Tugger

Supplier Raise Equipment
5250 Broadway
Denver, Colorado 80216
303-572-1504

Capacity 1100 lb. to 12,000 lb. line pull at 45 FPM to
150 FPM.

Drum Drum line capacities from 262' to 5740'. Drum
diameter/rope diameter ratios from 13.2 to 35.4.
Line sizes from 3/16" diameter to 7/8" diameter.

Drive Heavy duty continuous service radial piston air
motor requiring an air pressure supply of 90 psi.
Motor is directly connected by a gear reducer to
the drum. Motor rotation direction is reversable,
motor speed is controlled by a manual throttle
valve. A disengaging clutch for free spooling
of the drum is an optional feature.

Brakes Single heavy duty manually operated drum mounted
band brake is standard. An identical second
brake is optional.

Controls Automatic brake system and drum rotation
indicator are optional equipment.

Miscellaneous Units are tested to 50 percent overload, may be
floor, wall or roof mounted.

Cost Refer to supplier.

Remarks

The minimum modifications required to these units for emergency hoisting include:

- a) Inclusion of second brake and drum rotation indicator option.
- b) Drum rotation sensor for overspeed control.
- c) Automatic control system to shut off air supply and set brakes in overspeed or over-travel condition.
- d) Over and undertravel sensors. These could however be located remote from the hoist.

2. Beebe Electric Hoist

Supplier

Raise Equipment
5250 Broadway
Denver, Colorado 80216
303-572-1504

Capacity

200 lb. to 25,000 lb. line pull at 20 FPM to 90 FPM. Line pull based on 5:1 rope safety factor.

Drum

Drum line capacities from 288' to 875'. Drum dia./rope dia. ratios from 17 to 21. Line sizes from 1/4" diameter to 1 1/4" diameter.

Drive

Reversible electric motor 1/3 HP - 20 HP.
1/60/115-230 V.A.C. or 1/60/230-460 V.A.C. on all models. Direct drive gearbox to drum on models to 3500 lb. capacity, and direct drive gearbox and chain reduction drive to drum on models from 1300 lb. and up. Chain drive has minimum ultimate safety factor of 6.

Brake Single spring set power released brake on electric motor.

Controls Upper and lower travel limit switches, motor torque limiter, magnetic reversing starters and two button, press to run, momentary control switches are optionally available.

Miscellaneous Units are tested to 100 percent overload.

Cost Approximately \$60,000 for 25,000 lb. unit.

Remarks The minimum modifications required to these units for emergency hoisting includes:

- a) Addition of second brake located on hoist drum.
- b) Add-subtract drum rotation counter for depth indication or equivalent.
- c) Drum rotation sensor for overspeed control.
- d) Automatic control system to shut off power and set brakes in overspeed or overtravel condition.
- e) Travel limit switch and starter and control switch option.

3. Compressed Air Products

Supplier Compressed Air Products, Inc.
P. O. Box 80704
832 So. Fidalgo
Seattle, Washington 98108
206-762-6960

Capacity 920 lb. to 5780 lb. line pull at 174 FPM to 1021 FPM. Line pull based on 5:1 rope safety factor.

Drum Drum line capacities from 674' to 36,600'. Drum dia./rope dia. ratios from 45.7 to 107. Line sizes from 3/16" diameter to 7/8" diameter.

Drive A radial piston air motor drives the drum directly through a parallel shaft gear reducer. The motor requires an air pressure supply of 90 psi. Motor rotation direction is reversable, motor speed and direction are controlled by a single lever which operates a four-way throttle valve.

Brakes Spring set, air released automatic multiple disc brake located between air motor and gear reducer. Automatic band brake located on the drum. Unit is spring set and air released. Both brakes hold 300 percent of capacity.

Controls Linear depth indicator with air limit switches for under and overtravel. A speed control governor is also available.

Miscellaneous A multiplicity of mounting arrangements are available. Unit can also be purchased with a muffler base.

Cost For 5780 lb., 174 FPM unit with all accessories except the muffler: \$10,860.

Remarks

The minimum modifications required to these units for emergency hoisting include:

- a) Addition of overspeed sensor driven off the drum.
- b) Addition of control logic (preferably pneumatic) to cut air supply to unit in the event of an overspeed situation.

4. Sanford - Day - "Brownie" Hoist Retarder

Supplier

Mannon Transmotive/Sanford - Day
Mining Equipment
P.O. Box 1511
Knoxville, Tennessee 37901
615-525-6224

Capacity

12,000 lb. and 24,000 lb. line pull at 50 FPM and 40 FPM.

Drum

Drum line capacities of 300' and 450' are standard.

Drive

The drive comprises a 20 HP or 30 HP electric motor. 220 or 440/3/60 driving a parallel shaft gear, or chain and gear reduction to directly drive the drum.

Brakes

Spring set thrustor type brake operates at electric motor shaft. Regenerative motor braking prevents system overspeed.

Controls

Two element push-button for lower and haul. Slack rope sensor.

Cost

Refer to supplier.

Miscellaneous

This equipment is primarily designed to control the movement of railroad cars on grades to 3 percent.

Remarks

The minimum modifications required to these units for emergency hoisting include:

- a) Addition of second braking system operating directly off the drum.
- b) Overspeed sensor and automatic brake initiation.
- c) Depth indicator.

C.5 Safety Equipment and Control Devices

Safety equipment and control devices serve two principal functions in mine escape hoists. First, they can be used to provide important safety features such as protection against overspeed, overtravel and undertravel. Second they can be used to automate or partially automate the operation of the escape hoist. Typical equipment available is described in the following section.

1. Simplex and Lilly Hoist Controllers

Manufacturers: Logan Actuator Co.
4956 No. Elston Ave.
Chicago, Illinois 60630
312-736-7500

The Simplex and Lilly Controllers provide a means for electrically shutting off the power to the hoist and the energy to physically set the brakes in the event of overspeed, overtravel, undertravel and failure to begin deceleration within sufficient distance

available to make a smooth stop. The units also provide a cage position readout dial. The unit is positively linked to the hoist drum by means of a chain drive or shafting. Drum rotation drives a flyball governor unit and a depth indicator pointer. To this pointer are attached two cams. Each cam profile and position, represents the proper deceleration of the hoist and the upper or lower travel limit point. The controller includes a contactor unit which has two contact points. One point is connected to the cam position, the other to the output of the governor. The hoist speed as measured by the governor and the position of the cage and thus the cam, are summed in the contactor unit; whenever that sum corresponds to an unsafe condition, the contacts are opened. This characteristic of open contacts for an unsafe condition can be used in a circuit to cut the motor power and actuate the brakes. The controllers also include a gravity brake actuator which consists of a weight held by a solenoid. Loss of power through electrical failure or opening of the contactor, causes the solenoid to release the weight unit. Suitable linkages between the weight unit and the brake cause the brake to set.

2. Safety Brake System

Manufacturer: Safety Lift Corp.
4630 Vance St.
Wheat Ridge
CO 80033
303-422-5301

This unit is mounted directly to the travelling cage. A weighted safety rope is suspended the full length of the shaft and this rope is spooled several times around two independent grooved drums. During cage travel the rope is stationary and the drums are driven by the rope. Drum rotation is sensed electrically and mechanically and an overspeed condition will set brakes located within the drums. The brakes are electrically and mechanically set. Electrical power for the system is provided by battery or trailing cable. The system can be connected to the draw bar such that braking is initiated by rope failure.

The system can also be initiated from within the cage. The unit includes a manual lowering facility within the cage.

3. Overspeed Sensing

The following manufacturers supply overspeed sensing devices:

Hubble Industrial Controls - Euclid Type C, Price \$400-680
50 Edward St.
Madison, Ohio 44057
216-261-6132

Speed Detectors, Inc. - ESS-1/2 Price \$145
32 West Monroe St.
Bedford, Ohio 44146
216-232-1880

Winterbam Manufacturing Co.
Putnam, Connecticut
203-928-6551

Hobart Manufacturing Co.,
Columbia, South Carolina
803-754-8800

Inertial Switch, Inc.
New York, New York
212-586-5880

4. Rotary Counters

The following manufacturers supply rotary counters:

Veeder-Root
Hartford, Connecticut
203-527-7201

General Electric Company
General Purpose Control Products Dept.
P.O. Box 2913
Bloomington, Illinois

5. Limit Switches

The following manufacturers supply limit switches:

General Electric Company
General Purpose Control Products Dept.
P. O. Box 2913
Bloomington, Illinois

Namco Controls
Cleveland, Ohio
216-268-4200

Honeywell Micro Switch Division
Freeport, Illinois
815-232-1122

Robert Shaw Controls Company
Columbus, Ohio
614-875-2351

C. 6 Automatic Elevator Control Systems

An automatic elevator control system, consisting of position sensing devices and a control unit, can be used to control an emergency mine hoist. While automatic elevator control systems are assembled from standard components, they are typically custom designed to suit a given customer's application. Various manufacturers contacted indicated that the price range, less installation, for a simple two-stop control system begins at approximately \$2500 and can increase depending upon the type of components used, shaft depth, the type of mechanical drive used, and the maximum operating speed.

A partial list of elevator control manufacturers follows. They should be contacted for further details.

Marshall Elevator Company
Pittsburgh, PA.
412-431-1340

Armor Elevator Company, Inc.
Louisville, KY
502-361-7181

Atlas Elevator Company
Chicago, Illinois
312-472-1260

Virginia Elevator Controls
Richmond, VA
804-643-6775

C.7 Emergency Rescue Hoists

There is a need, especially in mine development areas, for portable, on-call, man-rated equipment capable of lifting men through several hundred feet. Wire rope climbing equipment as shown in Figure 37 appears particularly suited to this need. It is portable, weighing approximately 100 lbs., is currently man-rated for numerous above ground applications and can be electric or air powered. Commercial units currently have a lifting capacity of 1000 lbs., and can be fitted with bosun's chairs. Lifting speeds are in the 20-30 FPM range and the equipment is not depth limited. In a situation where miners are unable to climb to the top of a shaft this equipment could rapidly be anchored to the top of the shaft and lowered to them by hand. Since the self contained unit is controlled by the person travelling in the shaft he would be able to negotiate shaft obstruction himself. This would not be possible with other forms of easily deployed free-hanging equipment.

Typical manufacturers of this type of equipment are:

Ohio Hoist Mfg, Co,
321 South Beaver St.
Lisbon, Ohio 44432
216-424-7283

Sky Climber Inc.
17311 South Main St.
Gardena, California 90248
213-321-6414

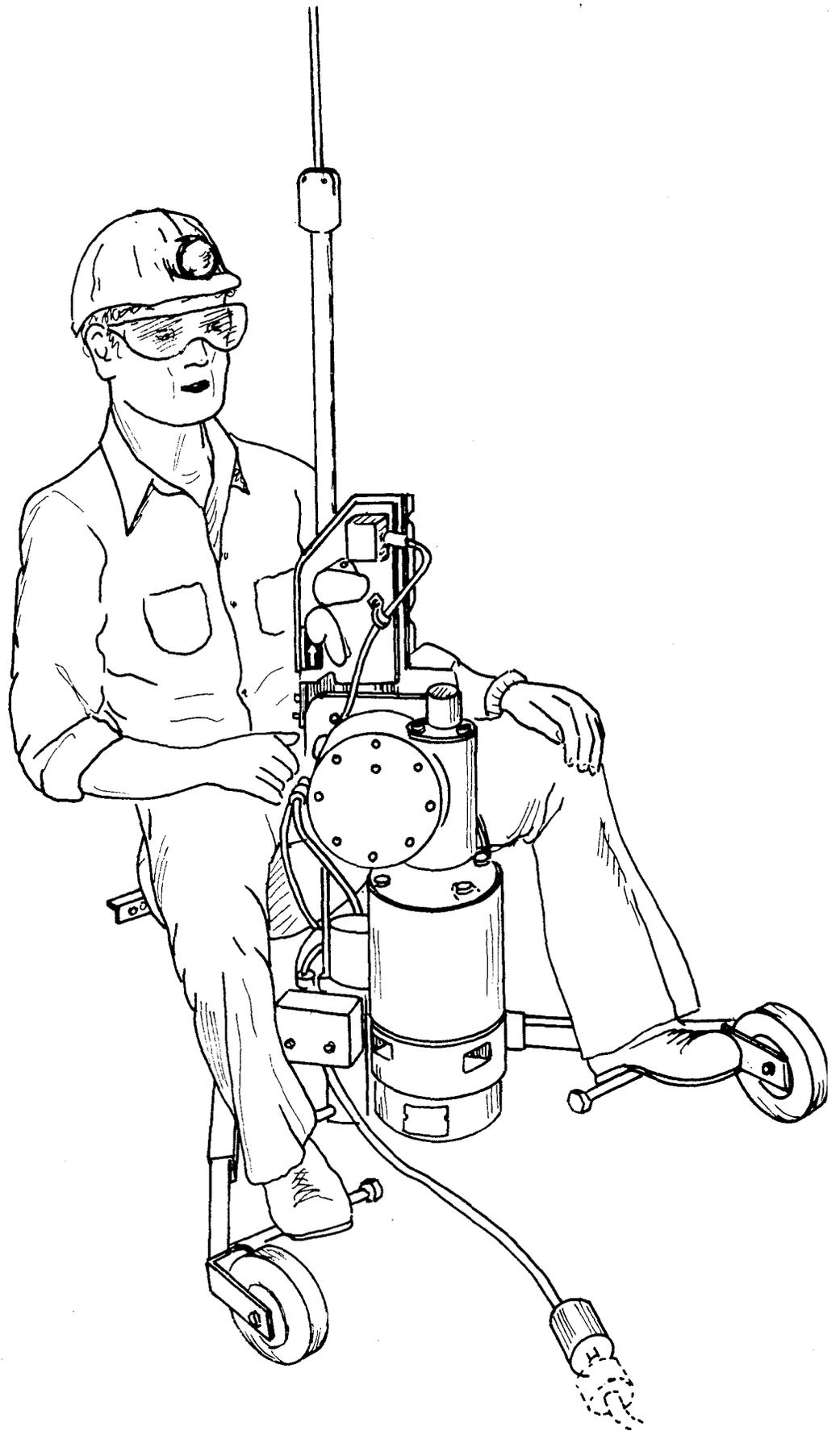


Figure 37. - Rope Climbing System Suitable for
Mine Emergency Rescue Service

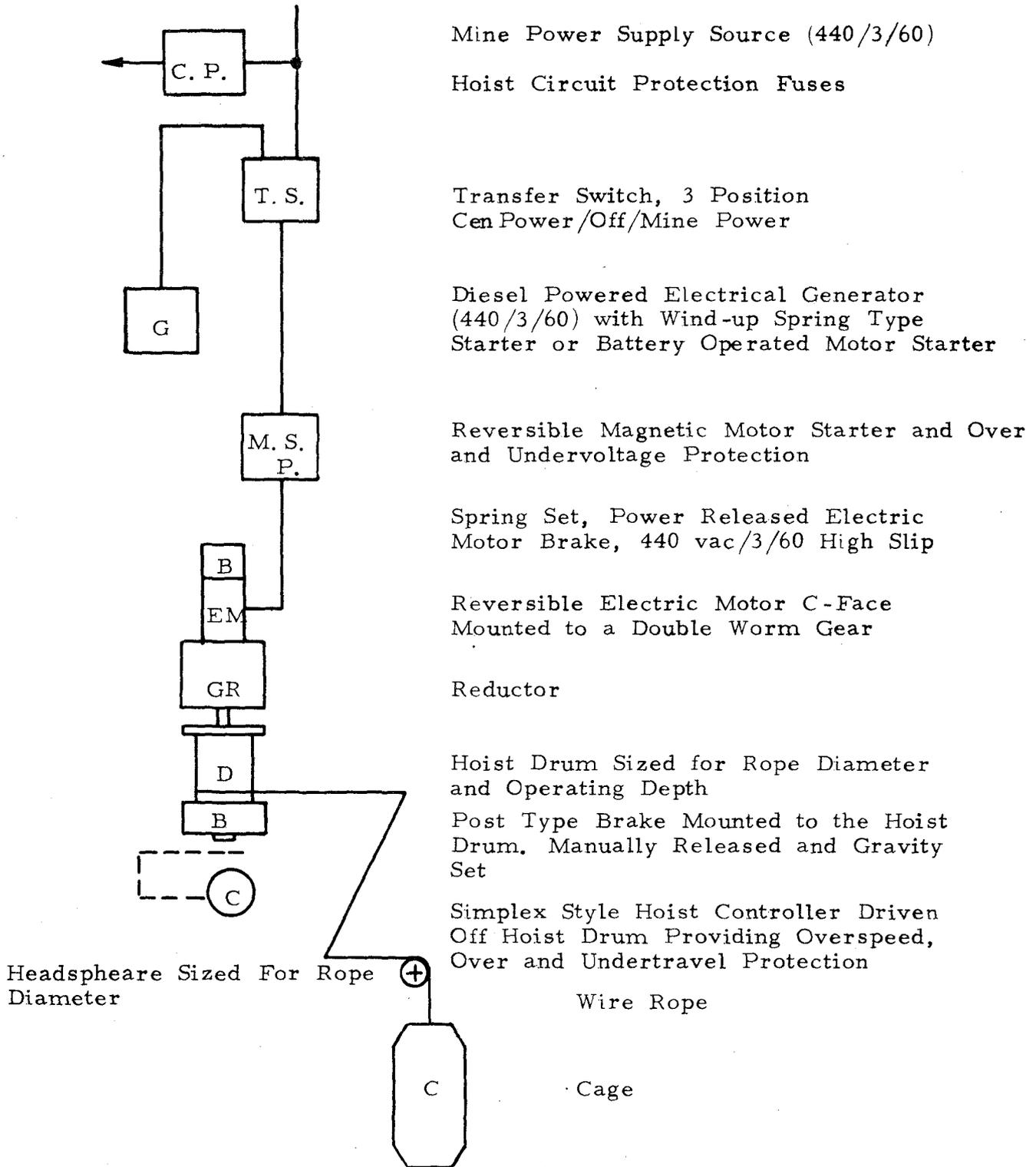


Figure 38 - Layout - General Arrangement of Typical Acceptable
Electrically Powered Mine Emergency Escape Hoist

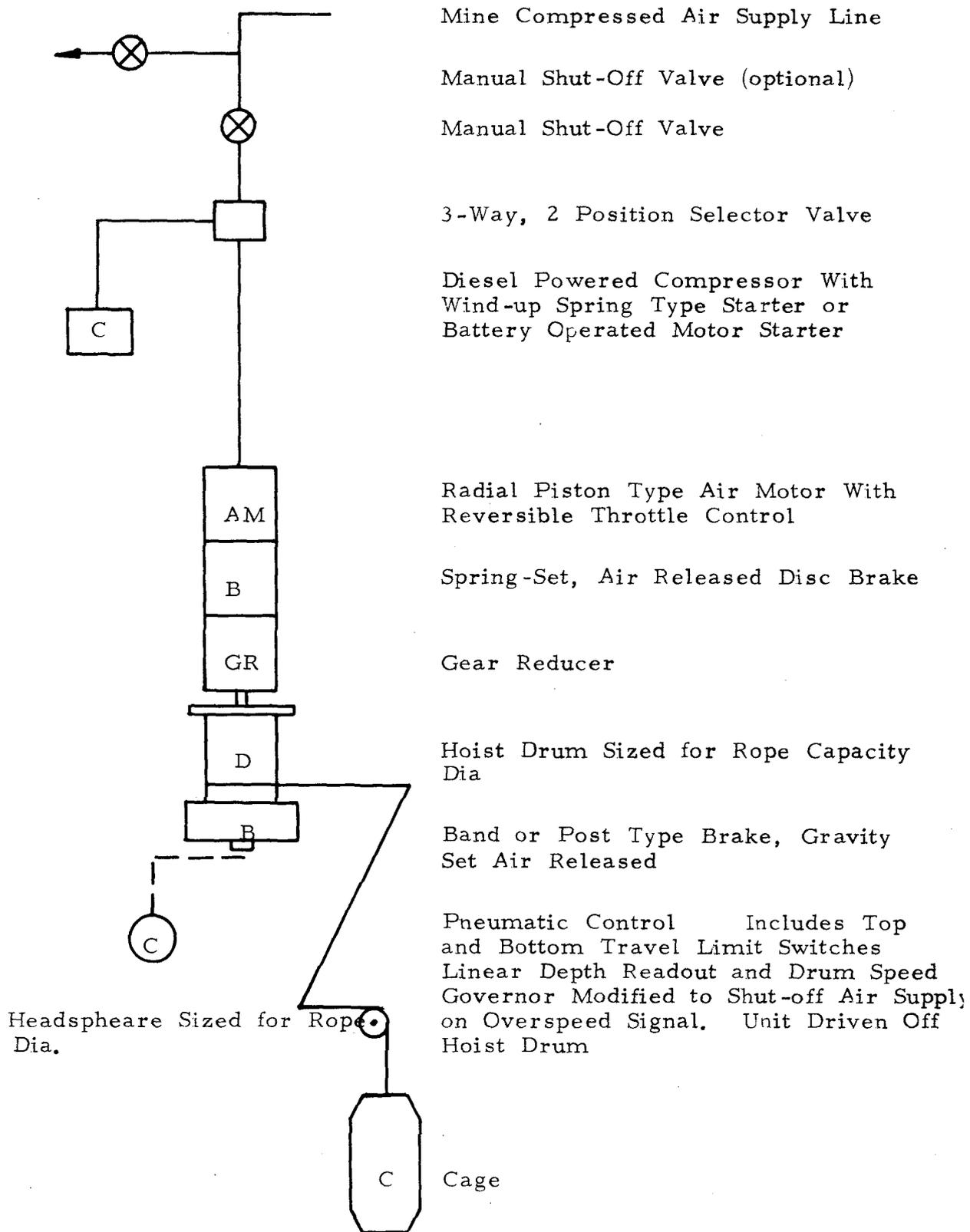


Figure 39 Layout - General Arrangement of Typical Acceptable Air Powered Mine Emergency Escape Hoist

APPENDIX D

FIRE RETARDANTS FOR TIMBER

D.1 Most Effective Salts

A. Ammonium Phosphates

Monammonium phosphate and diammonium phosphate (salts of ortho phosphoric acid) are superior to the triammonium salt in fire-resisting properties. Of these two, the monammonium salt is chemically the more stable. It is also held very retentively by a number of woods, thus reducing leaching out of the salt if exposed to water. Saturated aqueous solutions of mon- or di-ammonium phosphates have vapor preservatives corresponding to an atmospheric relative humidity of 92 to 93 percent; the wood, will, therefore, not attract any moisture at humidities below this figure.

Low concentrations (1 lb dry fire-retardant per cubic foot of the dry, treated timber) will stop flame and high concentration (5 lbs. per cubic foot) will prevent smoldering.

B. Ammonium Sulphate

In low concentrations ammonium sulphate has only a small effect on flame propagation, but its effect is marked when concentrations of the order of 20 percent are employed. It has no appreciable effect on smoldering. It is more corrosive to metals than are the phosphates, but is less corrosive than ammonium chloride or magnesium chloride. It is possible to leach it out of wood by prolonged and continuous action of water. The vapor pressure of the saturated solution corresponds to 81 percent atmospheric humidity.

C. Boric Acid

In low concentrations boric acid has only a small effect on the spread of flame but the retarding effect is marked at high concentrations. It inhibits smoldering, is a very weak acid and has very little corrosive effect on metals. It is practically non-hygroscopic, and timber treated with it is not likely to become damp even at relative humidities over 95 percent. It is toxic to wood-destroying fungi, and certain proprietary timber proofing processes appear to involve the combined use of monammonium phosphate and boric acid.

D. Ammonium Borate

Ammonium borate has a moderate effect on flame propagation when present in large quantities, and a very good effect on stopping smoldering at high or low concentrations. It is not available in commercial quantities. Its hygroscopicity is similar to that of ammonium sulphate.

E. Ammonium Chloride

Ammonium chloride has a noticeable effect in suppressing flame, even at low concentrations; it is very efficient at high concentrations. Low concentrations do not prevent smoldering, but high concentrations are quite effective. It is highly corrosive to most metals, particularly iron and steel. It can be leached out of timber and in saturated solution has a vapor pressure corresponding to relative humidity of 79.5 percent.

F. Magnesium Chloride

Magnesium chloride has a noticeable effect on flame propagation even when present in low concentration; and marked effect with a high concentration. The smoldering which follows the flame is extinguished or reduced, but not stopped, however high the concentration may be.

It is hydrolised by moisture, with the production of hydrochloric acid, and is corrosive to iron and steel. The vapor pressure of the saturated solution corresponds to 35 percent relative humidity and the timber treated will, therefore, always be covered with a film of solution.

D.2 Principal Types of Coating

A. Sodium Silicate

Sodium silicate is a good fire retarder when freshly applied, but it loses its effectiveness if the relative humidity is at all high; thus exposure to a relative humidity exceeding 65 percent causes a serious decrease in the effectiveness after only one month. In fire, sodium silicate swells to a frothy mass (intumescence) which hardens and insulates the wood against heat. This property is destroyed by exposure to moisture.

Manufacturers of many of the proprietary paints containing silicates state that their products have overcome this difficulty.

The reagent may be applied alone; or, better, in a mixture with lime-water and common salt; or with inert fillers such as kaolin or asbestos.

B. Ammonium Phosphate

Strong solutions (25 to 35 percent) of monammonium phosphate or diammonium phosphate give good protection. Two or three coats of hot solution should be applied either with a large flat brush or an ordinary paint spray gun. The solution should be applied as hot as possible, as this improved penetration, and it should be the aim of the operator to apply 4 lbs of reagent, i. e., one gallon of 33 percent solution to every 100 square feet of surface.

C. Calcium Sulphate

Fire-resisting finishes of the calcium sulphate type are based on anhydrite, to which is added an accelerator and a plasticiser to facilitate brushing. These finishes are applied as a layer, 1/16 in thick, preferable in one coat. They are very resistant during the actual period of ignition; an appreciable time is required for the evolution of their water of crystallisation and, until this water has been lost, the temperature cannot rise to a point where decomposition of the wood begins.

An additional advantage of this type is that they dry white (or light grey) and this is useful underground for improving illumination by reflection.

D. Sodium-Silicate-Calcium Sulphate

This combination forms the basis of some of the commonest types of fire-resistant paints. A solution dries to a good off-white color and gives reasonably good protection.

E. Vermiculite (Pyrox Process)

Vermiculite is an 'exfoliated' micaceous mineral, a 1/8 in. coating of which gives good protection.

F. Urea Formaldehyde Resins

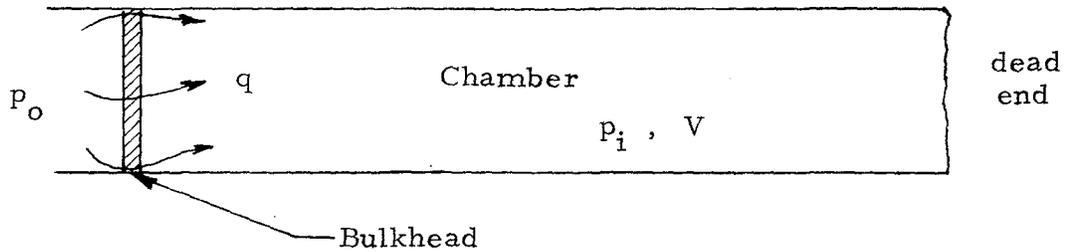
Paints of this material mixed with ammonium phosphate are reasonably effective. When heated the coating swells, blackens and produces a cellular insulating layer.

G. Cement Base Coatings

When intact, cement base coatings provide good fire-resistant protection for timber. The basic difficulty is to ensure that

the coating remains available. Even under normal usage there is the possibility that the timber will shed the cement coating due to differential rates of drying and there is some difficulty in securing good adhesion. The performance of coatings under fire conditions is even less predictable; so much depends on the cement mixture and the method of application. Nevertheless, fireproofing of timber by 'gunniting' with cement-sand mixtures in situ has been practiced in both the U. S. A. and South Africa, and good results are claimed when the mixtures and the conditions under which they are applied are carefully controlled.

APPENDIX E
REFUGE CHAMBER LEAKAGE ANALYSIS



Variables

P_o = pressure outside of chamber (psi)

P_i = pressure inside of chamber (psi)

q = leakage flow rate (cfm)

Q = total leakage (cu. ft.)

V = chamber volume (cu. ft.)

t = time (minutes)

\bar{p} = nominal atmospheric reference pressure (14.7 psi)

A = chamber leakage coefficient (cfm/psi)

$$\Delta P = P_o - P_i$$

Boyle's Law

$$\frac{P_i(t)}{P_i(t + dt)} = \frac{V - qdt}{V}$$

(E. 1)

as $dt \rightarrow 0 \rightarrow \frac{dP_i}{dt} = \frac{q}{V} P_i$

The flow rate can be expressed in terms of the pressure differential, Δp , as follows

$$q = A(\Delta p)^n \quad (\text{E. 2})$$

where n is frequently equal to or close to 1⁽⁸⁾. Making this assumption, and substituting (E. 2) into (E. 1) we obtain

$$\frac{dp_i}{dt} = \frac{A}{V} p_i (p_o - p_i) \quad (\text{E. 3})$$

This is a non-linear differential equation. It can be simplified by recognizing that $p_i = \bar{p} + \epsilon$, where ϵ , will be on the order of 1 psi. Since $\bar{p} = 14.7$ psi, we can say that $p_i \approx \bar{p}$, and write (E. 3) as

$$\frac{dp_i}{dt} = \frac{A}{V} \bar{p} (p_o - p_i) \quad (\text{E. 4})$$

1. Solution for linear pressure rise rate

We assume $p_o = \dot{p} t + \bar{p}$

then the solution to (E. 4) is

$$p_i = \frac{\dot{p}V}{\bar{p}A} \left(e^{-\frac{\bar{p}A}{V} t} - 1 \right) + \dot{p}t + \bar{p} \quad (\text{E. 5})$$

Substituting into E. 2, we obtain

$$q = \frac{\dot{p}V}{\bar{p}} \left(1 - e^{-\frac{\bar{p}A}{V} t} \right) \quad (\text{cfm}) \quad (\text{E. 6})$$

This can be integrated to obtain the total gas flow into the chamber

$$Q = \frac{\dot{p}V}{\bar{p}} \left[t - \frac{V}{\bar{p}A} \left(1 - e^{-\frac{\bar{p}A}{V} t} \right) \right] \quad (\text{cu. ft.}) \quad (\text{E. 7})$$

2. Solution for step pressure rise

We assume $p_o = \text{constant}$

In this case, (E. 3) can be solved directly

$$p_i = \frac{p_o}{\left(\frac{p_o}{\bar{p}} - 1\right) e^{-\frac{Ap_o}{V} t}} \quad (\text{E. 8})$$

Substituting into (E. 2)

$$q = \frac{A p_o}{1 + \frac{\bar{p}}{p_o - \bar{p}}} e^{-\frac{Ap_o}{V} t} \quad (\text{E. 9})$$

$$\approx A(p_o - \bar{p}) e^{-\frac{Ap_o}{V} t}$$

$$Q = \frac{V (p_o - \bar{p})}{\bar{p}} \left(1 - e^{-\frac{Ap_o}{V} t}\right) \quad (\text{E. 10})$$

Figure E.1 shows how solutions (1) and (2) can be combined to illustrate the leakage characteristic of a chamber subjected to a gradual pressure rise which eventually stabilizes after a time t_o . As can be seen, the parameter $V/\bar{p}A$ represents a time during which leakage is delayed. The larger the chamber volume and the better the seal (increasing V and decreasing A respectively), the greater is this delay.

APPENDIX F

GOVERNMENT OFFICES CONTACTED DURING SURVEY

1. MESA Inspection Offices
 - . North Central District
Duluth, Minnesota
 - . South Central District
Dallas, Texas
 - . Rolla Subdistrict
Rolla, Missouri
 - . Rocky Mountain District
Lakewood, Colorado
 - . Salt Lake City Subdistrict
Salt Lake City, Utah
 - . Spokane Field Office
Spokane, Washington
 - . Osburn Field Office
Osburn, Idaho
 - . Phoenix Subdistrict
Phoenix, Arizona

2. MESA Research and Management
 - . Denver Technical Center
Denver, Colorado
 - . Pittsburgh Technical Center
Pittsburgh, Pennsylvania
 - . Metal and Non-Metal Office
Washington, D. C.

3. State Offices (State plan States)
 - . Arizona State Mine Inspector
Phoenix, Arizona
 - . New Mexico State Mine Inspector
Albuquerque, New Mexico

APPENDIX G

TABLE IX

MINE A

1. General

Total Employees: 3000
Maximum No. of Men Underground/Shift: 800
Shifts/Day: 3
Type of Ore: Copper
Daily Production (TPD): 25,000
Mining Method: Room and Pillar
Vein: Dip/Thickness: 10°/15 ft.
Number of Levels/Max. Depth: 1/0 to 1800 ft.

2. Haulage, Conveyances and Travelways

Main Haulage: Rubber Tire/10 miles belts

Man-Ways - Typical Route of Travel to most Remote Sites: Rubber Tired Vehicles

Hoists - Capacity/Speed/Depth:
Depth under construction

3. Ventilation

2,500,000 cfm - 5 surface fans

4. Compressed Air

N/A cfm
10" and 12" lines

5. Incendiary Storage

2 day powder
1000 gal. fuel oil

6. Communications

1 complete system - all shops, dinner areas, and feeder/breaker stations
2 partial systems

7. Escapeway Systems

Man Check System: Section boss log and punch cards

Alarm System: Mine phones with paging system

Posting of Escape Route Maps: No

Escape Signs: Every intersection, fluorescent paint

Evacuation Drills: 2/yr/shift

Refuge Chambers - 1 cinder block - No longer required

TABLE X

MINE B

1. General

Total Employees: 400
Maximum No. of Men Underground/Shift: 200
Shifts/Day: 3
Type of Ore: Lead, Zinc, Silver, Copper
Daily Production (TPD): 2,300
Mining Method: Square set, cut and fill, open stope, long hole
Vein: Dip/Thickness: 30° - 45°/8 ft. max.
Number of Levels/Max. Depth: 13/2700 ft.

2. Haulage, Conveyances and Travelways

Main Haulage: Rail

Man-Ways - Typical Route of Travel to most Remote Sites: Rail/Hoists/Walk

Hoists - Capacity/Speed/Depth:

No. 1 15 man/1100 fpm/5000 ft.
No. 2 dbl drum 30 man per side/1000 fpm/4500 ft.
No. 3 dbl drum 14 man per side/1000 fpm/4500 ft.

3. Ventilation

260000 cfm
1800 HP

4. Compressed Air

1400 cfm
110 psi
4 compressors on surface 12" line

5. Incendiary Storage

1/2 week supply powder
300 gal. fuel oil

6. Communications

Mine phones, sand fill phones at all shaft stations, shops, hoist rooms

7. Escapeway Systems

Man Check System: Time cards and computer cards

Alarm System: Stench in compressed air and ventilation

Posting of Escape Route Maps: All stations, shops, hoist rooms, main intersections

Escape Signs: None

Evacuation Drills: 2/yr/shift

TABLE XI

MINE C

1. General

Total Employees: 300
Maximum No. of Men Underground/Shift: 190
Shifts/Day: 3
Type of Ore: Lead, Zinc, Silver
Daily Production (TPD): 900
Mining Method: Cut and fill, backstope brest down
Vein: Dip/Thickness: 90°/4' untimbered/30' timbered
Number of Levels/Max. Depth: 13 active/7700 ft.

2. Haulage, Conveyances and Travelways

Main Haulage: 24" gauge, diesel/main, battery/levels

Man-Ways - Typical Route of Travel to most Remote Sites: Train/Hoist/Walk

Hoists - Capacity/Speed/Depth:

No. 1 Dbl drum 27* men per side/1500 fpm/5700 ft.

No. 2 Dbl drum 18 men per side/800 fpm/3150 ft.

No. 3 Dbl drum 18 men per side/1000 fpm/2150 ft.

* Only 9 men during ore hoisting

3. Ventilation

100,000 cfm main, 300 hp. total

4. Compressed Air

8000 cfm, 100 psi

3 underground compressors, 10" pipe

5. Incendiary Storage

1 week supply powder

Fuel oil on surface

6. Communications

2 telephone systems, 1 sound, 1 bell system at stations, shops,
hoist rooms

7. Escapeway Systems

Man Check System: Brass

Alarm System: Stench in compressed air

Posting of Escape Route Maps: No

Escape Signs: Yes

Evacuation Drills: 2/yr/shift

TABLE XII

MINE D

1. General

Total Employees: 380
Maximum No. of Men Underground/Shift: 200
Shifts/Day: 2
Type of Ore: Lead, Zinc
Daily Production (TPD): 2000
Mining Method: Shrinkage stoping
Vein: Dip/Thickness: 80°/5 ft.
Number of Levels/Max. Depth: 10/2900 ft.

2. Haulage, Conveyances and Travelways

Main Haulage: Rail

Man-Ways - Typical Route of Travel to most Remote Sites: Rail Car/Hoist/Walk

Hoists - Capacity/Speed/Depth:

No. 1 12 men/420 fpm/1400 ft.
No. 2 10 men/280 fpm/1700 ft.
No. 3 19 men/300 fpm/1000 ft.
No. 4 dbl drum 18 men each side/450 fpm/400 ft.
No. 5 18 men/335 fpm/500 ft.

3. Ventilation

100,000 cfm
5 fans plus natural ventilation

4. Compressed Air

11,000 cfm/7 underground/6 surface compressors

5. Incendiary Storage

300 gal. Fuel
1/2 week powder

6. Communications

Bell telephone at stations, shops, hoist rooms

7. Escapeway Systems

Man Check System: Brass

Alarm System: Compressed air stench, injected by hoist operators

Posting of Escape Route Maps: At some shaft stations and major raises

Escape Signs: Few

Evacuation Drills: 2/yr/to stations

TABLE XIII

MINE E

1. General

Total Employees: 64
Maximum No. of Men Underground/Shift: 32
Shifts/Day: 2
Type of Ore: Uranium
Daily Production (TPD): N/A
Mining Method: Modified room and pillar
Vein: Dip/Thickness: Lens and lod stream bed/8 ft.
Number of Levels/Max. Depth: 1/1300 ft.

2. Haulage, Conveyances and Travelways

Main Haulage: Rail, 36" gauge, diesel and battery
Man-Ways - Typical Route of Travel to most Remote Sites: Hoist/Walk
Hoists - Capacity/Speed/Depth:
12 man/400 fpm

3. Ventilation

250000 cfm
7 fans - approximately 700 total horsepower

4. Compressed Air

1800 cfm
100 psi
2 compressors (surface) 6 in. line

5. Incendiary Storage

1 day powder
Fuel line from surface

6. Communications

Crank type at stations and shops

7. Escapeway Systems

Man Check System: Brass
Alarm System: Stench in compressed air
Posting of Escape Route Maps:
Escape Signs: Major intersections and stations
Evacuation Drills: 2/yr/Shift

TABLE XIV

MINE F

1. General

Total Employees: 175
Maximum No. of Men Underground/Shift: 79
Shifts/Day: 3
Type of Ore: Lead, Zinc
Daily Production (TPD): N/A
Mining Method: Random room and pillar
Vein: Dip/Thickness: Massive
Number of Levels/:Max. Depth: 2/1000 ft.

2. Haulage, Conveyances and Travelways

Main Haulage: Front end loaders, skips

Man-Ways - Typical Route of Travel to most Remote Sites: Hoist/Trucks

Hoists - Capacity/Speed/Depth:

25 men/934 fpm
6/860

3. Ventilation

200,000 cfm

2 (100 HP) Fans underground 72" Joy

4. Compressed Air

4500 cfm

5. Incendiary Storage

7600 gal fuel oil

4700 gal. hydraulic oil

explosives 2 week supply (5 tons)

6. Communications

1. Bell system with 4 underground phones
2. Intercom

7. Escapeway Systems

Man Check System: Time card

Alarm System: Phones, intercom, stench in compressed air

Posting of Escape Route Maps: None

Escape Signs: None

Evacuation Drills: 2/yr.

TABLE XV

MINE G

1. General

Total Employees: 433
Maximum No. of Men Underground/Shift: 187
Shifts/Day: 3
Type of Ore: Lead, Zinc
Daily Production (TPD): N/A
Mining Method: Block caving, caving stopes, open stopes, shrink stopes
Vein: Dip/Thickness: Massive
Number of Levels/Max. Depth: 22/2475 ft.

2. Haulage, Conveyances and Travelways

Main Haulage:

Man-Ways - Typical Route of Travel to most Remote Sites: Hoist/Walk

Hoists - Capacity/Speed/Depth:

50/1250 fpm/
30/1250 fpm/
2 Hoists 10 men/2600 fpm/
15/1250/

3. Ventilation

366,200 cfm
Total horsepower 6 fans 755 HP

4. Compressed Air

7 compressors total flow 25,000 cfm

5. Incendiary Storage

30,000 No.
2800 gal. oil

6. Communications

Bell, cage radio to hoistman

7. Escapeway Systems

Man Check System: Time cards

Alarm System: Stench and phone, vent and compressor

Posting of Escape Route Maps: N/A

Escape Signs: Very few

Evacuation Drills: 2/yr

TABLE XVI

MINE H

1. General

Total Employees: 159
Maximum No. of Men Underground/Shift: 86
Shifts/Day: 3
Type of Ore: Limestone
Daily Production (TPD): N/A
Mining Method: Room and pillar
Vein: Dip/Thickness: Massive/soft
Number of Levels/Max. Depth: 1/280 ft.

2. Haulage, Conveyances and Travelways

Main Haulage: Rubber tired vehicles

Man-Ways - Typical Route of Travel to most Remote Sites:

Hoists - Capacity/Speed/Depth:

None

3. Ventilation

600,000 cfm - includes some natural ventilation

4. 20 fans - 300 HP
Compressed Air

3 surface compressors - total 5500 cfm

5. Incendiary Storage

100,000 No.
500 gal hydraulic oil
200 gal. fuel oil

6. Communications

One phone to mine office

7. Escapeway Systems

Man Check System: Tags

Alarm System: Stench in compressed air, vehicle with siren and
flashing lights

Posting of Escape Route Maps:

Escape Signs: None

Evacuation Drills: 2/yr.

TABLE XVII

MINE I

1. General

Total Employees: 111
Maximum No. of Men Underground/Shift: 56
Shifts/Day: 3
Type of Ore: Salt
Daily Production (TPD): N/A
Mining Method: Room and pillar
Vein: Dip/Thickness: Flat/30 ft.
Number of Levels/Max. Depth: 1/1130 ft.

2. Haulage, Conveyances and Travelways

Main Haulage: Conveyor, LHD

Man-Ways - Typical Route of Travel to most Remote Sites: Hoist/Rubber Tired Diesel

Hoists - Capacity/Speed/Depth:

No. 1 db1 drum 6 men/600 fpm/1130 ft.

No. 2 single drum 12 men/600 fpm/1130 ft.

3. Ventilation

160,000 cfm

4. Compressed Air

None

5. Incendiary Storage

40,000 No. AN/FO (2 weeks)

500 gal fuel oil

200 gal fuel oil

6. Communications

Bell system

7. Escapeway Systems

Man Check System: Brass

Alarm System: Siren on truck

Posting of Escape Route Maps:

Escape Signs: At major intersections

Evacuation Drills: 2/yr/shift

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