A mining research contract report
OCTOBER 1983

DEVELOPMENT OF GUIDELINES FOR RESCUE CHAMBERS, VOLUME II, APPENDICES

Contract J0387210

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

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

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

17\. Document Analysis a. Descriptors
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Barricading
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FOREWORD

This report was prepared by Foster-Miller Associates, Inc. (FMA), Waltham, MA, under United States Bureau of Mines (USBM) Contract No. JO387210. The contract was initiated under the Minerals Health and Safety Technology Program. It was administered under the technical direction of Pittsburgh Research Center with John Kovac acting as Technical Project Officer. Larry Guess was the Contract Specialist for USBM. This report is a summary of the work recently completed as a part of this contract during the period July 1978 to July 1982. This report was submitted by the authors on 31 October 1983.

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

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

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APPENDIX A

HISTORY OF BARRICADING

This appendix contains an analysis and evaluation of the experiences of miners who had to choose between barricading and escaping. Previous similar studies examined those choices during the years 1909 to 1940. Since then, 40 miners succumbed to the toxic afterdamp from fires and explosions whereas 127 lived because with strong leadership they waited patiently behind well-located and well-constructed barricades.

Barricading was described in the 1912 Bureau of Mines' Technical Paper 24. (1) The 1923 Bureau's Miners' Circular 25 detailed 18 fires and explosions in which 441 miners survived behind barricades. (2) The vast differences between "good" and "bad" barricades were thoroughly documented and illustrated. In 1940, Dan Harrington and Bill Fene, who had been involved in more than 100 rescue and recovery operations, hailed barricading as a life-saving measure in Miners' Circular 42. (3) Since 1963, thousands of miners learned the whys, wheres and hows of barricading in the Bureau's award-winning film "Plan for Survival." In 1970, the National Academy of Engineering recommended greater emphasis on research for rescue and survival, including barricading. (4)

The following discussions bring the records on barricading to date. They are based on available Federal, State, Union and Coroner reports for 86 of the 89 fires and explosions which from 1940 through 1980 claimed five or more lives.* They include three others in which no lives were lost in part because of barricading. Information from those reports was supplemented by the author's personal knowledge of 7 and his discussions with persons directly involved in 18 of those 92 accidents.

This appendix is divided into the following subsections:

a. A.1 Summary and Conclusions

b. A.2 Influence of Technology on Barricading

c. A.3 Individual Mine Accidents, 1940 to 1946

d. A.4 Individual Mine Accidents, 1947 to 1953

*Official reports have not been released on the explosions in the No. 9 Mine (November 20, 1968) and in Scotia (March 9 and 11, 1976).

A.1 Summary and Conclusions

The history of barricading is summarized in Table A-1. To allow comparisons among the five periods, the data are for only those fires and explosions in which five or more miners died. Information prior to 1967 is sparse on accidents causing the deaths of up to five miners.

A strong relationship between the decline in disasters and advances in technology is inferred by the data in Table A-1, as further explained in subsection A.2. Neither the decline nor the advances, however, appears to have affected dependency on barricading; in fact, these data and those in Figure A-1 teach us nothing about barricading other than they helped some miners to live while others died.

TABLE A-1. - History of barricading in mine disasters

	Time period					
	1909 to 1922	1923 to 1939	1940 to 1946	1947 to 1953	1954 to 1969	1970 to 1980
DISASTERS						
Total during period	148	125	38	19	23	9
Per Year	10.6	7.4	5.4	2.7	1.4	0.8
FATALITIES						
Total during period	3885	3926	777	393	398	183
Per Year	278	231	111	56	25	17
BARRICADES						
Number built	16	28	5	0	4	2
Could have been built	80	30	10	10	5	2
LIVES SAVED by barricading	324	552	30	0	68	29
LIVES WHICH MIGHT HAVE BEEN SAVED	1391	625	177	65	54	108

41
MINE DISASTERS

3871 MINERS
UNDERGROUND

	LIVED	DIED
1509 UNAFFECTED	1509	-
652 DIED IMMEDIATELY	-	652
TRIED TO ESCAPE		
202 IMMEDIATELY	95	107
1286 SUBSEQUENTLY	1084	202
BARRICADED		
61 IMMEDIATELY	12	49
161 SUBSEQUENTLY	115	46

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

The data in Figure A-1, for the years since 1940, are for 14 fires and explosions in which some miners barricaded and 27 others in which barricades might have saved lives. Those 41 were the only incidences from 1940 through 1980 in which the author believes barricading could be considered an appropriate safeguard. In the other 51 disasters, again in the author's opinion, death came from flames and violence and few if any survivors were at risk as long as there was neither a second explosion nor a major disruption of ventilation. Second explosions, such as in the 1968 No. 9 Mine disaster, could be expected to cause the deaths of most persons attempting escape, destroy some if not all barricades, or prevent timely, efficient rescue operations.*

*After 10 years of monumental effort, attempts to reach all working sections in the No. 9 Mine had to be abandoned. There have been more than 10 other fires and explosions during the past three decades in which second explosions or major ventilation disruptions prevented rescue teams from reaching trapped miners. Rescue might have been made to some through boreholes drilled from the surface to near their place of refuge had the technology been available.

Figure A-1 summarizes actions of miners in the 41 fires and explosions previously referred to. The data show the majority were at risk. The data also show fewer than one of five miners who had to choose between barricading or escape decided to barricade; and, one of every four miners who chose to escape, died in the attempt.

Since 1940, barricading was probably saved at least 127 miners. Most of them credited their lives to having been trained in barricading and to the strong leadership exercised by at least one of the trapped miners. The deaths of 401 other miners who tried to escape or who built bad barricades indicates that today as it was years ago many miners do not understand the basic principles that bear so greatly on life or death following fire or explosion in a mine.

Death from fire or explosion in a mine may not come quick. Most escape the violence and flame. Many, however, fall victim to the toxic afterdamp after traveling long distances. To quote Dan Harrington and Bill Fene, pioneers in mine rescue and survival, "this report has been written in the hope that any miner who may be trapped in a mine by an explosion or a fire may escape death by knowing how others have saved their lives by sealing themselves promptly behind well-located and well-constructed barricades."

An explosion in extensive mine workings is such a complex phenomenon that no one can explain with certainty all the reasons for its devious path, fluctuating violence, changing flame shape, the distance of flame travel and other characteristics. What happens at any point along the path of an explosion depends to an important degree on its past history. The air in advance of the explosion flame is preconditioned; i.e., mixed with mine dust and/or gas, precompressed, and preheated. These processes are affected by the availability of fuel, the availability of oxygen, the distribution and amount of rock dust and other quenching agent, the nature and potency of the ignition zone, and the geometry and other properties of the mine passageways.

From the above, it seems likely that neither escape from explosion nor places of refuge from explosion-produced gases can be preplanned with certainty. Thus, until oxygen self-rescuers are available to all and miners are properly trained in their use, knowing where and how to barricade will continue to be a life-saving measure. The record is also clear on the fact that the lives of barricaded miners depend on properly-conducted mine rescue operations.

A.2 Influence of Technology on Barricading

Major changes in mining practices, equipment and regulations have occurred over the years. During those years, there also was a marked reduction in the frequency and severity of fires and explosions in mines. To consider the impact of technological advances and changes, for the future as well as in the past, on the need for miners to know when, where and how to barricade, the history of barricading was examined during the following six periods:*

a. 1909 to 1922 - Barricading based on intuition and heresay.

b. 1922 to 1939 - Barricading starts to become part of training.

c. 1940 to 1946 - War years

d. 1949 to 1953 - Mechanized mining begins

e. 1954 to 1969 - Federal Coal Mine Safety Act (1952) is implemented.

f. 1970 to 1980 - Federal Mine Safety and Health Act (1969 and 1977) is implemented.

The following paragraphs discuss each of these periods in more detail.

1909 through 1922 was the period described in Miners' Circular 25, when barricading was based mainly on intuition and heresay. Investigations into the causes for explosion were in their formative years; few miners believed coal dust could either propagate the flame from or increase the violence of explosions.

1923 through 1939 was the period described in Miners' Circular 42, when progressive operators and USBM specialists made barricading part of their training programs. The causes of explosions were well-known, and preventative measures such as rock dusting and water allaying were beginning to be used. Black powder, however, was the common blasting agent. Open flame

*The reader will note this history emphasizes coal mining; this is due solely to the fact that the number of and deaths from fires and explosions in coal mines far exceeds those in metal and nonmetal mines.

carbide lamps were used by most miners; indeed, the use of permissible electric cap lamps was believed to create a hazard, "gas accumulations could not be ignited as with carbide lamps." (5) Self-rescuers were considered a hazard too; the senior reviewer of the USBM Pond Creek disaster investigation report (6) rejected the recommendation for self-rescuers stating "The so-called rescuer... is very likely to be a menace to the lives of the vast majority of those who try to use it."

1940 through 1946 were the war years, when to quote John L. Lewis, "the demand for maximum tonnage at minimum cost, little provision of time for maintenance and supervision, the shortage of skilled labor, led many to neglect even rudimentary precautionary measures." In 1941, Congress passed the Coal Mines Inspection and Investigation Act which gives the USBM its first authority to examine health and safety conditions in coal mines. Each state, however, had the sole right to establish and enforce regulations; the kinds of regulations and the efforts made to enforce them differed greatly among states. This too was a period of strong growth in the United Mine Workers Union. Their "Strikes for Safety" closed many coal mines and led the Government to seize the mines. This in turn led, in 1946, to the Lewis-Krug Agreement and the consensus-developed Federal Mine Safety Code for Bituminous Coal and Lignite Mines. Those two documents were intended to assure both safety and production. The power of enforcement, which included withdrawal of miners from imminent danger, was vested in the Coal Mine Administrator, a naval officer in Washington, DC; the authority was not delegated to inspectors in mines.

1947 through 1953 was the period when tremendous postwar industrial demands caused many mines to change from hand-and-mule to mechanized mining. Shovels, for example, were replaced by dc-powered continuous miners that when started produced a current flow approaching a bolted fault. These and many of the other new tools for miners presented powerful but little understood sources for ignition of methane and coal dust. The increased hazard fortunately was tempered by a major albeit unplanned advance in safety, at least a major cause for reducing the toll from fires and explosions. With hand loading it was not uncommon to have 50 to several hundred miners on a single split of air; mechanization, to be efficient, required numerous separated sections. This period began with the deaths of 111 miners in the Centralia No. 5 explosion. The reprecussions led some states to revise mining laws and enforcement practices; some wage agreements required compliance by both miners and operators with the 1946 Code. This period ended with the loss of 110 lives in the Orient No. 2 explosion. From that disaster came the Federal Coal Mine Safety Act which, though it became law in 1952, could not be implemented until 1954.

1954 through 1969 was the period when, for the first time, inspectors of the USBM had authority to enforce safety in mines. That authority, however, could be exercised only if the State in which the mine was located failed to enforce either the Act or equivalent State law. Further, only states had rights to remedy unhealthy working conditions. The Act was intended only to reduce the chance for explosion. Among its key provisions were: excessive accumulations of coal dust were to be removed; 65 percent incombustible was to be maintained; smoking, carrying smoking materials and using nonpermissible face equipment was prohibited in gassy mines; neither black powder nor open flame carbide lamps could be used. A few specifics on ventilation and mining practices were given. This period closed when the loss of 78 lives in the Consol No. 9 Mine explosion led to the Coal Mine Health and Safety Act of 1969.

1970 through 1980 was the period when the Act of 1969 and its 1977 amendments to include noncoal mines were being enforced. Enforcement practices during this period differed greatly from those of the prior period; violations led to fines and frequently to withdrawal of miners. Possibly of greater importance were the technical solutions being developed, improved and used. Chief among these, in this author's opinion, was the almost universal use of ac- rather than dc-powered face equipment together with the limitation of one mining machine to a single split of air. Other major changes were using well maintained trailing cables and grounding circuits, bleeder entries, slippage and sequence switches on belt conveyors and the virtual elimination of closely spaced posts and sets.

As noted earlier, disasters involving barricading prior to 1940 have been previously documented. Miners built barricades in 14 mine fires and explosions in the years from 1940 through 1980. They did not but could have in 27 others. Factors impacting those experiences are discussed in the following four subsections, which contain analyses of individual mine accidents in the four time periods subsequent to 1940.

A.3 Mine Accidents, 1940 to 1946

As previously discussed, these were the war years. Production of coal, metals and nonmetallics were critical to our Nation's defense. Many miners were those who were either too young or too old to serve in our armed forces; many had little prewar mining experience. In the typical coal mine, hundreds of miners worked in adjoining rooms blasting coal off the solid with black powder and dynamite and hand shovelling the coal into wooden cars.

During these 7 years, 777 miners lost their lives in 38 disasters. In five disasters 30 miners barricaded and lived. These five disasters are described in the following five subsections. Table A-2 lists an additional 10 mine accidents during this period in which miners did not barricade, and the reasons for such action.

A.3.1 Belva No. 1 Mine Explosion, December 16, 1945 (16)

Background

Of 31 miners underground at the time of this explosion only six of the nine who barricaded lived. The greater portion of the mine, illustrated in Figure A-2, was engulfed by flames. Stoppings were destroyed or damaged out to the Portal. For some undetermined reason, only the workings between Nos. 3 and 5 Left, where the nine miners barricaded, were relatively free of afterdamp.

Belva No. 1 Mine, in Fourmile, Bell County, KY, was in the 34-in. thick Straight Creek coal seam. Methane and coal dust ignited by a blown-out shot was the cause for this explosion. Coal dust, unprotected by rock dust, propagated the flame.

Barricading and Other Key Events

The shift had just begun. The motorman and brakeman of the last mantrip into the mine were placing mine cars in 5 Left when they were thrown about by a strong rush of air filled with dust. Dense smoke made them realise they could not escape so they went into 5 Left where they met seven miners.

After realizing their situation, they searched for a place to barricade. They chose 1 Left (see center area on Figure A-3). They took a mine door from 3 Left, to block flows from 3 Left into their area of refuge. Brattice check curtains hastily hung across other openings enclosed a volume of 80,000 ft^3. Under best conditions, that volume might support the lives of the nine miners for up to 300 hr.

TABLE A-2. - Ten accidents in which miners did not barricade, 1940 to 1946

Mine	Date	Miners in danger but did not barricade		
		Survived	Died	Reasons for not barricading
Boyd (7)*	1-5-43	16	1	They stopped blower fan to prevent fire gas flows towards them. Used air from compressed air line until rescued.
Carswell (8)	1-22-41	13	1	Although he was badly injured, the foreman led 10 miners out. Teams rescued three others, one of whom died later from burns and asphyxiation.
Christoper No. 3 (9)	5-12-42	61	5	Foreman ordered 54 miners building barricades at bottom of a borehole to join him. He led them and six others to safety through old returns. Another five died trying to escape through smoke-filled main headings.
Daniel Boone (10)	10-27-41	38	0	These 38 miners believed they could escape; three were injured by smoke inhalation.
Havaco No. 9 (11)	1-15-46	255	14	All but 20 decided to escape. Those 20 were too injured to do anything for themselves; 14 of them died from asphyxiation.
Nellis No. 3 (12)	11-6-43	11	1	Foreman led 10 through smoke. Of those too injured to do anything for themselves, one died.
Peabody No. 47 (13)	12-28-41	6	1	They believed they could escape; one succumbed to CO.
Pond Creek No. 1 (6)	1-10-40	0	66	Fifteen died in a group at the mouth of their section; one was too injured to do anything for himself; 50 others who tried to escape died of CO.
Sunnyside No. 1 Mine (14)	5-9-45	62	0	They believed they could escape. Rescue teams later saved 10 overcome by CO.
Willow Grove (15)	3-16-40	95	0	Three miners unaware of explosion worked until quitting time, when they were met by a rescue team. Sixty-nine who were aware waited in workings free of toxic gases because outby blown-out overcasts and stoppings had short-circuited air; they were rescued 5 hr later. Another 23 who attempted escape through the main headings, collapsed and were saved 6-1/2 hr later.

*Numbers in parenthesis refer to references in subsection A.8.

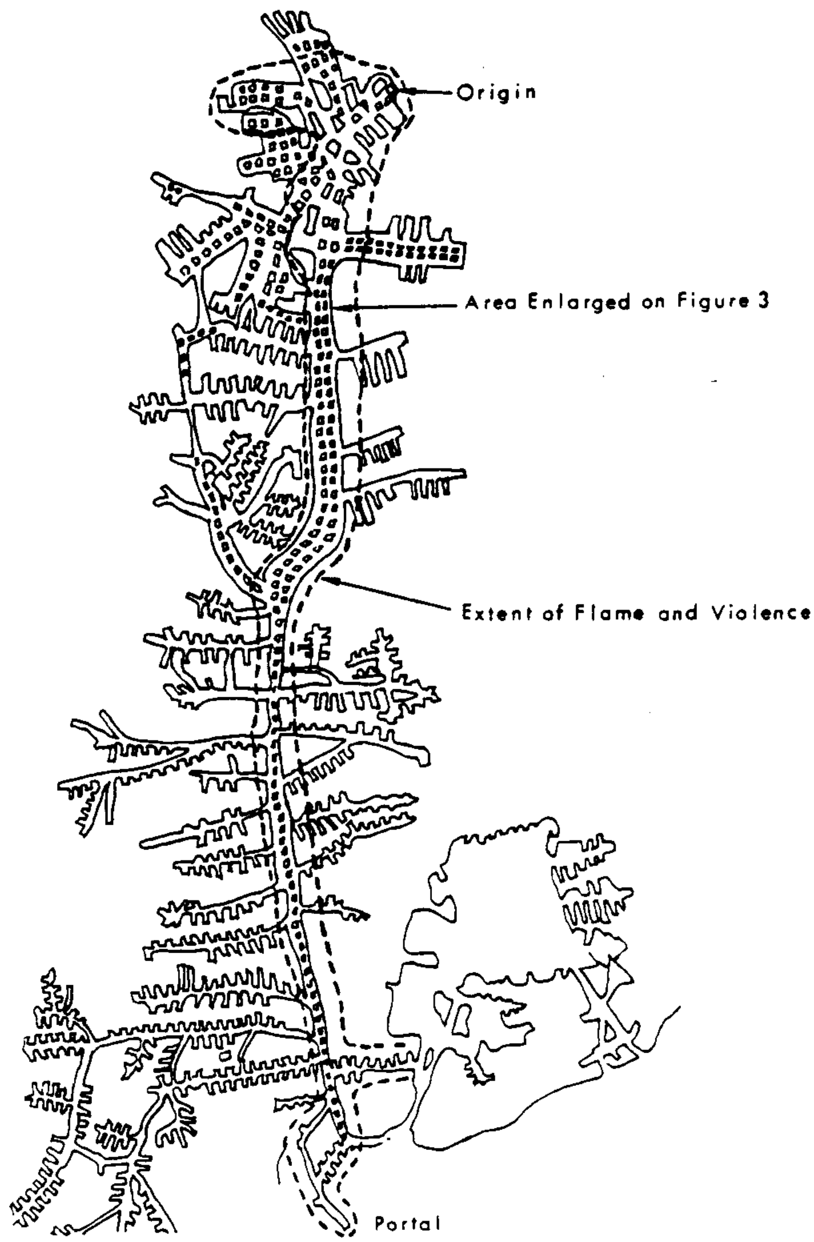

FIGURE A-2. - Belva No. 1 Mine explosion.

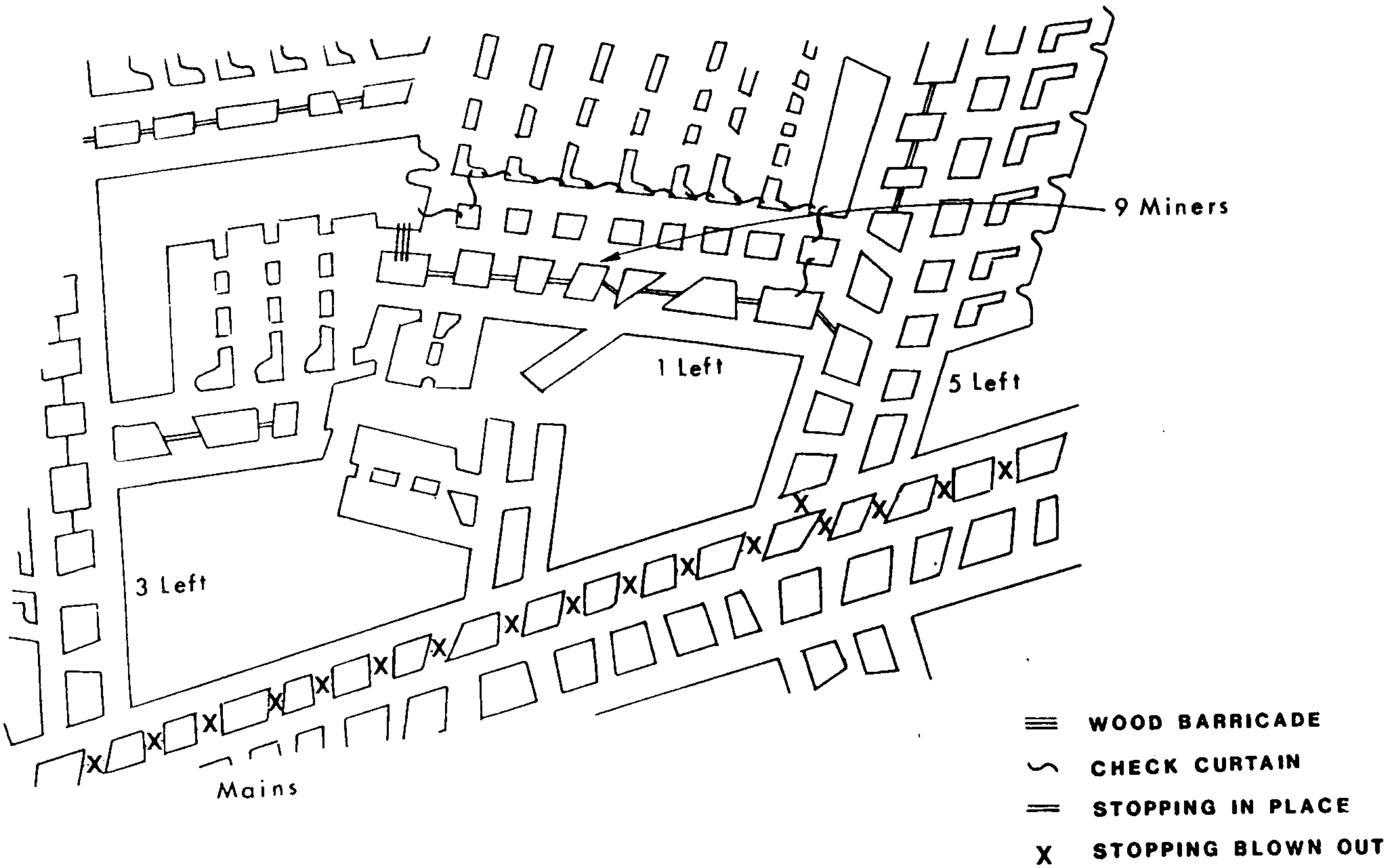

FIGURE A-3. - Barricades in Belva No. 1 Mine.

During the next 2 days the group made several attempts to escape. Each attempt stopped when one of the group "went down;" they dragged themselves and their collapsed buddy back into the barricade.

On those trips they marked the ribs with chalk to tell others where their barricade was. While behind the barricades most laid with their faces on the floor.

Rescue teams reached the barricade 54 hr after the explosion. One of the nine was dead. They brought the remaining eight out on stretchers. One survivor died 2 days later. The third died several months afterwards, but as a direct result of CO and smoke inhalation. That miner had diabetes; persons who suffer from diabetes are likely to suffer severe-to-fatal restriction of arterial blood flow as a result of exposure to CO-concentrations that otherwise might not be lethal.

A.3.2 Nu-Rex Mine Explosion, May 5, 1943 (17)

Background

Flames and forces extended from a face 2200 ft through headings, up the slope and into the tipple. Eighteen miners lived because they barricaded as described later. Three other miners, unaware of the explosion until found by a rescue party 2 hr later, lived because they were on a separate split of air. Two miners working on the slope and 75 ft from the portal crawled out to safety though both were severely burned and one had broken his leg. Ten miners died. In summary, of the 33 miners underground:

a. Eighteen barricaded and lived.

b. Six could have barricaded, did not and died.

c. Four were killed by the flames and forces of the explosion.

d. Three were not exposed.

e. Two were injured, escaped and lived.

The Nu-Rex Mine, near LaFollette, TN, was in the 32-in. thick Rex coal seam. The explosion occurred shortly after 1 p.m. when face operations broke into an area that had been abandoned for more than a year, presumably, methane flowed from that area into the active face.

Electrical arcs from a nonpermissible cutting machine were the likely cause for the ignition. However, shot holes had already been loaded; subsequent blasting of the cracked-methane filled coal could have led to blown-out shots and "cutoffs" which experience has taught might have caused a more widespread explosion, being a more powerful and positive ignition source than an electrical arc.

Barricading and Other Key Events

Four miners in 2 Right (see right side of Figure A-4) were buffeted by a surge of air. Soon afterwards dust and smoke created almost zero visibility. These four following the ribs towards the No. 2 Main Headings encountered such dense smoke and foul air they thought it best to retreat. They crawled through a room they knew was cut into No. 1 Right (see heavy arrow line). Because the air was clearer, they decided to barricade. In their search for materials they met 14 miners who were attempting escape from 1 Right. They prevailed on those 14 to stay; a most persuasive factor was two of the 14 had just encountered dense smoke near No. 3 room.

A barricade was built near the end and across the two entries. Multiple layers of brattice cloth, ventilation tubing, and their coats were used for this. As the hours passed some miners became resless. Considerable coaxing was necessary to prevent their leaving. One did, but 50 ft from the barricade he collapsed. Fortunately, his cries were heard and he was helped back to the safety of the barricade where he recovered. Seven hours later a rescue team reached them; good ventilation to the barricade was restored; and, the 18 miners were saved.

Barricading was the probable cause for those 18 miners living through this disaster. The bodies of six others who had been working in 1 and 2 Right were found in the No. 2 Main Headings. They showed signs typical of death from an oxygen deficiency.

Had this explosion occurred today, barricading would not have been the critical lifesaving measure it was then. All but the four miners at the origin of the explosion, could have survived. The 18 who barricaded and the other six who died had at least 20 min to obtain oxygen self-rescuers. With oxgen, those 24 miners could have escaped the mine without difficulty in less than 40 min. Further, compliance with present regulations for rock dusting, coal accumulations, ventilation and permissibility probably would have limited explosion forces and flames to a far smaller extent.

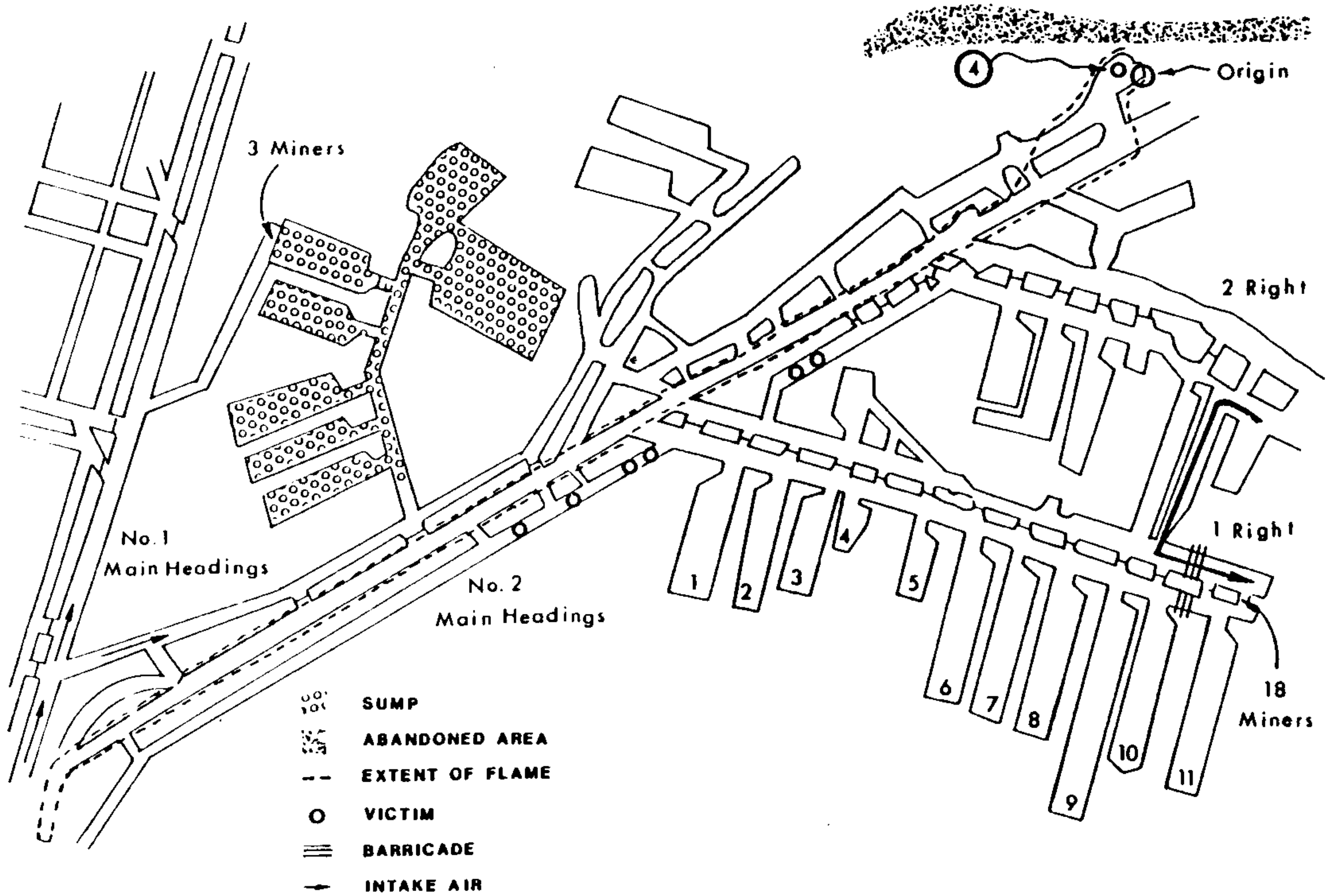

FIGURE A-4. - Part of Nu-Rex Mine where barricading saved 18 miners.

A.3.3 Smith Mine Explosion, February 27, 1943 (18)

Background

The worst coal mine disaster in the history of Montana occurred on a Saturday morning in the Smith Mine at Washoe, in Carbon County. Only three of the 77 miners underground survived. Those three were working just off the slope near the portal. Five of those who died built a partial barricade while most of the other 69 miners were felled by carbon monoxide or an oxygen deficiency as they attempted to escape.

This explosion left no evidence as to its cause or origin. It destroyed most of the ventilation controls in the two-entry Mains and in the mouths of the adjoining five panels. Numerous sources for ignition existed; for example, miners smoked and used carbide cap lamps; they blasted with black powder and fuse; they had neither rock dust nor water to inert coal dust; and, all mining equipment had open electrical motors and circuits.

The Smith Mine was in two coal beds locally termed the No. 2 and 3. The coal is subbituminous and 8 to 9 ft thick. A blowing system of ventilation without bleeders caused large bodies of methane to accumulate in abandoned and mined-out areas; that ventilation system and mining layout kept active faces and haulage roads relatively free of methane.

Barricading

Figure A-5 shows the portion in the No. 3 bed affected by the explosion. Also shown is the place where five miners barricaded. They built one good barricade of wood and brattice but did not barricade the other opening into their area. The explosion occurred at 9:30 in the morning; notes written in chalk on rough boards by the five told their own story of how they calmly awaited the poisonous gases they knew were coming. The last note was written at 11 that night. Rescue teams reached them 7 days later.

A.3.4 Sonman "E" Mine Explosion, July 15, 1940 (19)

Background

Few if any of the 63 miners who lost their lives in this explosion were killed outright by burns and violence. Many were still alive 7 hr afterwards.

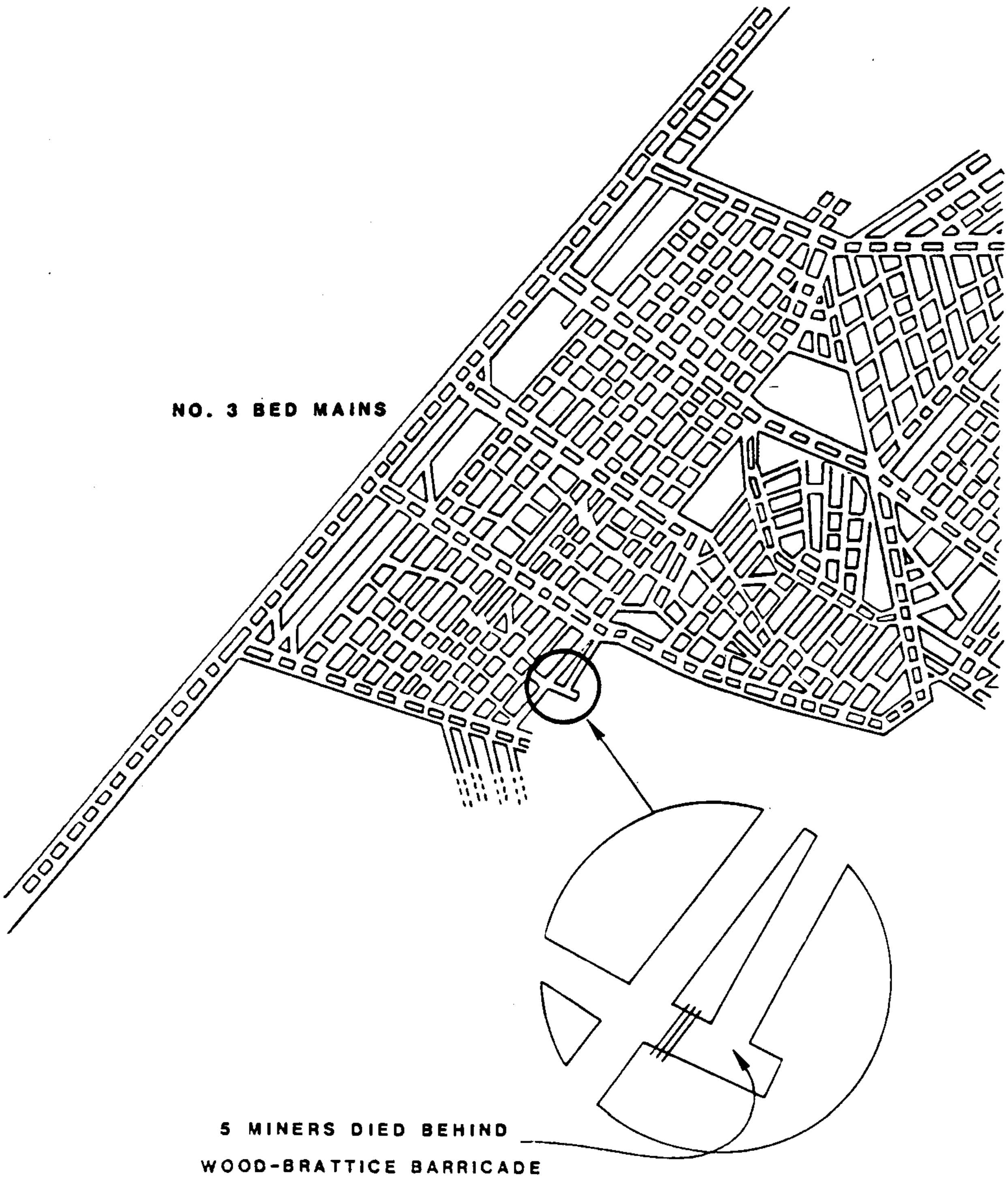

FIGURE A-5. - Smith Mine.

The Sonman "E" Mine, in Cambria County, PA, was in a 34-in. thick portion of the Upper Freeport locally termed the "E" seam. The coal is low-volatile and comparatively not to gassy. A sample of air, collected by an inspector less than 15 min before and from the same split of air in which the explosion occurred, contained 0.18 percent methane. Samples obtained in that split during the preceding 2 months contained from 0.00 to 0.17 percent methane.

The explosion is believed to have been caused when electrical arcs from a locomotive ignited an explosive concentration of methane on the 16 Right haulage road (see central, upper portion of Figure A-6). As indicated by the way flames extended (see Extent of Flame), the methane probably was forced into the haulage road by the sudden collapse of small pillars in the old workings between 16 and 17 Right; that methane-laden sandstone was 24 to 30 ft above the "E" seam. Although rock dusting was sparse and the mine was dry, coal dust was not an important factor in the spread of flame; thus it is likely this explosion involved layered methane rather than an extensive body of the gas.

At the time of the explosion 350 miners were underground. The 257 miners in areas unaffected by the explosion left the mine without difficulty, however, notifying them of their need to leave was so delayed that had conditions worsened more miners might have died. The probable activities of the other 93 miners are discussed below.

Barricading and Other Key Events

Six miners were working in No. 17 and 18 rooms (see top, center of Figure A-6). Two of them were at the junction of the rooms with 16 Right when they saw the flash of flame that preceded the explosion. They and the other four were knocked down by the forces that developed. After gathering together, they tried to travel through rooms connecting 16 and 17 Right. They found the air unbearably hot. They returned to 16 Right. One separated from the group; his body was later found among the miners who barricaded inby No. 26 room (see Figure A-9). The remaining five "forced" their way through smoke and dust so thick they could "see only about 1 ft ahead." Their straight-line distance of travel was 1500 ft; the time spent to escape exceeded 4 hr.

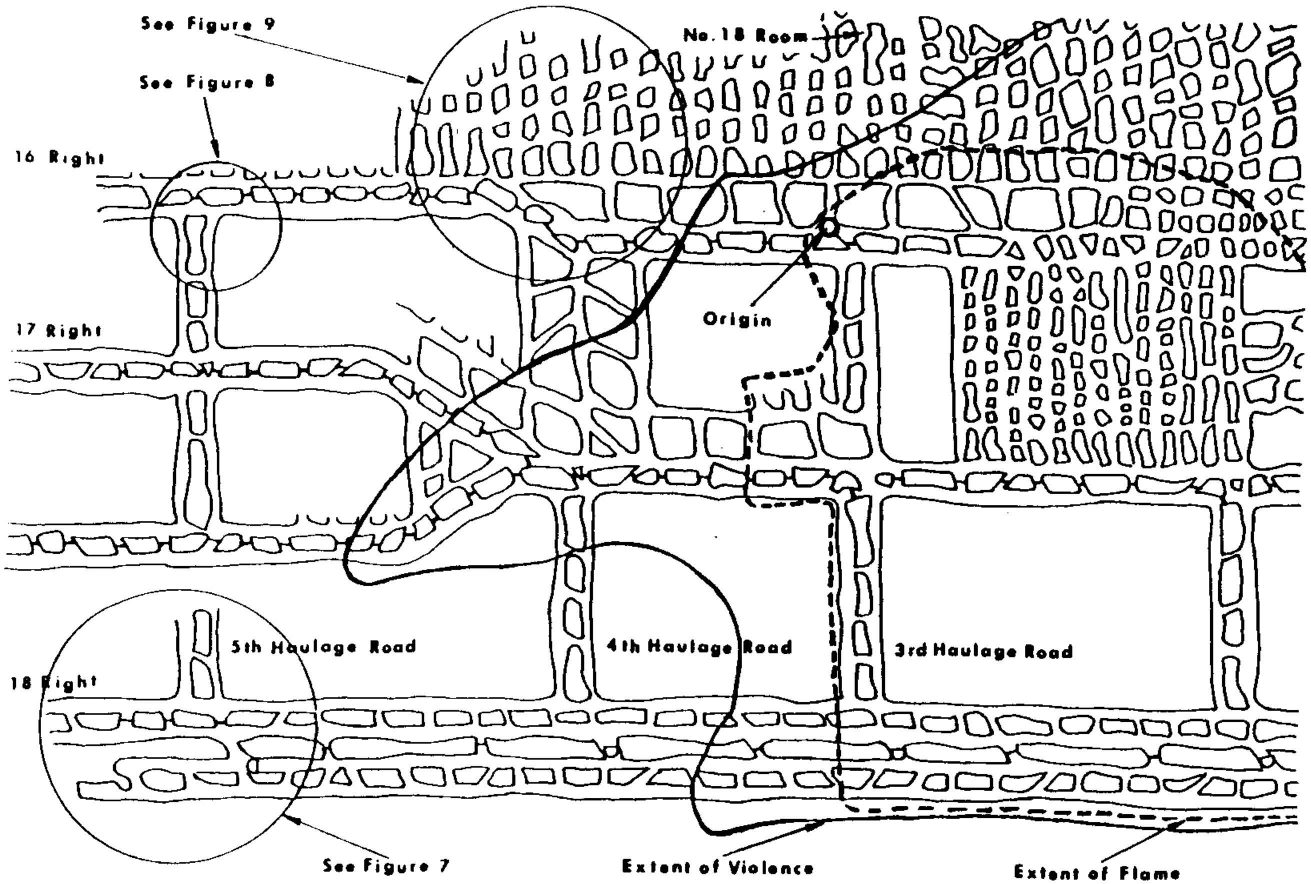

FIGURE A-6. - Area of Sonman "E" Mine affected by explosion.

Thirteen other miners also escaped from the explosion area. They were working in the six faces at the end of 18 Right (Figure A-7). Explosion forces threw all of these men to their knees; six suffered hearing problems thereafter. They "ran" from their working places to the door on the 2 Face, the haulage Road. They headed out 2 Face. When they reached third Haulage Road, the smoke was too hot and dense to continue. They retreated, trying to find a clear route to 17 Right. Two miners decided to barricade back in their working place. They told the others to go to the barricade if they could not get out. They began a barricade across 2 Face. They did not, however, open stoppings to short-circuit the intake but explosion-fouled air flows coming towards them in 3 and 4 Face entries. This was a bad error from the standpoint of barricading; however, this error may have saved their lives.

Before the barricade was finished the other 11 miners returned. They brought with them a flame safety lamp they had found. After much discussion they decided to try escape once more, this time through 1 Face, the return. Three miners, with the lamp, made an initial exploratory trip which brought them to safety 2500 ft away. One returned and led the others out.

Another group of miners built the barricade, shown in Figure A-8. Because seven jackets were used to pack one wall it was presumed seven miners were involved; no one was found there. Five had joined the groups totalling 34 and two the group of seven discussed later. On the track just outside were two cap pieces; one with an arrow pointing towards the barricaded area; the other with "men in trap door." As indicated in Figure A-8, the barricade walls were well-built and the barricaded volume was 2300 ft^3. That volume should have provided a safe atmosphere for seven relatively quiet miners for almost a day. Rescue crews reached this barricade 13 hr after the explosion.

Figure A-9 shows rooms 25 through 35 off 16 Right. One barricade had been built; a second had been started 52 ft inby. Nothing else had been done to stop airflows. More than enough materials and tools were immediately available. It was here that 41 miners were found dead 12 hr after the explosion. Two were building the uncompleted second barricade when they were overcome. Thirty-two miners in three separate groups were found in sitting and lying positions nearby. Notes indicated some were alive at 6 p.m., 7 hr after the explosion. Notes also told of the air becoming noticeably bad at 4:30. Another group of seven miners were away from the others; two of these had come from the good barricade shown in Figure A-8. The possible

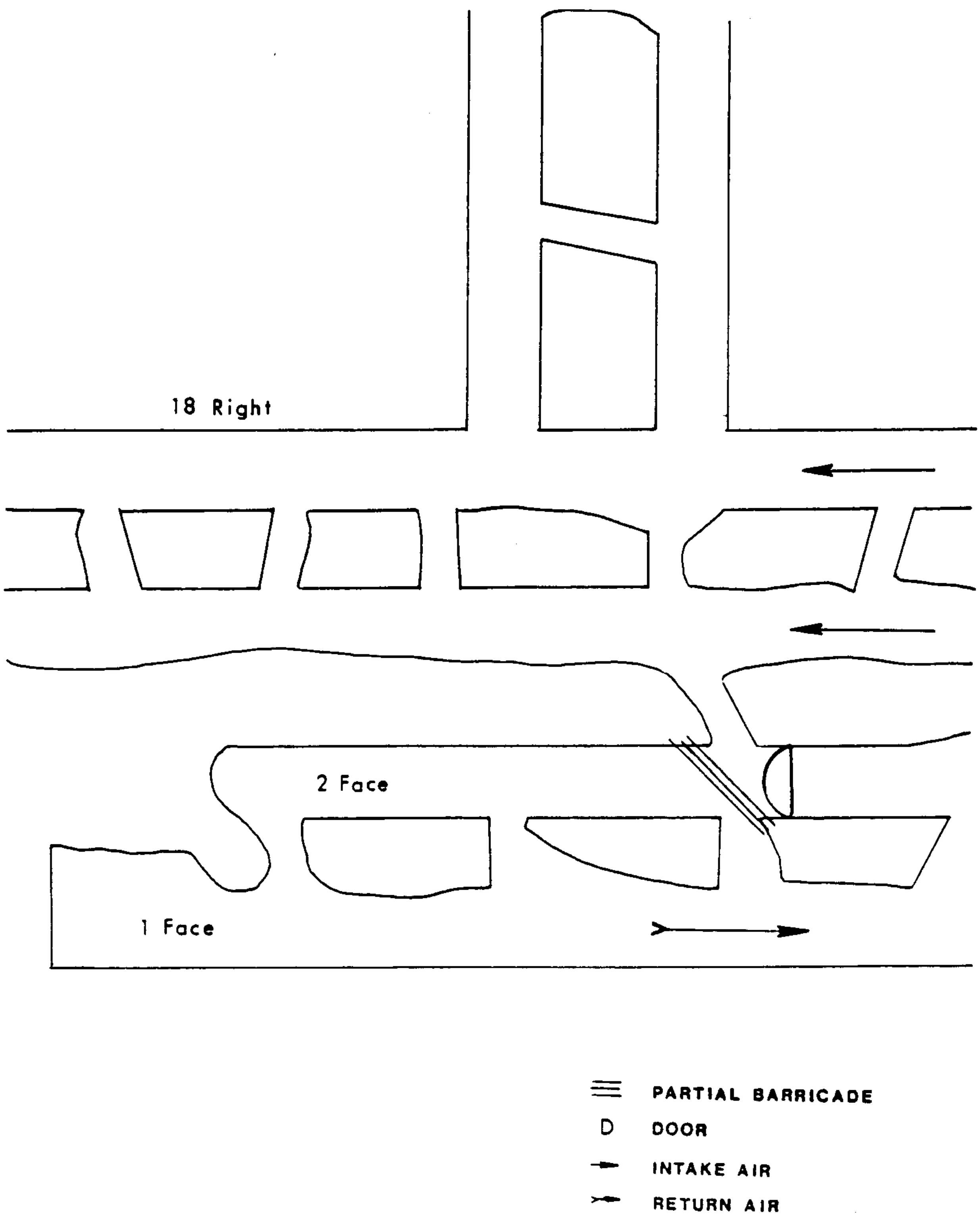

FIGURE A-7. - Barricade started in 18 Right, Sonman "E" Mine.

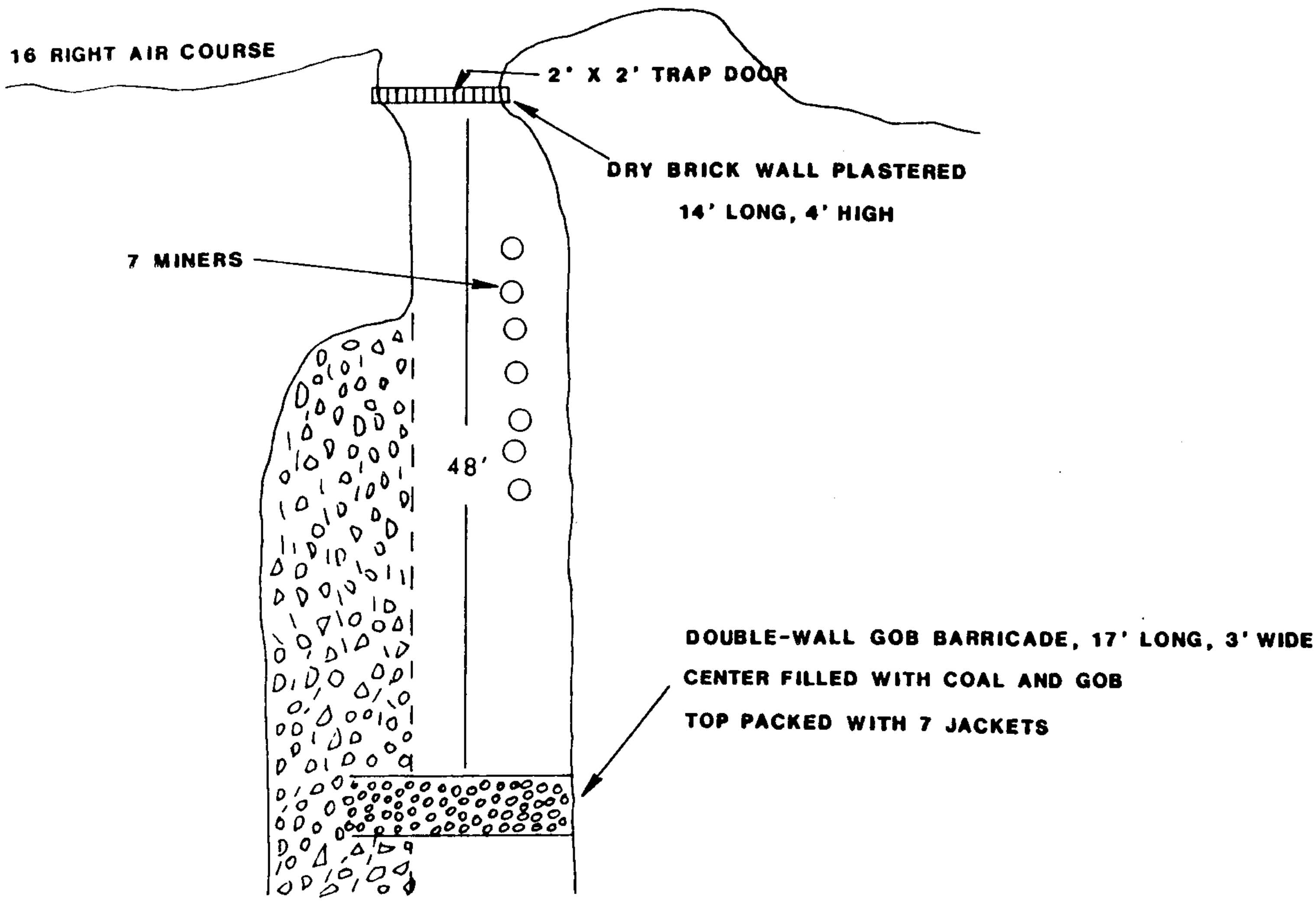

FIGURE A-8. - Barricade off 16 Right air course, Sonman "E" Mine.

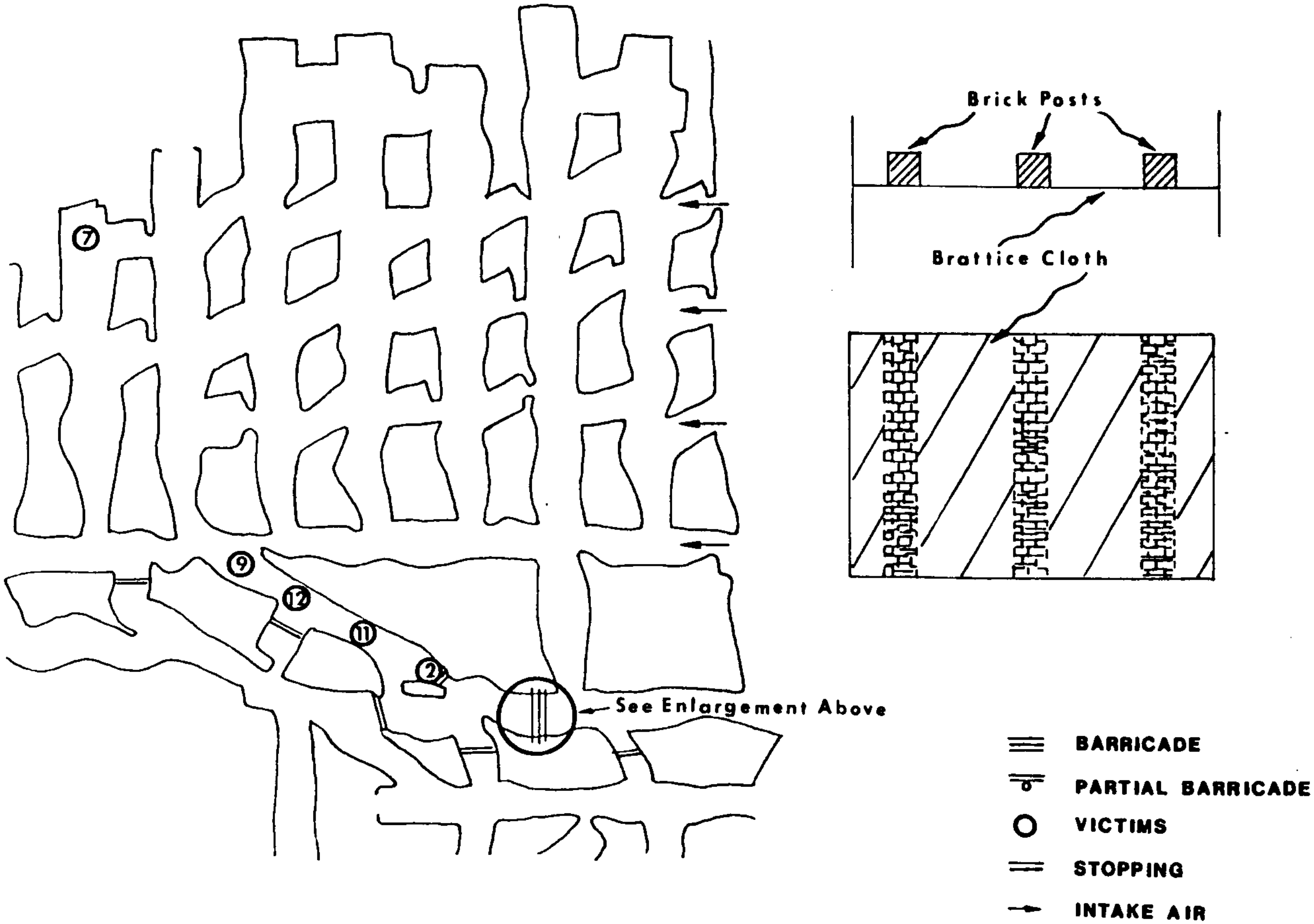

FIGURE A-9. - Partial barricading of No. 25-31 rooms,
16 Right, Sonman "E" Mine.

reasons for disperate groups are not appropriate to mention in this report; let it suffice to believe that with leadership and cohesive action many of these miners, if not all, would have lived through this explosion.

The other 20 miners who died were "rovers," such as wiremen, trackmen, motormen, snappers, and pumpmen. One had the flame safety lamp later found and used by the miners from 18 Right faces to reach safety. Only two of these 20 showed signs of direct exposure to the explosion, the motorman and snapper of the trip that probably ignited the methane. The other 18 may not have been aware of their hazard; their bodies were found where one would have expected them to be working.

A.3.5 Three Point Mine Explosion, September 16, 1943 (20)

Background

Using a match to light a flame safety lamp also ignited methane in the "Slant" entry of the Three Point Mine, Three Point, KY. The ignition raised coal dust into suspension which led to intense flame and powerful forces progagating out into the 12 Left Main Headings (see Figures A-10 and A-11).

At the time of the explosion 50 miners were underground. Of those:

a. Thirty-two escaped without mishap.

b. Twelve in the "Slant" and in 1 Right were killed by flames and violence.

c. Six working at the faces of 12 Left, 3000 ft inby the explosion area, barricaded and lived.

Three Point Mine was in the 44 to 78 in. thick Harlan coal seam. The Mine Superintendent was involved in the Belva Mine explosion described before.

Barricading and Other Key Factors

Dust and smoke billowing into the inby areas off 12 Left (Figure A-11) alerted the six miners working there. Individually they began to travel out. Dense smoke brought them all to a stop 1200 ft from their work areas. They found brattice and quickly hung it across the entry to stop the inflow of smoke. They retreated to a side entry where they found mine ties and

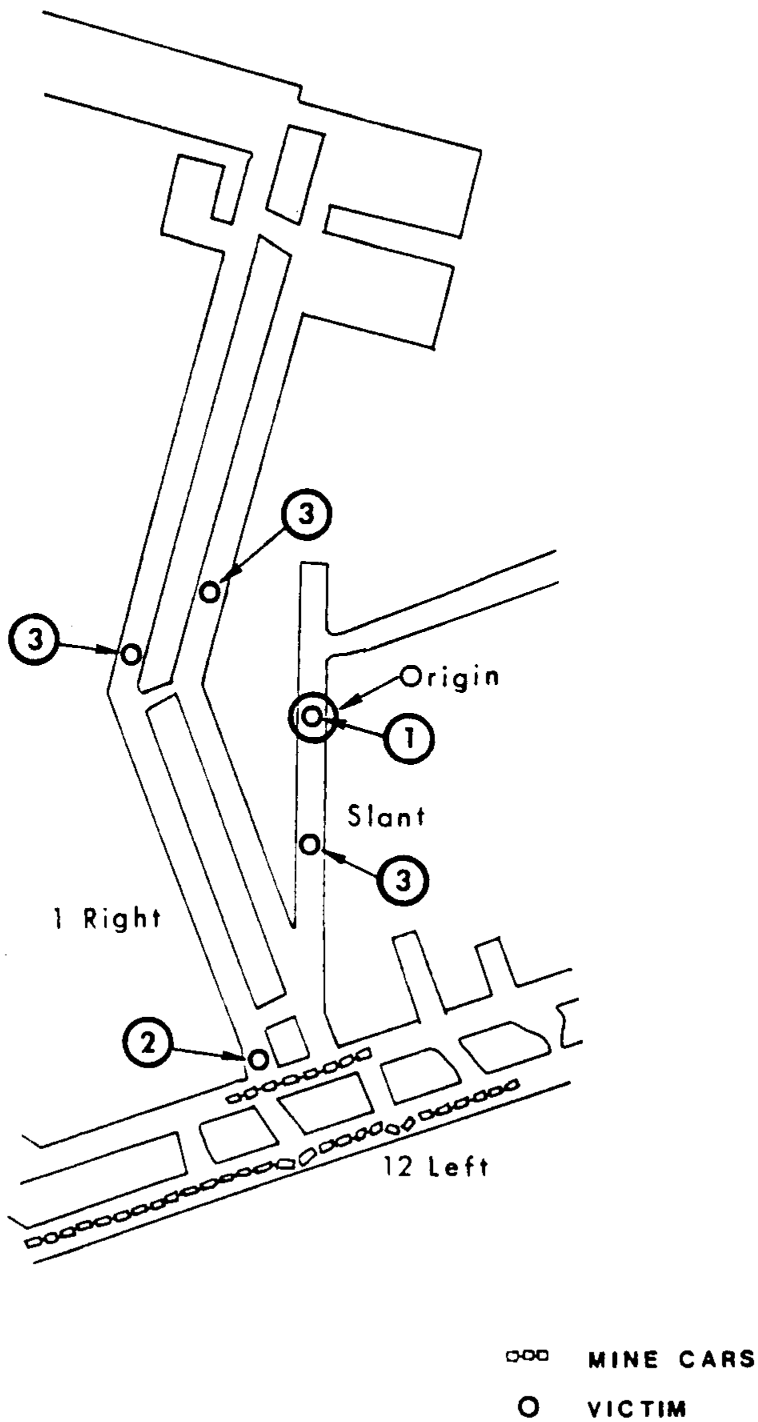

FIGURE A-10. - Explosion area in Three Point Mine.

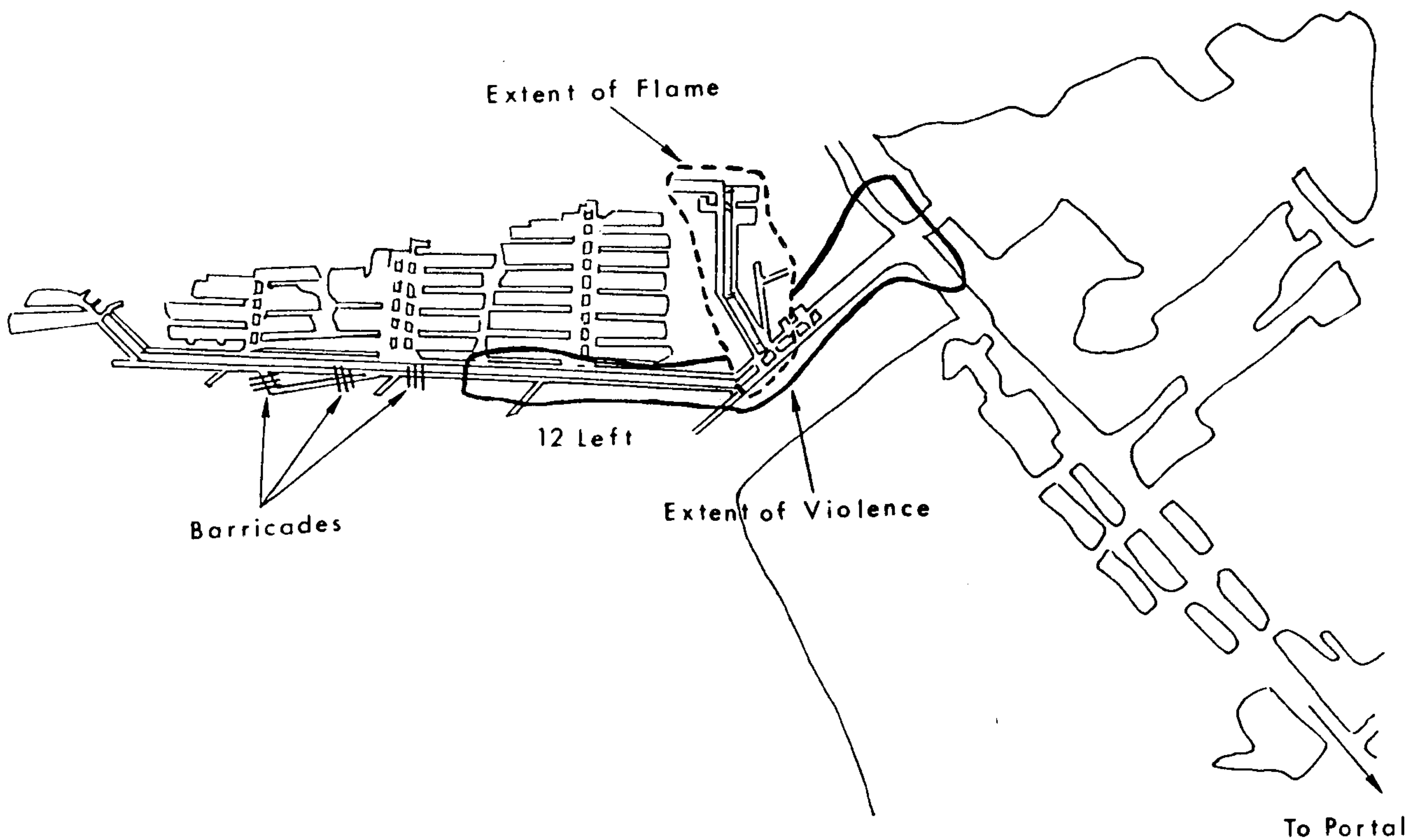

FIGURE A-11. Barricades saved six miners in Three Point Mine explosion.

flexible ventilation duct. They built up walls of ties at the two openings into the side entry. The duct was slit lengthwise and hung flat against the ties. Coal and dirt was packed into spaces between the ties and the ribs.

Rescue teams after finding no one alive in the Slant and 1 Right areas began their way into 12 Left. Footprints leading out and then back in brought them to the first barricade, or really the check curtain. After restoring ventilation, the rescue teams reached the barricaded area and brought the six miners to safety, 14 hr after the explosion.

A.4 Mine Accidents, 1947 to 1953

These were the years of growth. As it was throughout the Nation, changes in mining practices were great. Many mines were operating two to three shifts a day, 6 days a week. Continuous miners supplanted hand loading; locomotives were replacing mules and horses; miners traded helmets for stiff fiber mine hats; strong union growth changed the tradition of fathers training sons at the working face.

During those 7 years, 393 miners lost their lives in 19 disasters. No one attempted to save his life by barricading. Analysis of those 19 disasters indicated barricades might have been used successfully with the potential for saving at least 65 lives in the 10 disasters summarized in Table A-3.

A.5 Mine Accidents, 1954 to 1969

This period began with a severe loss of market for coal; railroads and utilities were using $1.50 to $2.00 per barrel oil and home builders were installing low-cost gas furnaces. The period also began with USBM inspectors enforcing what many miners considered a new set of rules.

During these 16 years, 398 miners lost their lives in 23 disasters. Despite the essentiality of lowest cost production and highest productivity for survival of a coal mine, both the annual toll in life and number of disasters were half as many as in the previous period, 1947 to 1953.

Barricades saved 68 miners in six mines. Those experiences are described in the following six subsections.

Table A-4 lists an additional five mine accidents in which miners did not barricade, and the reasons for such action.

TABLE A-3. - Ten accidents in which miners did not barricade, 1947 to 1953

Mine	Date	Miners in danger but did not barricade		
		Survived	Died	Reasons for not barricading
Bunker (21)*	10-15-51	30	0	Mine foreman ordered men out.
Carpentertown Mine (22)	2-2-52	69	1	Foreman ordered crews out. Of five too injured to do anything for themselves, one died of CO poisoning.
Centralia No. 5 (23)	3-25-47	7	46	They believed they could escape. Of the 111 who died, 46 could have barricaded.
Edgewater Mine (24)	7-30-48	303	5	They chose to escape. Of the 52 injured by flames, smoke and gases, five died.
Franklin (25)	12-11-47	17	3	Foreman led noninjured miners out to safety leaving three too injured to travel.
Kerns (26)	4-30-47	3	0	They believed they could escape.
Kings (27)	7-27-48	3	1	Miners escaped through smoke carrying injured buddy who later died from asphyxiation.
Lake (28)	7-16-50	2	5	Five attempted bare-face rescue of two in mine at time of fire. The seven attempted to escape together.
Orient No. 2 (29)	12-21-51	4	1	Mine Manager ordered miners out; five did not go; one of four rescued shortly afterwards died of smoke inhalation. The fifth was rescued 58 hr later.
United Gas No. 1 (30)	10-31-51	4	3	Of the seven who decided to escape three died from CO.

*Items in parenthesis refer to references in subsection A.8.

TABLE A-4. - Five accidents in which miners did not barricade, 1954 to 1969

Mine	Date	Miners in danger but did not barricade		
		Survived	Died	Reasons for not barricading
Belle Isle Mine (31)*	3-5-68	0	20	No reason; the 20 miners could have barricaded.
Carbon No. 2 (32)	12-16-63	12	0	They believed they could escape; one was injured by smoke inhalation.
Compass No. 2 (33)	4-25-63	14	0	Mine Foreman ordered miners out; they travelled through dense smoke.
Jamison No. 9 (34)	11-13-54	2	3	They believed they could escape through smoke and gases.
Mars No. 2 (35)	10-16-65	3	7	A foreman led his crew around fire. Seven others, who were also inby, were killed by CO.

*Numbers in parenthesis refer to references listed in subsection A.8.

A.5.1 Bishop Mine Explosion, Pocahontas Fuel Co., October 27, 1958 (36)

Background

Shortly after the start of the day shift, 22 miners in Second Left (Figure A-12) were killed by forces and flames from an explosion. The explosion began with ignition of methane while blasting coal at the face.

Mine officials, meeting on the surface, observed rock dust blowing out of the intake and man shafts. They realized at once it took a force more powerful than a roof fall to force dust up and out a shaft against the intake air current. Immediately they sent men to all fans to make sure they were operating. Electrical power into the mine was deenergized. Contact by phone was made to all sections except Second Left. The miners were told to walk out of the mine. The foremen of the Pin Ridge Left and Main Sections informed the officials that concussion from the explosion was felt in their sections, thick clouds of dust were present, and, therefore, the 37 miners intended to barricade. The 148 miners from all the other areas subsequently arrived on the surface without mishap.

Bishop Mine, in McDowell County, WV, produces coal from the Pocahontas Nos. 3, 4 and 5 coal beds. At the time of this explosion only the No. 3 seam was being mined. It averaged 72 in. in thickness in the Pine Ridge Mains and Left Sections. The coal is low volatile. At least five explosions have occurred in this mine since 1937.

Barricading and Other Key Events

Most Bishop Mine safety meetings included discussions of the procedures that need to be taken and the value of barricading in the event of fire or explosion. Just a few months before this explosion barricading was a major subject given by the USBM in an accident prevention course for these miners and officials. That training supplemented by the telephone communications probably saved the lives of the 37 miners who barricaded. Rescue teams later found their routes to safety filled with smoke and toxic gases.

In the Pine Ridge Main Section, two foremen and 20 miners constructed the barricades shown in Figure A-13. Their first and most important step was to short-circuit airflows into the section. This was critical to prevent toxic airflows into their

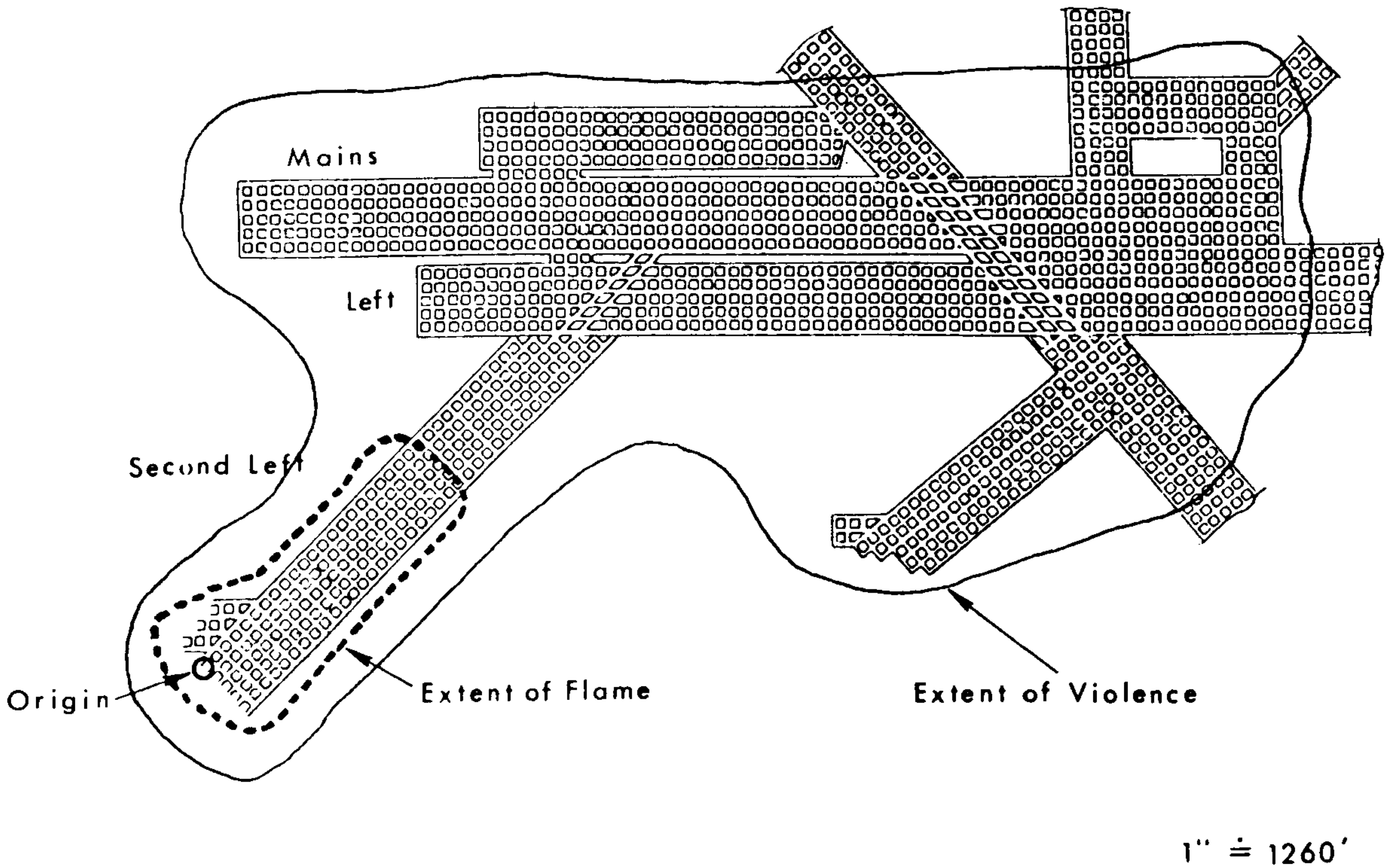

FIGURE A-12. - Bishop Mine explosion.

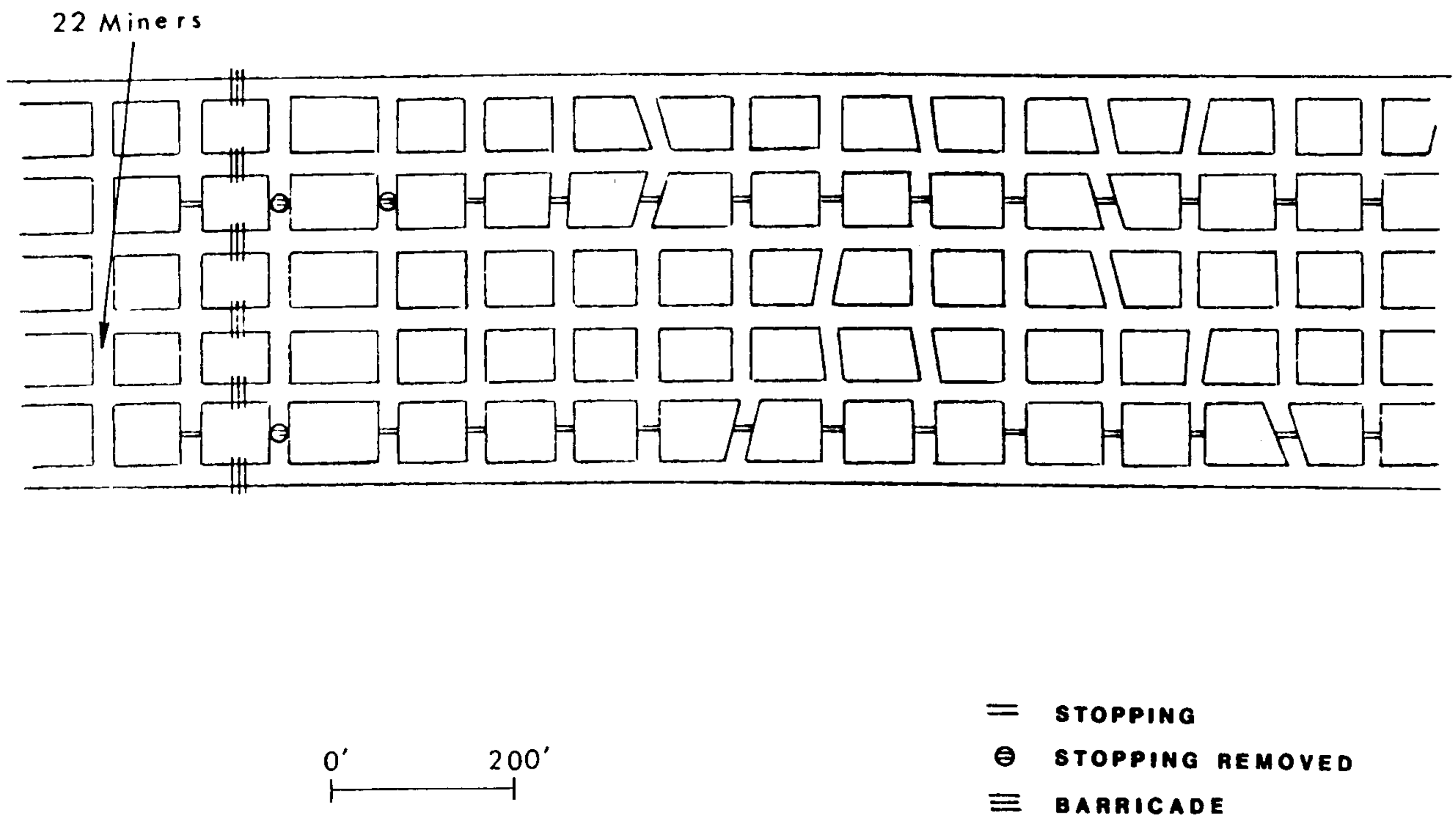

FIGURE A-13. - Barricades in Pine Ridge Main, Bishop Mine.

place of refuge. For this they knocked out the third and fourth stoppings from the faces on the left split and the stopping between the Nos. 4 and 5 entries in the third crosscut outby the faces. Barricades made of three to four plies of canvas were erected across all the entries inby the knocked-out stoppings. These barricades utilized existing check curtains. Also, air and water pipelines were extended into the barricaded area.

In the Pine Ridge Left Section (Figure A-14), two foremen and 13 miners knocked out half a stopping between Nos. 5 and 6 entries at the fourth crosscut outby the faces and erected barricades made of two to five plies of canvas.

The men in the Pine Ridge Main Section were rescued slightly more than an hour after the explosion. The men in the Pine Ridge Left Section remained behind their barricade almost 2 hr in good physical condition. The volumes behind the barricades were large enough to support life for several weeks.

A.5.2 Cane Creek Mine Explosion, August 27, 1963 (37)

Background

Cane Creek was being developed to mine potash near Moab, UT. Underground development practices used numerous sources for ignition of methane; the mine workings penetrated oil shales that liberated methane. A 2789 ft deep shaft was the only opening from the surface.

Prior to this explosion there had been several ignitions of methane. In those, miners were injured but not killed. Of the 25 miners underground when gas was ignited this time:

a. Eighteen died:

    1. Twelve from the forces of the explosion

    2. Three from irrespirable atmosphere in 3U Drift

    3. Three from irrespirable atmosphere behind a poorly constructed barricade in 2 South Drift

b. Seven barricaded in 3U Drift and lived.

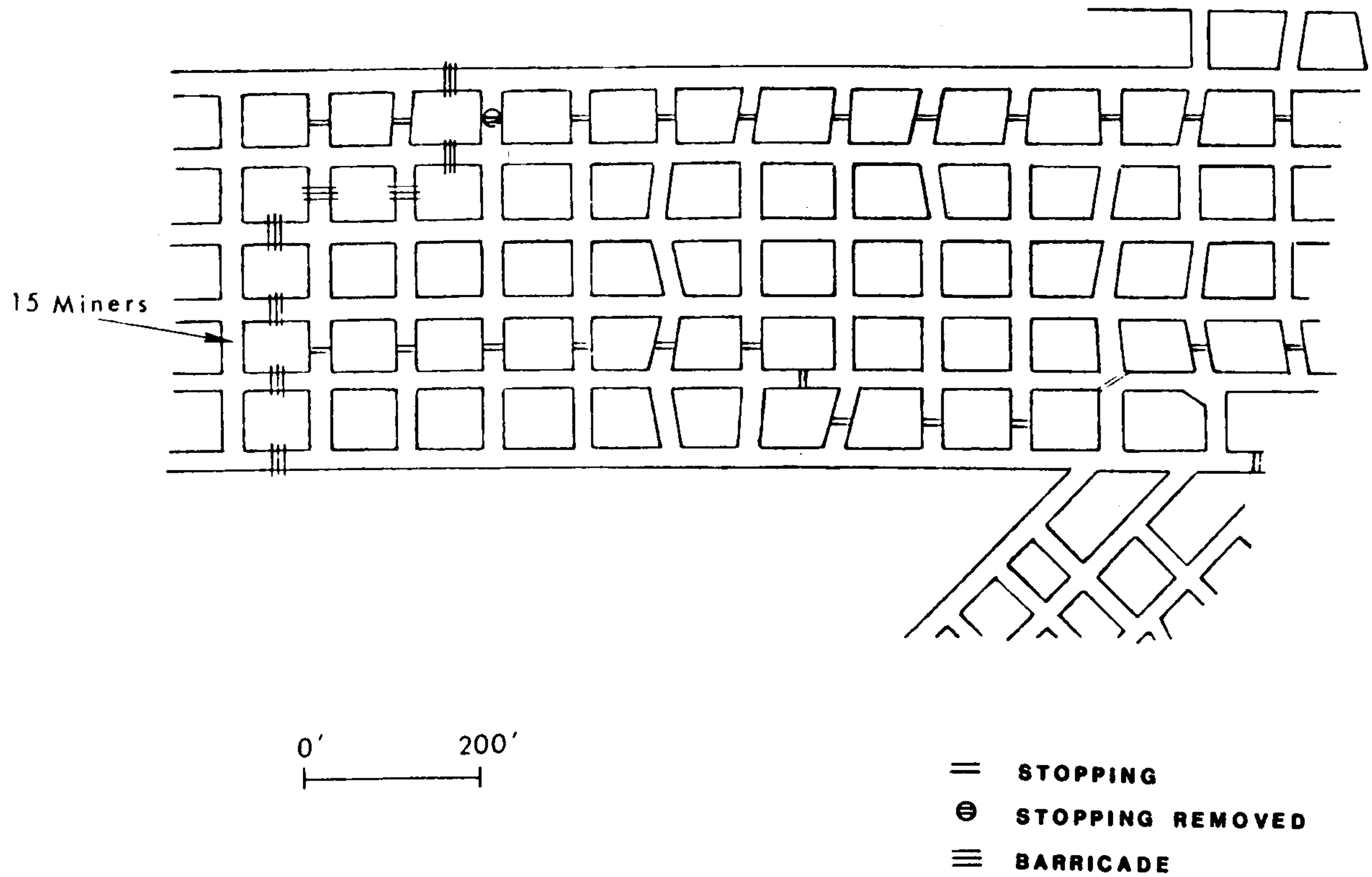

FIGURE A-14. - Barricades in Pine Ridge Left, Bishop Mine.

Barricading and Other Key Factors

Figure A-15 is a single-line drawing of Cane Creek Mine. Also shown are the barricades built in the 3U and 2 South Drifts. These drifts were 8 to 10 ft high and 18 to 20 ft wide.

3U Drift

Forces from the explosion were felt by the eight miners in 3U Drift. After recovery from the initial shock they attempted to make their way to the shaft station, riding in a shuttle car part way. They were joined by two miners at the top of 3U. The 10 men continued their attempt to reach the shaft station, but dense smoke soon prevented further travel. Visibility became so poor they could barely see each other. They retreated, groping their way back to 3U accounting for each other along the way. After retreating less than 1000 ft, three refused to continue. Rescue teams found them with their heads near the end of a metal ventilation duct (see 3 near outby end of 3U Drift).

The remaining seven stopped at the Transformer Station, about 950 ft outby the 3U face. Here they attempted to build a barricade by cutting open the flexible duct used for blowing air to the faces. Because of highly irregular back (roof) conditions this barricade could not be made airtight; also, so much smoke was present while the barricade was being erected they decided to move inby towards the face and to erect a barricade where rock bolts and chain link fencing secured the back. This second barricade, less difficult to erect, prevented smoke, which was reported to be shouler high, from moving further inby. Then they made a third barricade of opened-out flexible tubing about 25 ft inby the second. This was more airtight; it was fastened to the chain link fencing at the back and held tight against the ribs with pieces of wood and pipe. The opened end of the vent tubing within the barricade was closed with pieces of flexible tubing.

While the first barricade was being erected, the lead miner separated the compressed air line, hoping the escaping air would hold back the smoke; however, there was no pressure in the line. He then found three men lying on the floor with their heads near the vent pipe near the top of 3U Drift. He asked them to move enough for him to get air from the vent pipe but was told there was no air there. He then advised the three to move inby to the barricade. He returned to the barricade; the other three remained and died. Later, about midnight, he and another miner left the barricade to repair the separated compressed air line hoping, in case pressure was restored, air would flow into the barricade.

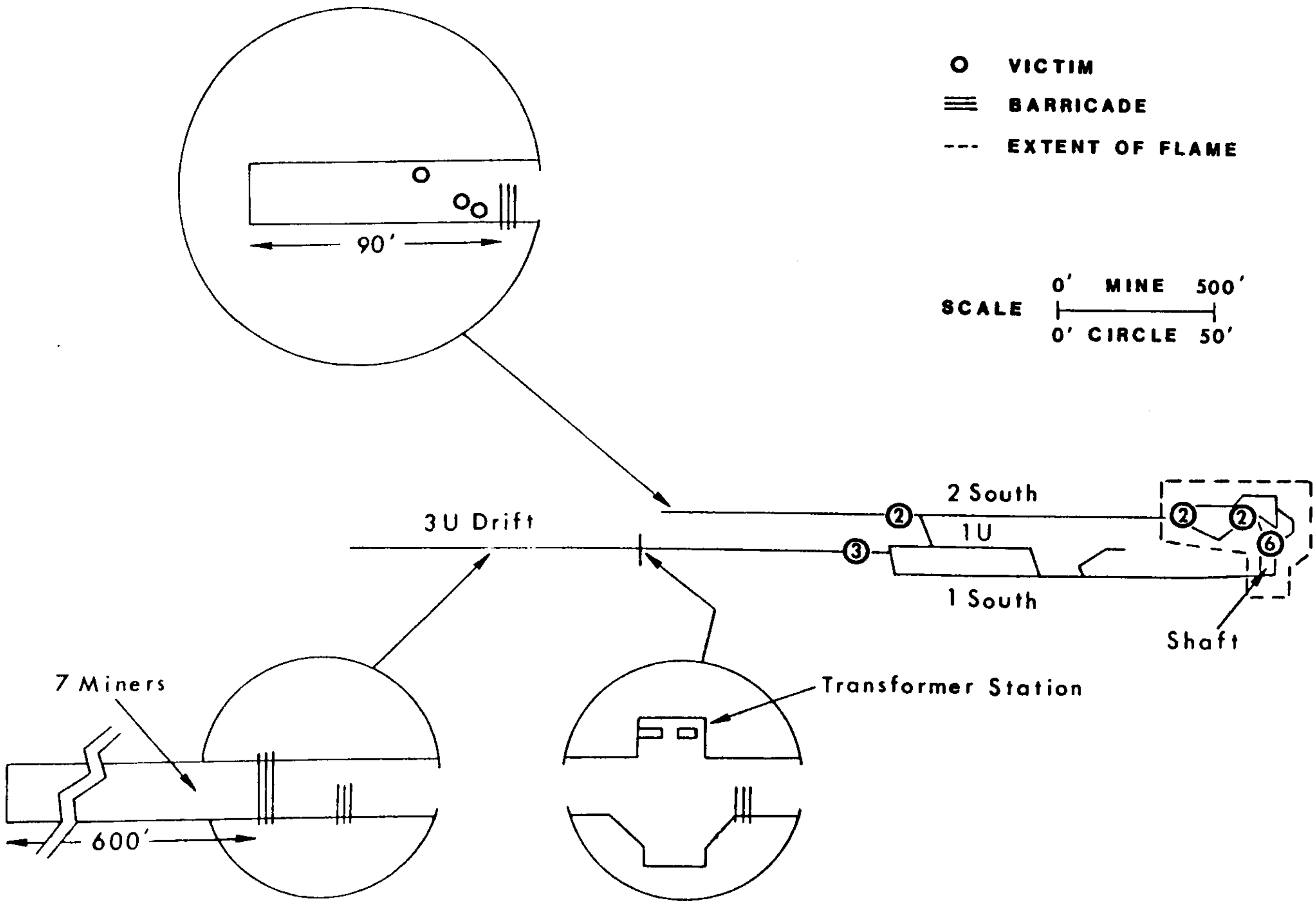

FIGURE A-15. - Barricades in Cane Creek Mine explosion.

The barricaded men rested and awaited rescue on spread-out tubing. They had a 10-gal container about one-fourth full of water. This water was supplemented by water drained from the waterline. A water manifold was connected to the air line at the "resting place" and hoses were attached to the manifold's four outlets. This proved valuable after rescue parties made temporary repairs to the compressed air line allowing air to reach the trapped men.

Each miner had an electric cap lamp and the lead miner had a flame safety lamp. To conserve lights, only one cap lamp was kept lit. There was little moving about in the barricade.

About 15 hr after the explosion, the lead miner and another man left the barricade, one carrying the lighted flame safety lamp. It was stated that flame was yellow when the lamp was held at face level, but would get reddish when lowered toward the floor. Along the way they made some repairs to the compressed air line and finally reached the shaft station where they found compressed air being delivered from the surface. About 100 ft of the air line was missing; the two got pipe and other materials to repair the section of 3-in. compressed air line to 3U Drift. They were successful to the point where only a short span remained to be connected. This was made continuous 30 hr later by a rescue crew. The two men attempted to attract attention on the surface by hammering on the compressed air line in the shaft. They were not heard. Fortunately a rescue team was finally able to get down the shaft, 19 hr after the explosion. The team found the two miners and had them hoisted to the surface.

Rescue teams reached the other five miners in the 3U barricade 50 hr after the explosion. All were in good spirits and shape because of their wise efforts to make the barricade airtight, to have water, to prepare the air line for the eventual flow of compressed air, and to remain quiet. They credited their actions to the strong leadership and direction of the lead miner.

2 South Drift

Following the explosion, some of the 2-South crew erected a barricade 90 ft outby the face. This barricade, of ripped-open flexible tubing, was not airtight. Three died of asphyxiation behind the barricade. Footsteps in the settled dust showed one miner had traveled from 2 South Drift into 1U North and back, a distance of at least 1600 ft. The bodies of two other members of the crew were found 727 ft outby; they had been killed by violence.

A.5.3 Crichton No. 4 Mine Fire, January 8, 1965 (38)

Background

Late in the second shift on 2 South Mains a permissible air compressor caught on fire. Smoke flowed against the air current and through stoppings into the belt entry. The Section Foreman instructed the crew to barricade in No. 7 entry. He and another miner went to find the problem. They rode the belt conveyor past the smoke-filled area. When the miner telephoned for help, the Section Foreman knocked blocks from the stopping outby the fire between the neutral, and intake entries (Figure A-16). Intense heat and smoke prevented him from removing the stopping into the return. He then went inby the fire and removed another stopping.

On receiving the telephone call, officials ordered all others from the mine except those who were needed to fight the fire. It was extinguished almost 2 hr after it had been detected.

Crichton No. 4 Mine, in Nicholas County, WV, is the 44-in. thick medium-volatile Sewell coal bed. No injuries were suffered by any of the 67 miners who were underground.

Barricading

The four miners left in the section used brattice cloth and boards to erect the 2 × 4 barricades shown in Figure A-16. Initially, they could have left the section by travelling the No. 3 or 4 entry. Once the two stoppings were broken out, however, smoke moved toward the faces into those intakes. Then, the barricades were needed.

After the fire was extinguished, the Section Foreman wearing a filter self-rescuer went to his barricaded men. Others, meanwhile, erected check and line curtains. When the air was made safe, the barricaded miners were taken out.

A.5.4 Island Creek No. 22 Mine Fire, March 8, 1960 (39)

Background

Arcing from a locomotive ignited timbers under an overcast on the West Mains. This was the main haulageway into the Nos. 4 and 7 Sections where 20 miners were working.

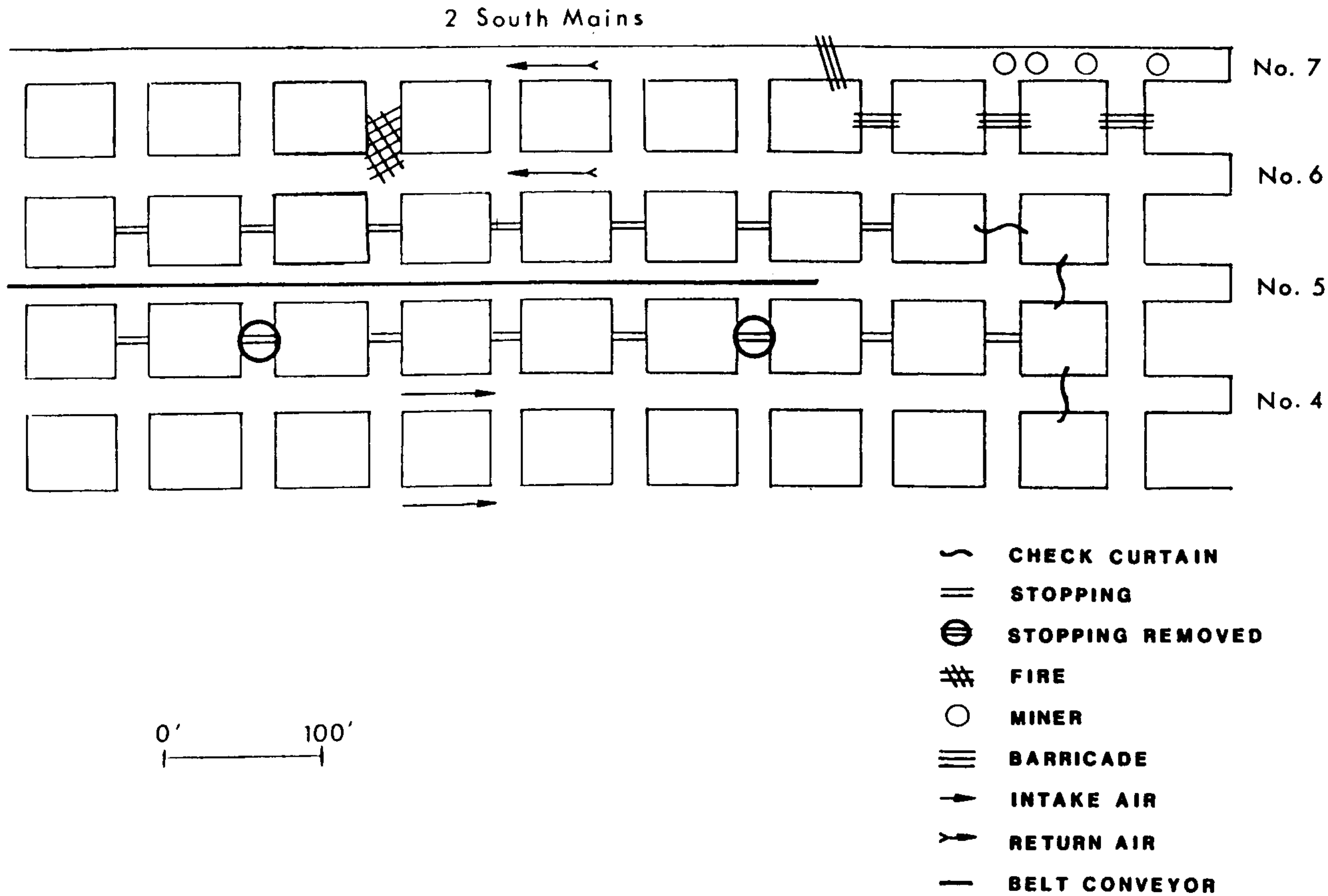

FIGURE A-16. - Barricades in Crichton No. 4 Mine fire.

Flames propagated on "skin-to-skin" timber sets fed by 65,000 cfm of air. A motorman telephoned the dispatcher saying he could not get out because of the heat. He was told to take the miners in No. 7 Section to No. 4 (see Figure A-17); and, to tell the safety engineer, who was in No. 4 Section that day, to lead the miners to safety. During this conversation the telephone and power circuits inby the fire were lost; further communications were not possible.

Some miners thought the way to safety was via the Elk Slope Portal. Two disagreed, saying the route was caved and inaccessible. Those two miners left the group and went around the fire through old returns, long stretches of which could be travelled only "on your belly." Four hours later they reached safety. En route, they opened the airlock doors, thus short-circuiting most of the air and smoke from the fire away from the 18 trapped miners.

Island Creen No. 22 Mine, near Holden, WV, was in the 66-in. thick Lower Cedar Grove coal seam. The fire begain at 8:30 a.m., just 30 min after the miners had travelled through the overcast towards their working places. This fire, more than any other in recent history, led to immediate and considerable research by the USBM. Among the major studies were:

a. Flame propagation in timbers and on conveyors

b. Improved generation of high-expansion foam

c. Urethane foam for rapid construction of fire seals

d. Evaluation of materials and methods for fighting mine fires

e. Travelability of escapeways.

Barricades

Ten miners, the division safety engineer, and the motorman who had spoken to the dispatcher at the mouth of No. 4 Section. After much discussion, two of the miners decided to attempt escape, which they did successfully as previously mentioned. Those two reported that the safety engineer instructed the No. 4 Section Foreman to take his crew to the Elk Creek Slope Portal while he would bring the No. 7 Section crew to the slope.

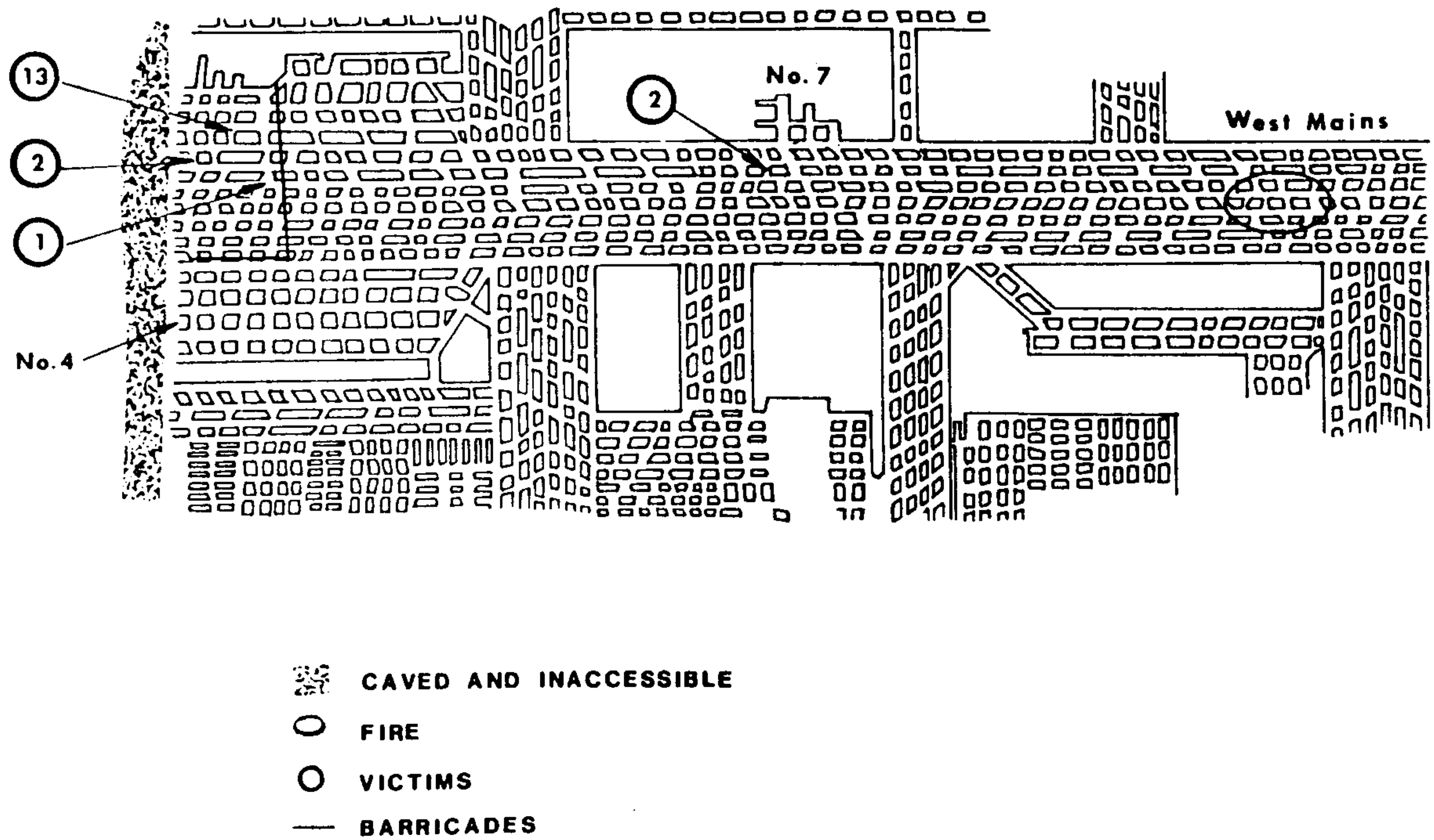

FIGURE A-17. - Fire affected Section of West Mains, No. 22 Mine.

What actually transpired is not known. Two of the eight miners in No. 7 Section did not go with the safety engineer; one was the No. 7 Section Foreman and the other was known to have a heart ailment. The safety engineer, the No. 4 Section Foreman and 14 miners hung single layers of brattice cloth across some openings. Seven days later, crews wearing all-service gas masks recovered the bodies.

In retrospect, it is possible to believe that with properly constructed barricades the 18 miners had some hope. The evidence they left indicated they had little hope. One piece of evidence was a note written by the No. 4 Section Foreman. That and other signs support the belief that at least 14 lived for several hours in the direct flow of air from and over the fire.

Their best chance for safety, other than escape, was to go to an area that could be isolated from fire gases. Elk Creek Slope was the wrong choice. It was the direct return for the fire gases.

No. 7 Section might have been appropriate. Airflows into No. 7 Section could have been short-circuited by opening two stoppings in the West Mains between the Section and the fire. Readily available wood planks, posts and brattice cloth could have been used to seal the three entries leading into No. 7 Section. The enclosed volume would have exceeded 56,000 ft^3. For 18 miners to live 7 days required a minimum of 46,000 ft^3. Physiological and psychological demands as well as oxygen absorption by coal and timbers, however, might have necessitated a barricaded volume of 90,000 or more cubic feet.

A.5.5 No. 28 Mine Fire, February 8, 1967 (40)

Background

No. 28 Mine, in Logan County at Verdunville, WV, is in the 45-in. thick high-volatile Eagle coal bed. About 8:30 p.m., a miner encountered smoke at the mouth of the Air Shaft Headings. Of the 60 men underground when the fire occurred, only the 10 miners in the Air Shaft Headings and the three who later came to their help were at risk. Of those 13, only one was injured by smoke inhalation.

The fire consumed 480 ft of PVC conveyor belting laid in loops in three mine cars and 200 ft of the same type of belt on the section conveyor. The three mine cars with the belting were parked in the East Mains track-belt entry near its junction with the Air Shaft Headings belt entry. Although approved as fire-resistant by the USBM, this quantity and type of belting is known to emit while burning ccpious quantities of highly toxic, acrid, dark smoke. The source of ignition could not be guessed at let alone determined by the investigators. Fortunately, the fire involved only the belting which was in a neutral airway ventilated by leakage.

Barricading and Other Key Events

Figure A-18 shows the area of the mine affected. A mechanic, en route to the Section, opened the door in the track entry into the Air Shaft Headings and was engulfed in smoke. He immediately closed the door and retreated to the East Mains where he pulled the power switch to stop the belt conveyors. He telephoned out, advising of the fire and asking for "help."

Shortly afterwards the night foreman and a beltman arrived. They deenergized all electric circuits inby. The foreman had brought a Universal gas mask and a box of six filter self-rescuers.

Meanwhile, the Air Shaft Headings Section Foreman and a roof bolter came out of the section. By following the track rails and wearing filter self-rescuers (the 30-min type) they were able to travel through the black smoke.

The night foreman put on the gas mask, carrying the box of six self-rescuers plus his own he returned to his men. He found them in fresh air at the shuttle-car discharge point. He told them they could travel to safety if they followed the track rails. There were seven self-rescuers and one gas mask for nine people. One, miner therefore, elected to stay. His buddy decided to stay with him.

The night foreman put on the gas mask. Carrying the box of six self-rescuers plus his own, he returned to his men. He found separated. Only the night foreman and one miner reached fresh air. Another miner reached a mine phone near the door on the track entry. The smoke was so thick he was concerned about proceeding. He called for help. The night foreman and the mechanic put on self-rescuers and brought him out.

Meanwhile, the other four miners retreated. They and the two who had remained knew help was near. They knew all they had to do was to barricade themselves for a short time against toxic fire products. They removed two check curtains to isolate

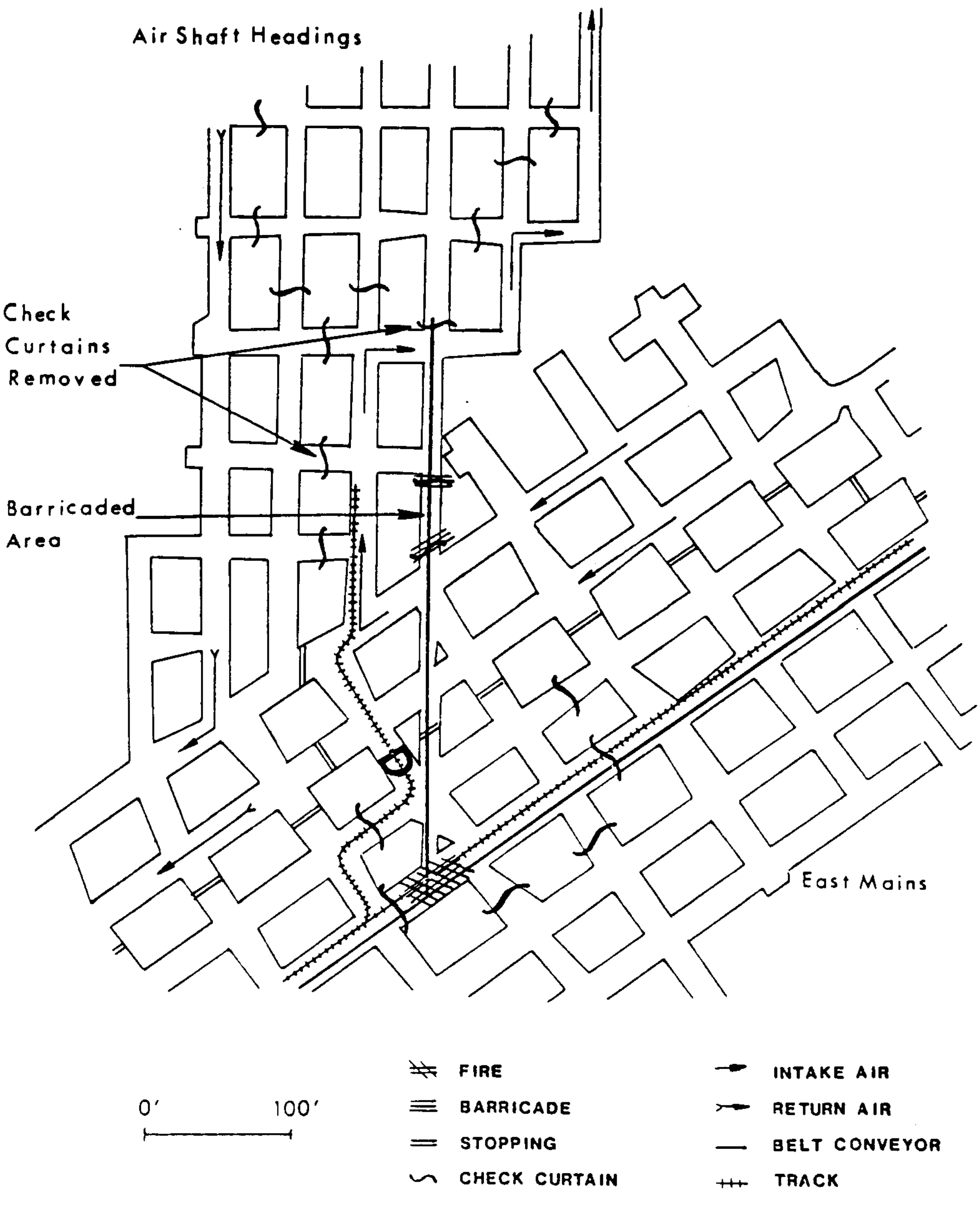

FIGURE A-18. - Barricade in No. 28 Mine fire.

the barricaded area from airflows and pressures. They made their barricade by adding more brattice to the two check curtains across the belt entry, using wood planks to hold the brattice against the roof, ribs and floor. The space, within 4000 ft^3, could be expected to provide safe air to the six miners for almost one day.* Two hours later, the fire was extinguished, the air was cleared, and the miners were brought to safety.

A.5.6 No. 31 Mine, Pocahontas Fuel Co., December 27, 1957 (41)

Background

The lives of 14 miners were saved because they had been trained to barricade. The explosion originated in the face of No. 4 entry, Q Left Airways (Figure A-19). All 11 miners in the area were killed by flame and forces. Flames extended through the seven entries into the mains, 1400 ft from the origin of the explosion. Forces, felt more than a mile away, destroyed stoppings almost to the face of Q Headings (Figure A-20). This short-circuited the air and stopped flows of toxic gases into Q Headings.

No. 31 Mine, in Tazewell County, VA, is in the 78-in. thick Pocahontas No. 4 coal seam. His low-volatile coal liberates considerable quantities of methane when mined. At the time of this explosion 158 miners were underground. Only the 11 who died and the 14 who barricaded were at risk.

Barricading and Other Key Events

A crew of 13 miners and a Section Foreman were advancing the Q Headings. The loss of power and air and the smell of burning led them to realize an explosion or fire had occurred. The foreman gathered the crew members and proceeded out the track entry. Dense smoke outby 2 Right blocked escape.

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*A minimum of 15 ft^3 of barricaded volume is needed to sustain one person for 1 hr. After the hour, that volume will contain about 14 percent of oxygen and 5 percent of carbon dioxide. That should support life, but most uncomfortably and barely. At least twice that quantity, or 30 ft^3, are needed to compensate for physiological and psychological factors, for oxygen absorption by coal and timber in the barricaded zone, and for leakage. These figures represent absolute minimums. In subsection 2.1.3 of the main text, for example, CO_2 levels in refuge chambers are set at a maximum of 1 percent.

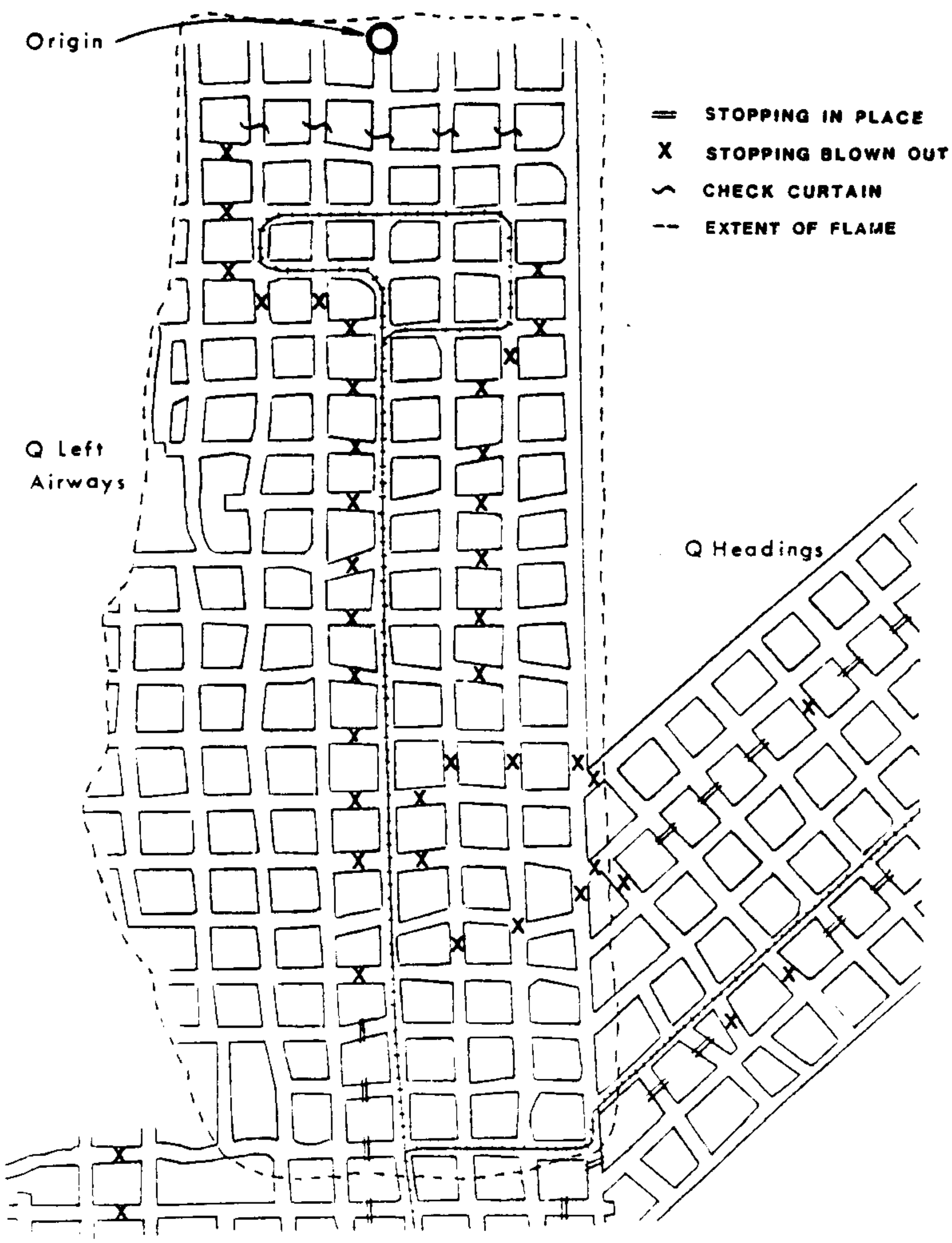


FIGURE A-19. - Origin of explosion, No. 31 Mine.

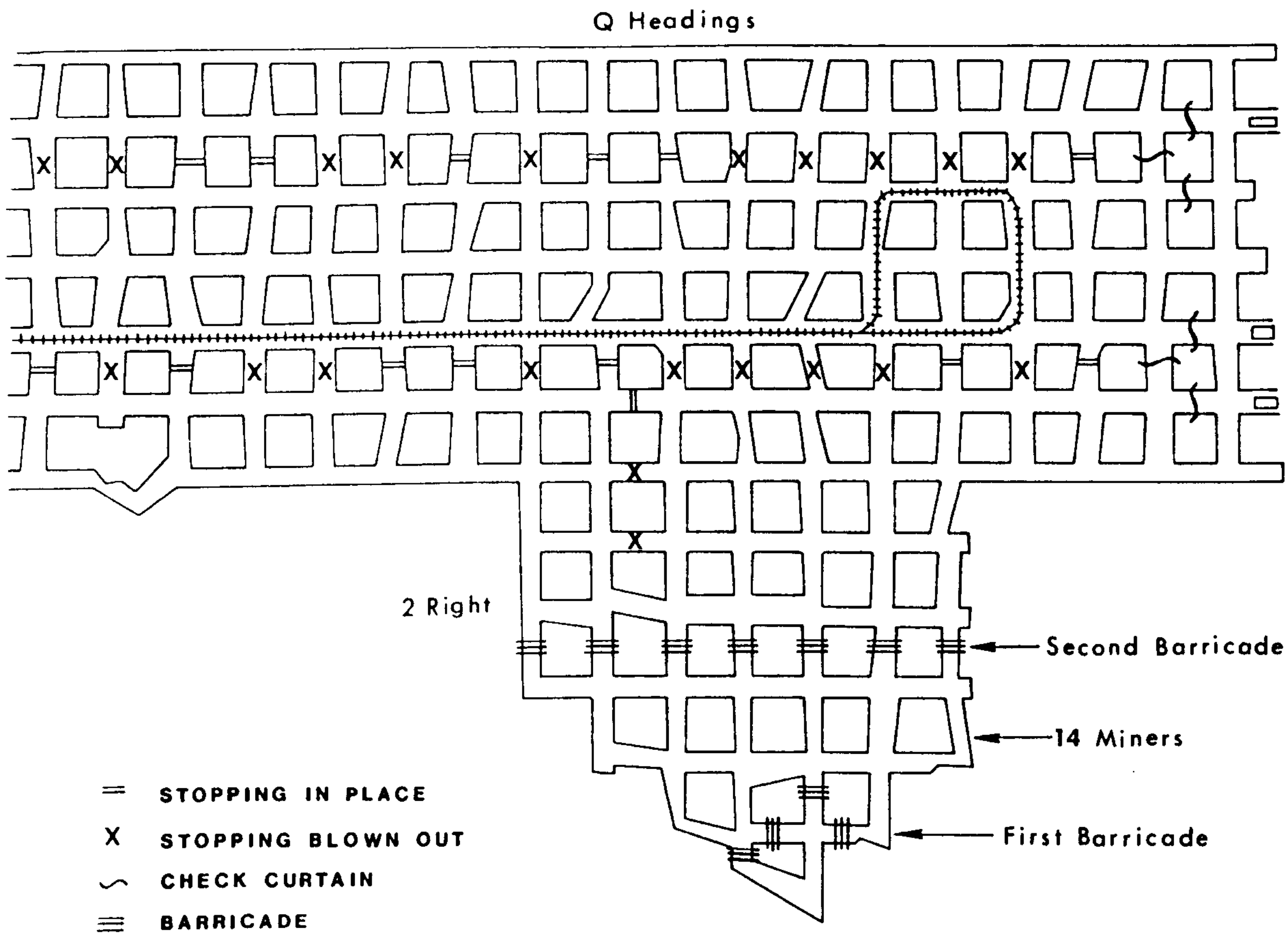


FIGURE A-20. - Barricades saved 14 miners in No. 31 Mine explosion.

They returned to the section where they gathered all available rolls of brattice cloth, spades, shovels, picks, flame safety lamps, and dinner pails.

They went to 2 Right where they built four barricades, shown as "First Barricade" on Figure A-20. These consisted of four to five layers of brattice spadded to the roof and ribs. Then they built the seven "Second" Barricades 200 ft outby the first. The 14 men quietly waited behind the barricades until they were rescued 4 hr after the explosion.

The decision to barricade proved to be a good decision. Their path to safety was blocked by at least 3000 ft of what rescue teams found to be an irrespirable atmosphere.

Their decision and their choice of barricading techniques and locations resulted from company safety meetings and conferences during the prior 6 months. What to do in the event you were trapped by fire or explosion had been a major topic. During one meeting, this Q Heading Section Foreman had discussed with higher officials the area where a barricade would be best. They agreed the locations where First and Second Barricades were built probably would be best. In those meetings the miners had been taught the barricader's rule-for=life, at least 15 ft^3/person/hr "and 30 is better."* The volume behind the Second Barricade exceeded 200,000 ft^3; that plus the explosion-ruptured stoppings having short-circuited airflows should have provided the 14 miners a safe atmosphere for more than 20 days.

A.6 Mine Accidents, 1970 to 1980

In the past decade both the number of disasters and disaster fatalities continued the rapid decline experienced in the prior 30 years. Many believed disasters were becoming a nightmare of the past. Nevertheless, despite strong safety laws, intensive enforcement of regulations by inspectors for the unions and operators as well as State and Federal agencies, and rapid implementation of new, safer methods and equipment, 183 miners died in nine disasters.

Refuge chambers saved 27 miners during one mine fire. In a mine explosion, six miners died behind a barricade which, had it built with care, should have saved their lives and perhaps the lives of two other miners. In a third, two miners lived for

*See footnote on page 53.

7 days before rescue by staying near the bottom of a borehole which brought fresh air to them while only 21, of the 91 who died, attempted to barricade. Those three accidents are described in the following three subsections. Table A-5 lists an additional two disasters in which barricading could have saved lives and reduced the risk of death.

A.6.1 Gordonsville Project Fire, April 19, 1978 (44)

Background

Gordonsville, a developing zinc operation in Gordonsville, TN, is illustrated in the single-line Figure A-21. It consisted of a mile-long, decline from which drifts were developed to the mining and haulage levels. Ore and waste rock from a crusher at the bottom of the decline was transported by a conveyor to the surface. A fan on the surface blew air to the workings through a 4-ft diam rubberized duct. Compressed air from the surface went to the workings through a 4-in. steel pipe. Twenty-nine miners were underground when the fire described below occurred.

TABLE A-5. - Two accidents in which miners did not barricade, 1970 to 1980

Mine	Date	Miners in danger but did not barricade		
		Survived	Died	Reasons for not barricading
Belle Isle (42)*	6-8-79	17	0	Inadequate training for emergency; 12 injured by smoke inhalation.
Blacksville (43)	7-22-72	0	9	They tried to escape through fire-gas filled entries.

*Numbers in parenthesis refer to references listed in subsection A.8.

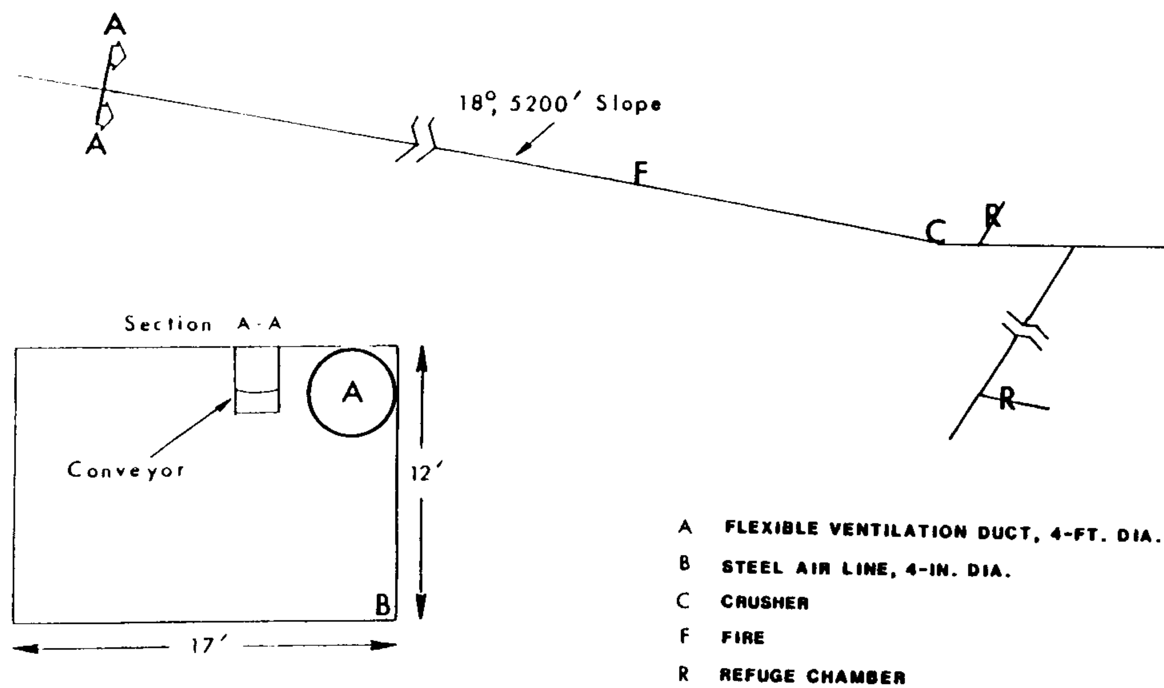


FIGURE A-21. - Fire affected area and refuge chambers in Gordonsville.

The transmission of a Scooptram was heating up; the operator was told to drive it out to the surface shop. When about 3500 ft from the portal, flames erupted from beneath the Scooptram. The fire could not be extinguished with a 10-lb and two 5-lb dry chemical extinguishers, the only fire control agents immediately available. The decline was the only way out of the mine, flames burned through the ventilation duct. The Shift Foreman went to the working areas to warn the miners. Two miners made their way around the burning Scooptram, reached the surface, and informed mine officials. The ventilating fan was turned off. Three mine rescue teams were assembled. They brought the fire under control within an hour.

Barricading

The 27 miners found safety in ready-made barricades, refuge chambers. These were well-constructed, contained food and water, and had a continuous replenishment of air from the compressed air line.

In 1970, the National Academy of Engineering proposed the use of refuge chambers. (4) These chambers were first described in 1912, in the Bureau of Mines Technical Paper 24, entitled "Mine Fires." (1) Since then, they have found relatively common use in noncoal mines. Typically, they are within 30 min from all working places. Often they are used by supervisors as an "office," by miners as their "dinner hole," and, as a place to assemble during major blasting operations and while waiting for a cage.

A.6.2 Scotia Mine Explosion, March 9, 1976 (45)

Background

Because of pending legal actions, the final reports of this disaster and the second on March 11, 1976 are not publicly available. The following, therefore, is limited to generally known information.

The Scotia Mine, Oven Fork, KY, is in the Imboden seam which locally ranges from 55 to 80 in. in thickness. Methane was ignited in 2 Southeast inby its junction with 2 Left. The forces of explosion extended through 2 Southeast.

Five miners in 2 Southeast were killed by flames and pressures. Ten miners died in 2 Left; six of those miners died behind a barricade in No. 5 room, 2 Left (see Figure A-22).

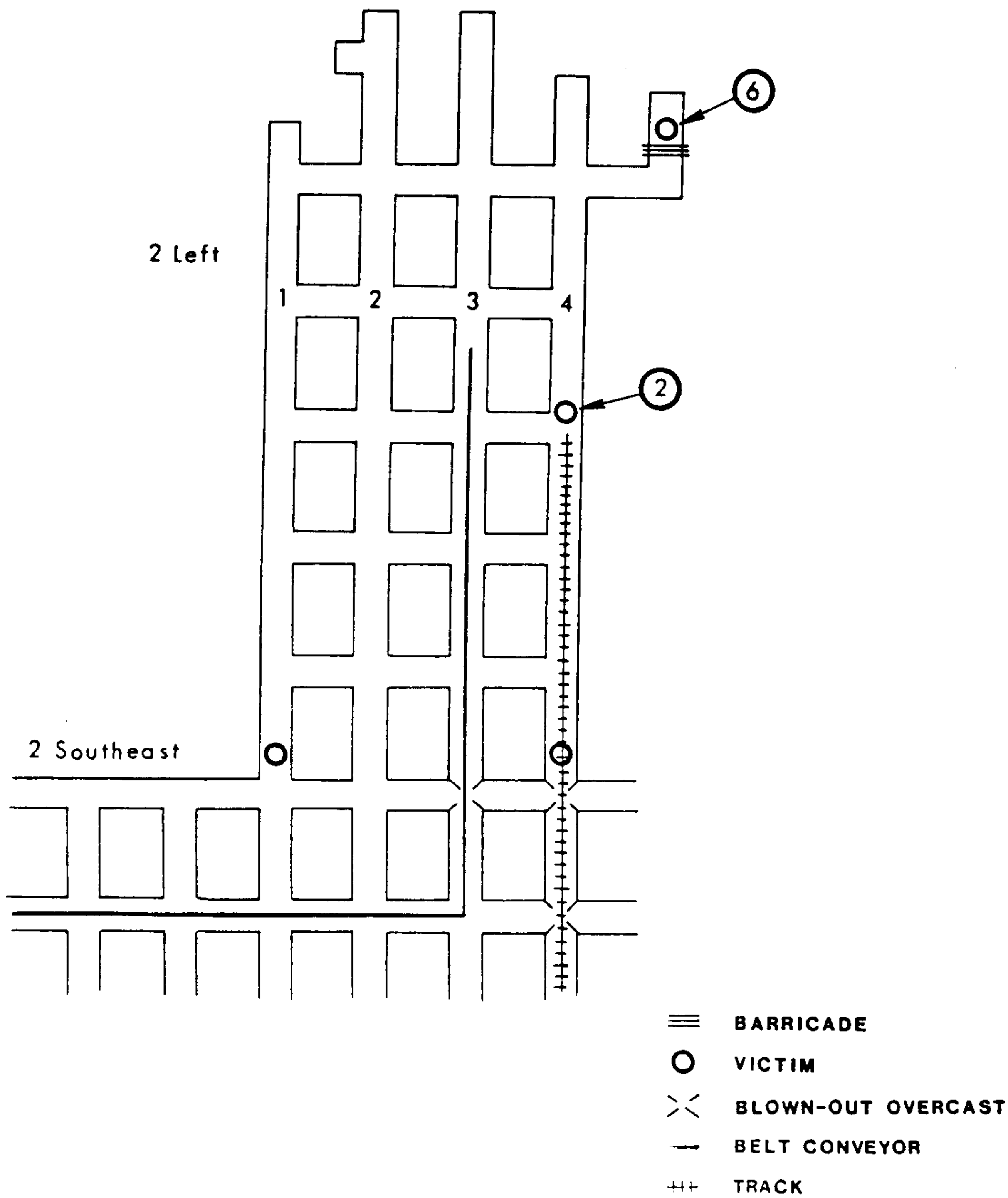


FIGURE A-22. - Barricade in 2 Left, Scotia Mine.

The two miners whose bodies were found at the end of the track in No. 4 entry normally worked with the six "barricaded" miners. They showed no evidence of death from flames or violence; it is possible they might have been behind the barricade at some time.

The section belt man reported that shortly after the explosion he had gone up 2 Southeast to within 400 to 600 ft of the 2 Left junction. The dense smoke forced him to leave. Soon afterwards, four other miners attempted to go up into 2 Southeast. They went 400 to 600 ft, about half the distance from the mains to the junction, before dense smoke forced retreat.

Seven hours later, mine rescue teams found no perceptible air movement at the mouth of 2 Southeast, "heavy CO" was in the return entry and dense smoke was in the track entry. Ten hours after the explosion the atmosphere at the junction with 2 Left contained 0.2 percent CO and 18 to 19 percent O_2.

Barricading

The barricade constructed in No. 5 entry was not much more than a brattice cloth check curtain. All of the materials needed to make a good barricade were immediately available. Airflows towards the barricaded area had been partially short-circuited because outby stoppings were blown out; check curtains across entries 1 through 4 might have prevented contamination of air around the barricade.

Footprints and discarded canister lids from self-rescuers indicated that some of these miners had traveled down the No. 2 entry as well as through the crosscuts between No. 5 entry and their working places after the explosion.

Unsubstantiated statements made to a Congressional Committee inferred the miners found behind the barricade and at the head of the track may have lived 6 hr. Rescue teams reached the barricaded area 11 hr after the explosion.

The barricade enclosed at least 4800 ft^3. For that volume, a properly-made barricade with the inflowing air short-circuited should support the lives of eight miners at least 10 and more likely for 15 to 20 hr.

A.6.3 Sunshine Mine Fire, May 2, 1972 (46)

Background

Sunshine Mine produces silver, copper and antimony at Big Creek Canyon, ID. Figure A-23 shows the general outline of the mine. Main access is through a 200-ft long adit to the Jewell Shaft, down that shaft to the 3100 and 3700 levels, then along a 5000-ft drift to the No. 10 Shaft. The No. 10 Shaft collared at the 3100 level, and was the sole means to the working levels.

Above the 3700 level the stopes were square-set and cut-and-filled with waste and rock. Lower level stopes were mined by horizontal cuts with sand fill. Ventilation prior to and during the fire has been detailed in a number of reports. (47-51)

Sometime between 11:30 and 11:40 a.m., smoke was seen flowing out of a number of places on the 3700 level. Numerous people began searching for the source. The airflow carried the smoke to No. 10 Shaft and then down to the lower levels. The chippy hoist, which could transport 48 miners at a time in No. 10 Shaft, was abandoned; smoke was so dense in the hoist room the operator had trouble breathing and could not see the control dials. Plastic brattice cloth and canvas at hand could have stopped most of the flow of fire gases into the chippy hoist room.

After fruitless search for the source of smoke the senior official underground ordered evacuation. Stench was released into the compressed air line at 12:03; shifters and motormen went to the working areas to call the miners out; and, the No. 10 Shaft double-drum hoistman was ordered to stop hoisting ore and to begin hoisting miners - the first of nine trips began at 12:10.

No attempt was made to prevent smoke flows into the double-drum hoist room. After a half hour, the regular hoist operator became ill and turned the controls over to his "partner." This second hoistman collapsed at 1:02; the evaucation stopped; 60 miners remained on the lower levels. In summary:

a. Eighty miners were evacuated.

b. Two miners were rescued 7 days later.

c. Ninety-one miners died; 21 of them were on the 5200 level, the only place where miners attempted to stop the flow of toxic air.

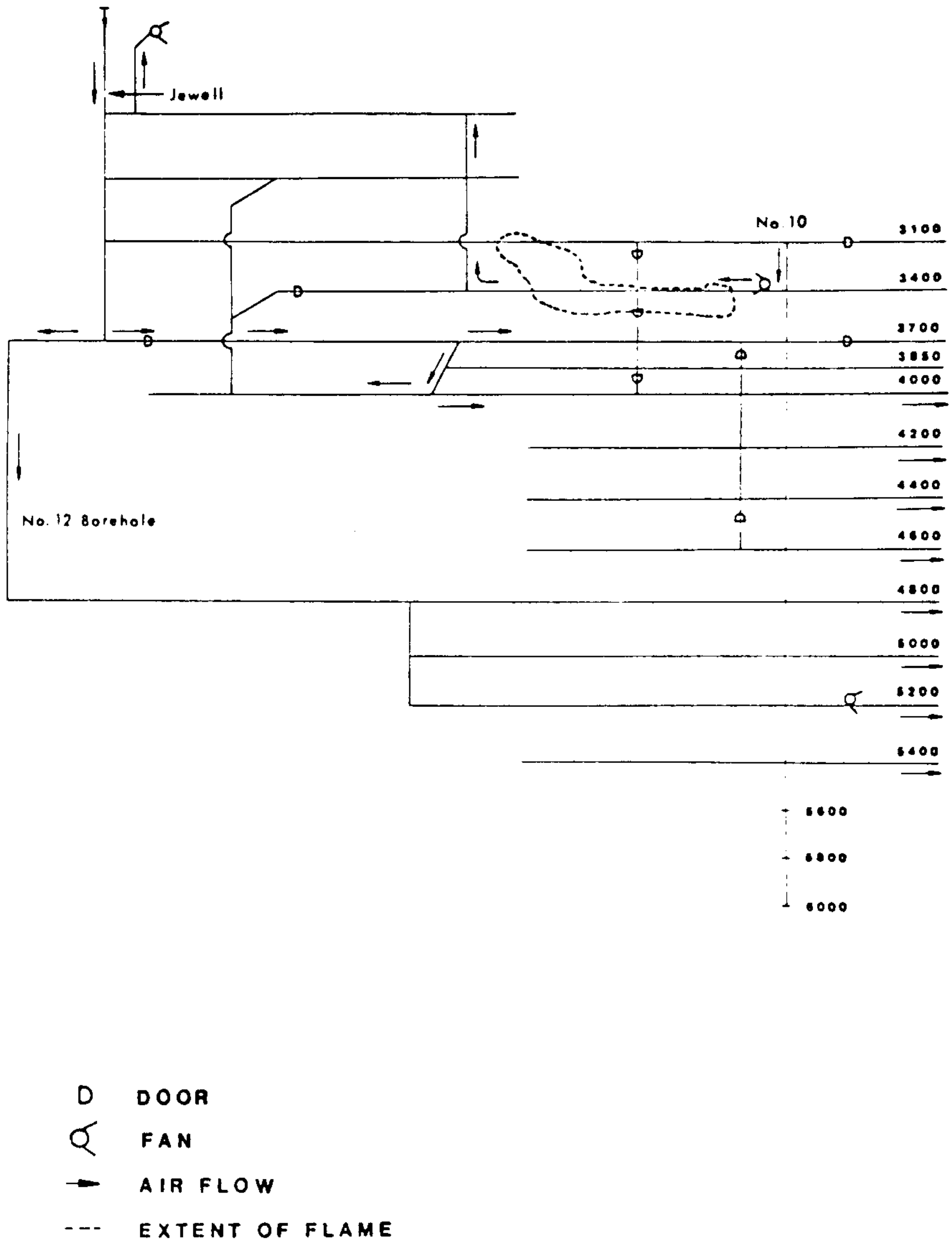


FIGURE A-23. - Schematic of Sunshine Mine.

The fire began as spontaneous combustion of timber in a manway between the 3550 and 3400 levels. This caused a section of the 3400 drift to collapse. The 3400 level was the main return; the collapse occurred downwind of the 3400-level booster fans. This caused the return air to split, part of it now went into old workings between the 3700 and 3400 levels, driving smoke and fumes that had collected in those workings into the main intake airflow on the 3700 level. The high-pressure air from 3400 level accelerated flaming which then spread through those workings and up into the 3100 level, the other main intake for the mine. The rapid flows of old and new fire products made every minute's delay critical.

The movements of some miners can be traced from information shown in Table A-6. Note that the cage never stopped at the 5200 level.

TABLE A-6. - Movement of some miners

Level	Miners on level prior to fire	Cate trips to level	Miners who died on the level
Jewell Adit	1	-	0
3100	3	-	31
3400	2	1	4
3700	52	4	16
4000	1	1	0
4200	4	1	3
4400	8	1	7
4600	20	3	0
4800	18	1	7
5000	25	4	2
5200	21	0	21
5400	8	1	0
5600 5800	10	1	0

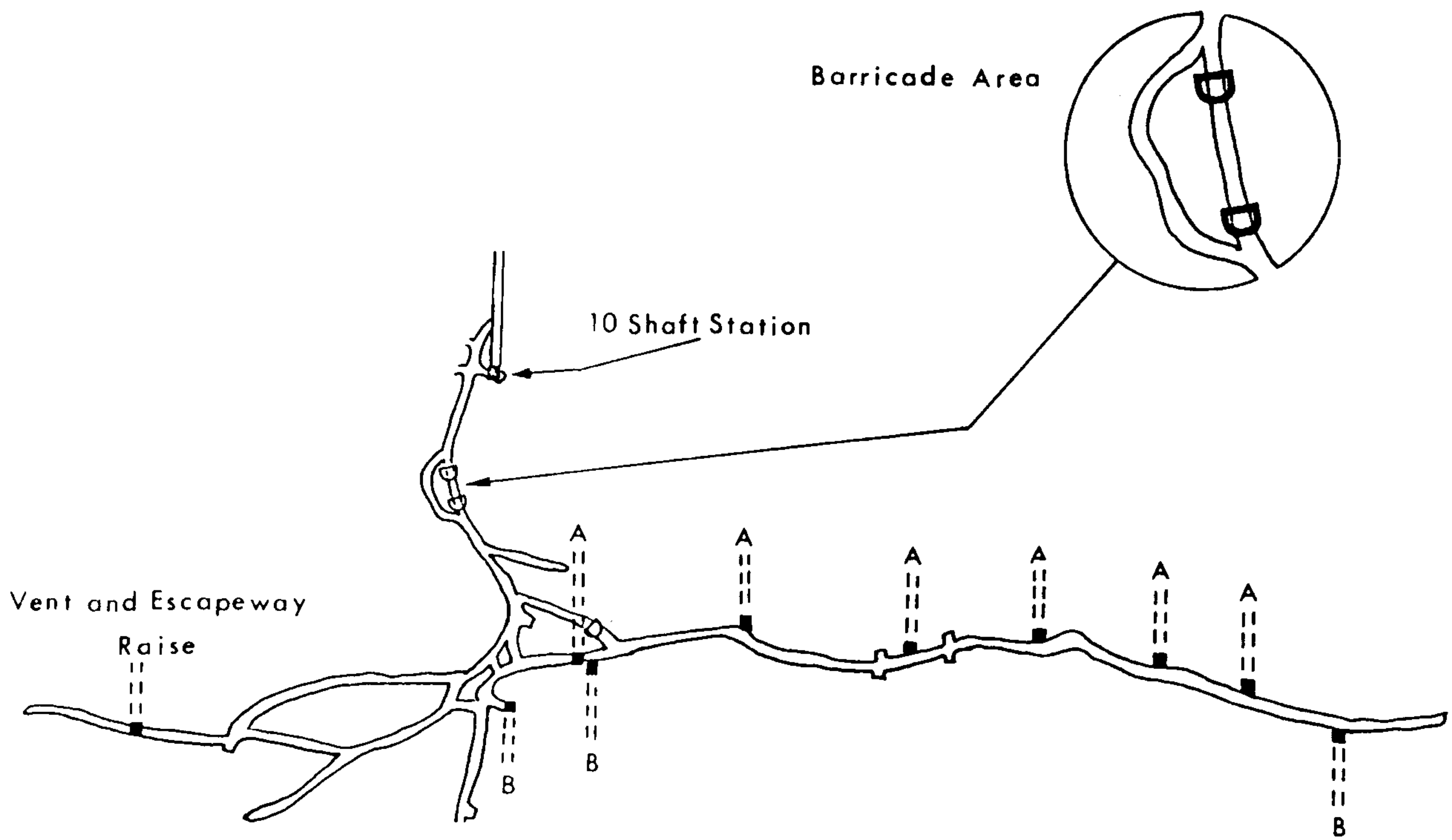
Barricading

Nothing is known about the attempt to barricade on the 5200 level (Figure A-24). Carbon monoxide killed the miners before the barricade was finished. Basically, the barricade was an attempt to make two doors airtight. The enclosed volume, less than 3000 ft^3, might have provided enough air to support the lives of 21 miners for 2 to 5 hr. Rescue crews would not have been able to reach them sooner than a week. A barricade in the drift from the Vent and Escapeway Raise might have provided a safe-air area for several weeks.

No. 12 Borehole, far left on Figure A-23, provided an uncontaminated flow of air from the Jewell Shaft to the 4800 level throughout the fire and during the months of recovery that followed. Two of the nine miners trapped on the 4800 level used that air and the water and food in abandoned miner's buckets until they were rescued 7 days later. These two are included in the summary total (Figure A-1) as "Could have Barricaded" not among those who "Barricaded."

A.7 Index of Mine Accidents

Table A-7 lists, in chronological order, all mine accidents discussed in the foregoing subsections.



A RAISE TO 5000 LEVEL

B RAISE FROM 5400 LEVEL

D DOOR

FIGURE A-24. - 5200-level barricades, Sunshine Mine.

TABLE A-7. - Chronological index of mine accidents

Date	Mine	Subsection Number or Table Number
1-10-40	Pond Creek No. 1	Table A-2
3-16-40	Willow Grove	Table A-2
7-15-40	Sonman "E" Mine	Section A.3.4
1-22-41	Carswell	Table A-2
10-27-41	Daniel Boone	Table A-2
12-28-41	Peabody No. 47	Table A-2
5-12-42	Christoper No. 3	Table A-2
1-05-43	Boyd	Table A-2
2-27-43	Smith Mine Explosion	Section A.3.3
5-05-43	Nu-Rex Mine Explosion	Section A.3.2
9-16-43	Three Point Mine Explosion	Section A.3.5
11-06-43	Nellis No. 3	Table A-2
5-09-45	Sunnyside No. 1	Table A-2
12-16-45	Belva No. 1 Mine Explosion	Section A.3.1
1-15-46	Havaco No. 9	Table A-2
3-25-47	Centralia No. 5	Table A-3
4-30-47	Kerns	Table A-3
12-11-47	Franklin	Table A-3
7-27-48	Kings	Table A-3
7-30-48	Edgewater Mine	Table A-3
7-16-50	Lake	Table A-3
10-15-51	Bunker	Table A-3
10-31-51	United Gas No. 1	Table A-3
12-21-51	Orient No. 2	Table A-3
2-02-52	Carpentertown Mine	Table A-3
11-13-54	Jamison No. 9	Table A-4
12-27-57	No. 31 Mine	Section A.5.6
10-27-58	Bishop Mine Explosion	Section A.5.1
3-08-60	Island Creek No. 22	Section A.5.4
4-25-63	Compass No. 2	Table A-4
8-27-63	Cane Creek Mine Explosion	Section A.5.2
12-16-63	Carbon No. 2	Table A-4
1-08-65	Crichton No. 4 Mine Fire	Section A.5.3
10-16-65	Mars No. 2	Table A-4
2-08-67	No. 28 Mine Fire	Section A.5.5
3-05-68	Belle Isle Mine	Table A-4
5-02-72	Sunshine Mine Fire	Section A.6.3
7-22-72	Blacksville	Table A-5
3-09-76	Scotia Mine Explosion	Section A.6.2
4-19-78	Gordonsville Project Fire	Section A.6.1
6-08-79	Belle Isle	Table A-5

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APPENDIX B

CHAMBER PRESSURIZATION CONSIDERATION UNDER TRANSIENT CONDITIONS

Considered in this section are the effects on chamber pressurization under changing barometric pressure and changes in the mine ventilation fan.

Barometric Pressure Changes

If the barometric pressure should rise rapidly the mine pressure outside the chamber could become higher than inside the chamber. If this occurs, hazardous gases can be forced into the chamber through stray leaks in the bulkhead seals. To quantitatively check the likelihood of hazardous gas being forced in, the following analysis considers the maximum rate that the chamber pressure can increase due to the injection of the breathing air. If the outside pressure were to rise such that the flow through the stopping is zero (neither in nor out), this would be the fastest outside pressure rise rate which would not lead to infiltration of outside gas (diffusion excepted). The pressure inside the chamber would rise at an equal rate due to the release of compressed air. For an ideal, isothermal gas, this pressure rise rate is:

$$\frac{dP_c}{dt} = P_o \frac{q}{V} \tag{B-1}$$

where

$\frac{dP_c}{dt}$ = rate of change of chamber pressure

q = the forced airflow per person = 1.9 ft^3/min/person

V = the chamber volume per person

The minimum recommended floor space per man is 12 ft^2 or a volume of 72 ft^3/person if 6 ft high. For estimation assume a volume 10 times larger (a worse case than the minimum volume) for example, 720 ft^3/person. Also assume $P_o \approx$ 30 in./hgr then,

$$\frac{dP_c}{dt} = 30 \text{ in./hgr} \frac{1.9 \text{ scf/person}}{720 \text{ scf/person}} \times \frac{60 \text{ min}}{1 \text{ hr}} = 4.7 \text{ in. Hg/hr}$$

An extremely high rise rate in barometric pressure would be a value such as 2 in. hgr/hr. Therefore the chamber pressure is expected to remain greater than the *mine* pressure during all increases in barometric pressure.

Ventilation Fan Changes

Suppose the mine exhaust fan(s) suddenly stops so that the air pressure just outside the chamber increases as a virtual step function to cause an initial differential pressure of ΔP_O. Now the pressure in the chamber will increase due to the released compressed air and due to the infiltration of air from outside the chamber, hence:

$$q = q_i + q_a \tag{B-2}$$

where

q_a = volumetric release rate of compressed air into the chamber

q_i = volumetric infiltration rate air from outside the chamber

Assume,

q_1 = $\alpha\ \Delta P$ (that is, Poiseuille flow through the stopping) (B-3)

ΔP = (outside pressure) - (chamber pressure) = $P_O - P_C$ (B-4)

α = stopping leak rate coefficient

Now,

$$\frac{d(\Delta P)}{dt} = \frac{d}{dt}(P_o - P_c) = \frac{dP_c}{dt} \tag{B-5}$$

(by differential of equation 4)

Then from equations 1, 2, and 3,

$$\frac{d(\Delta P)}{dt} = \frac{P_o}{V_c} q = \frac{-P_o}{V_c} (q_i + q_a) =$$

$$\frac{-P_o}{V_c} (\alpha \Delta P + q_a) \qquad \text{(B-6)}$$

Integrating equation 6, for example,

$$\int_{\Delta P_o}^{\Delta P} \frac{d(\Delta P)}{\alpha(\Delta P) + q_a} = -\int_{o}^{t} \frac{P_o}{V_c} dt \qquad \text{(B-7)}$$

yields:

$$\Delta P = \Delta P_o e^{-\frac{P_{o\alpha}}{V_c}} + \frac{q_a}{\alpha} \left(e^{-\frac{P_o \alpha t}{V_c}} -1 \right) \qquad \text{(B-8)}$$

From equations 8 and 3, the infiltration rate is, viz:

$$q_i = \alpha(\Delta P_o) e^{-\frac{P_o \alpha t}{V_c}} + q_a \left(e^{-\frac{P_{o\alpha t}}{V_c}} -1 \right)$$

and the total volumetric infiltration is, viz:

$$V_i = \int_o^T q_i dt = \int_o^T \left[\alpha (\Delta P_o) e^{-\frac{P_o \alpha}{V_c}} + q_a \left(e^{-\frac{P_o \alpha t}{V_c}} - 1 \right) \right] \qquad \text{(B-9)}$$

Now, τ is the time from when the step pressure is applied until $\Delta P = 0$, simply the time during which inflow can occur.

From equation 7,

$$\int_{\Delta P_o}^{o} \frac{d(\Delta P)}{(\alpha \Delta p + q_a)} = -\int_{o}^{\tau} \frac{P_o}{V_c}\, dt$$

which yields,

$$\frac{1}{\alpha}\, \ell n\, \frac{q_a}{(\alpha \Delta P + q_a)} = \frac{-P_o}{V_c}\, \tau$$

solving for τ:

$$\tau = \frac{V_c}{P_o \alpha}\, \ln \frac{q_a}{\alpha \Delta P + q_a} \tag{B-10}$$

Substituting for τ into equation (9), the infiltration volume is, viz:

$$V_i = \frac{V_c}{P_o} \left\{ \Delta P_o \left(1 - \frac{q_a}{\alpha \Delta P_o + q_a} \right) + \frac{q_a}{\alpha} \left[\left(1 - \frac{q_a}{\alpha \Delta P_o + q_a} \right) + \ln\left(\frac{q_a}{\alpha \Delta P_o + q_a} \right) \right] \right\} \tag{B-11}$$

If the infiltration gas contains Y_{CO}, the fraction of CO, the average CO concentration in the chamber due to this infiltration will be, viz:

$$\text{Percent CO in Chamber} = \frac{V_i}{V_c} Y_{co}$$

$$= \frac{100Y_{co}}{P_o} \left\{ \Delta P_o \left(1 - \frac{q_a}{\alpha\Delta P_o + q_a}\right) + \frac{q_a}{\alpha}\left[1 - \frac{q_a}{\alpha\Delta P_o + q_a} + \ln\left(\frac{q_a}{\alpha\Delta P_o + q_a}\right)\right]\right\} \tag{B-12}$$

Consider a severe example where:

P_o = 390 in. WG (30 in./hgr)

ΔP_o = 5-1/4 in. WG (This requires that the step change outside the chamber is 10-1/2 in. WG)*

α = 5 ft^3/min/in. WG

q_a = 28 ft^3/min (1.9 $\frac{\text{ft}^3/\text{min}}{\text{person}}$ × 15 persons)

Y_{co} = 0.02 (2 percent)

---

*If the ΔP increase is caused by a fan stopping or starting, the fan would have to have an operating ΔP somewhat larger than 10-1/2 in. WG, for example:

$$P_o = P_{fan} - \frac{q_a}{\alpha}$$

This is a high pressure fan for a mine fan but certainly not an upper limit. For a mine with a fan ΔP less than $\frac{q_a}{\alpha}$, the chamber would remain overpressurized always.

Namely: If the flow into the chamber can provide an overpressure greater than the fan capability, you will always stay overpressured even if the fan stops. Note that a way to do this is to have borehole resistance less than leakage resistance and just depend on free air leakage down the borehole (for example, pressure in chamber is kept at ambient outside pressure and flow is provided by mine fan sucking through leakage. If more flow is needed then chamber is always overpressured by definition).

Then:

$$\frac{2 \text{ percent}}{390 \text{ in. } 0.6} \left\{ 5 \text{ in. WG} \left(1 - \frac{28 \text{ ft}^3/\text{min}}{\frac{5 \text{ ft}^3/\text{min}}{\text{in. WG}} \times 5 \text{ in. WG} + 28 \text{ ft}^3/\text{min}} \right) + \right.$$

$$\frac{28 \text{ ft}^3/\text{min}}{\frac{5 \text{ ft}^3/\text{min}}{\text{in. WG}}} \left[1 - \frac{28 \text{ ft}^3/\text{min}}{\frac{5 \text{ ft}^3/\text{min}}{\text{in. WG}} \times 5 \text{ in. WG} + 28 \text{ ft}^3/\text{min}} + \right.$$

$$\left. \left. \ln \left(\frac{28 \text{ ft}^3/\text{min}}{\frac{5 \text{ ft}^3/\text{min}}{\text{in. WG}} \times 5 \text{ in.} + 28 \text{ ft}^3/\text{min}} \right) \right] \right\}$$

$$= 0.0073 \text{ percent (73 ppm) CO in the chamber.}$$

In this example the CO in the chamber is less than a concentration which will cause effects in 8 hr. Furthermore, this concentration will be reduced by the dilution of the released compressed air. If the dilution proceeded as a well stirred chamber, the concentration would be reduced by an e-fold factor (for example, ~ 0.37) every time constant. For example, consider $V_c = 6 \times 10^3$, then:

$$\frac{V_c}{q_a} = \frac{6 \times 10^3 \text{ ft}^3}{28 \text{ ft}^3 \text{ min}} \ \frac{1 \text{ hr}}{60 \text{ min}} = 3.6 \text{ hr}$$

Hence the CO concentration will be reduced well within 8 hr. This example is for rather severe conditions. A chamber supplied with 28 ft^3/min provides a reasonable insurance against gas infiltration due to changes in the fan for fans with differential pressure as high 10 in. WG.

APPENDIX C

DIFFUSIONAL INFILTRATION OF GAS

It is possible for dangerous gases to "leak" into a rescue chamber even when there is no actual air flow: a process called diffusion, in which molecules in an area of high concentration tend to migrate to areas of low concentration. Relatively simple equations can be used to determine this diffusion, or "leakage" rate.

To prevent diffusion of dangerous gases into a rescue chamber, the chamber should be sufficiently pressurized so that the air flow rate out of the chamber is much larger than the diffusion flow velocity inward. Using the assumptions listed in the following paragrpahs, it is shown that the required pressurization is extremely small: *Any chamber with a measurable overpressure will be protected from gas infiltration due to diffusion.* Several general assumptions are made, viz.:

a. The one dimensional diffusion equation applies, that is, the leaks are of small width-to-length ratio.

b. For the cases of interest, the outside concentration of gas is much larger than the inside concentration so that the difference between concentrations is virtually equal to the outside value of concentration.

c. The outside concentration level is held constant at a high lethal level, for example, 2 percent.

d. The airflow out of the chamber is Poiseuille flow through cracks in the stopping.

These assumptions are intended to permit conservative estimates of effects (worst cases) rather than to model typical situations.

Under the above assumptions, one can determine an average molecular drift velocity for CO (for example) as a function of the gas diffusion coefficient and the path length of the crack through the stopping. Hence.

$$\bar{V}_{CO} = \frac{D}{\ell}$$

where:

- $\overline{V}_{CO}$ - is the average molecular drift velocity
- D - is the gas diffusion coefficient of CO in air
- λ - is the average path length of the crack through the stopping.

The average velocity of outflow is given by the Poiseuille equation as:

$$\overline{V}_p = \frac{\Delta P_p m^2}{2.25 \lambda \mu}$$

where:

- ΔP_p - is the differential pressure to purge
- μ - is the air viscosity taken as 3.5×10^{-7} (lb-sec/ft^2)
- m - is the hydraulic radius of the crack taken as 2.6×10^{-3} ft (A crack of 4×100 ft $\times$ 1/16 in. sectional area)
- D - is the diffusional coefficient taken as 0.2 cm^2/sec or 2×10^{-4} ft^2/sec

Now set the outflow velocity ($\overline{V}_p$) to be ten times (a safety factor) larger than the diffusional infiltration velocity $\overline{V}_{CO}$ and calculate the required chamber overpressure setting.

$$\overline{V}_p = 10\ \overline{V}_D$$

then:

$$\frac{\Delta P_p m^2}{2.25 \lambda \mu} = \frac{10D}{X}$$

solving for ΔP_p,

$$\Delta P_p = \frac{22.5 \mu D}{m^2}$$

Insertion of example values,

$$\Delta P_p = \frac{22.5 \times 3.5 \times 10^{-7}(\text{lb-sec/ft}^2) \times 2 \times 10^{-4}(\text{ft}^2/\text{sec})}{(2.6 \times 10^{-3})^2 \ (\text{ft})^2} =$$

$$2 \times 10^{-4} \ \text{lb/ft}^2 \text{ or } 2 \times 10^{-5} \text{ in. WG}$$

A chamber overpressure of 2×10^{-5} in. of water is too small to measure by simple manometry. Therefore, any chamber with a measurable overpressure will be protected from gas infiltration.

APPENDIX D

COMPRESSED AIR STORAGE CONSIDERATIONS FOR SELF CONTAINED RESCUE CHAMBERS

In Appendices B and C, it was shown that a forced air supply of 2,680 scf/person/day to a rescue chamber can provide a breathable atmosphere by supplying O_2, removing CO_2 and by pressurizing the chamber to preclude the infiltration of hazardous gases. A possible source of compressed air is storage in tanks either within or in proximity to the rescue chamber. Costs and space considerations for stored compressed air are discussed in this appendix.

Cost and sizes will be estimated on the basis of containing 15 people for one day, then normalized to a person-day basis. This approach gives a reasonably realistic size system to permit scaling. One day air requirement for 15 people is:

$$2{,}680 \text{ scf} \times 15 = 40{,}200 \text{ scf}$$

Cylinders containing 311 scf at about 2,400 lb/in.^{2} may be purchased (long term renting is much too expensive) for about $250.* These cylinders are about 9 in. diam × 55 in. size. The required number of cylinders is 40,200 scf/311, scf= 130 (cylinders). It is estimated that regulators, flow meters, valves and connecting tubing could be procured within $2,500 for the system. If labor for installation is assumed to be $28/hr (salary and fringe), the cost of the system may be estimated as follows:

130 cylinders at $250 each	$32,500.00
Regulators, valves, flow meter, etc.	2,500.00
Cylinder moving: 0.08 hr/cylinder × 130 cylinders × $28/hr	280.00
Hardware connections 0.25 hr/cylinder × 130 cylinders × $28/hr	840.00
Total for 15 person-days	$36,120.00

This is equivalent to $2,400/person/day.

*1983 dollars; see Foreward.

To estimate the bulk volume of the 130 cylinders, consider them in a 10 × 13 array, hence:

$$10 \times 9 \text{ in.} \times 13 \times 9 \text{ in.} \times 55 \text{ in.} \times \frac{1 \text{ ft}^3}{1728 \text{ in.}^3} = 335 \text{ ft}^3$$

(Bulk volume for 15 person-days). On a person-day basis, the bulk volume is about 22.3 ft^3.

Air cylinders at a pressure of about 6,000 lb/in.^{2} are also available. The cylinder size is 10 in. diam × 51 in. and contains 490 scf of air. The per cylinder cost is about $500. Using this type of cylinder and redoing the above analysis, a system for 15 person-days would include 82 cylinders, cost about $43,000 and require about 242 ft^3 for the bulk volume of the cylinders. Normalized for a single person-day basis, the system cost is $2,900/person/day and 16.1 ft^3/person/day. Hence, for a 20 percent higher price a 38 percent bulk volume reduction is achieved.

APPENDIX E

LOCATION EXAMPLES

This Appendix applies the guidelines outlined in Section 4 of the main text to the problem of selecting rescue chamber locations in five actual working coal mines. One chamber location is proposed for each mine. The recommended selection of either compressed air line or borehole fan as the life support method is also indicated.

Table E-1 summarizes the seam heights and travel rates in each of the five mines, the costs of borehole and compressed air life support systems for the proposed chamber locations, and indicates the recommended life support system.

For purposes of cost, it is assumed that the mines have no existing compressed air plant, and that a loop or duplicate compressed air line is required for each chamber. A compressed air line was assumed to be 1 in. iron pipe costing $90/100 ft. A compressor capable of delivering 30 ft^3/min to the chamber was assumed to cost $6200. Direct and indirect labor cost for installation of air line was assumed to be $360/day, with lines installed at a rate of 300 ft/day.

Boreholes were assumed to cost $53/ft including casing.

TABLE E-1. - Travel times

Mine No.	Seam Height in.	Travel Rate* ft/min	Borehole Depth ft	Borehole Cost*	Compressed Air Cost*	Life Support Method Recommended
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Borehole
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Borehole
[illegible]	42	[illegible]	[illegible]	[illegible]	[illegible]	Borehole
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Compressed air
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	Borehole

[illegible]

*1983 dollars; see Foreward.

Mine No. 1

Mine No. 1 (Figure E-1) is an example of an older mine in which it is not possible to maintain an intake escapeway, according to the strict definition, that is continuous from each working section to the portal; a segment of the intake escapeway is not totally isolated from trolley and power lines. The mine is not extremely large, and seam height is 84 in. It should be possible to travel the escapeways from the active faces to the shaft bottom in 30 min. However, the lack of integrity of the intake escapeway makes the mine a candidate for a rescue chamber.

Figure E-2a shows the detail of the currently active faces and the intake and return escapeways; the gap in the isolated intake escapeway is apparent. Figure E-2b shows the structure contours of the seam superimposed on the workings of Figure E-2a and Figure E-2c shows surface features superimposed on the workings.

It was desired to locate the rescue chamber so as to be outby all working faces, inby the gap in the intake escapeway, readily accessible from both escapeways, and accessible by surface borehole. Also important in this instance is the structure of the seam, for water currently stands in some areas of the mine at an *elevation of about 1490 ft* as shown in Figure E-2a.

The chamber location suggested in Figure E-2a meets all of the above criteria and is also 35 ft above the current water level. In order to reach the chamber from several faces by means of the return escapeway, it is necessary to travel a short distance away from the portal, but the alternative is to locate the chamber at a much lower elevation. In order for the chamber to be readily accessible from the return escapeway, a door, clearly marked, must be placed in an overcast as shown in Figure E-2a. Signs indicating the direction to the chamber, readable from either direction, should be located at the escapeway intersection as shown in Figure E-2a.

Mine No. 2

Mine No. 2 (Figure E-3) is a large mine with a limited number of portals; it is not possible to reach the shaft from the working sections in 1 hr. This mine does in fact have a rescue chamber, although it is no longer being maintained because it is far from the currently active areas of the mine.

The proposed location of a new chamber is outby all of the working sections, accessible from both the intake and return escapeways and accessible by surface borehole. The location will remain within 1 hr of the working faces for several years, as current property boundaries limit further mine development.

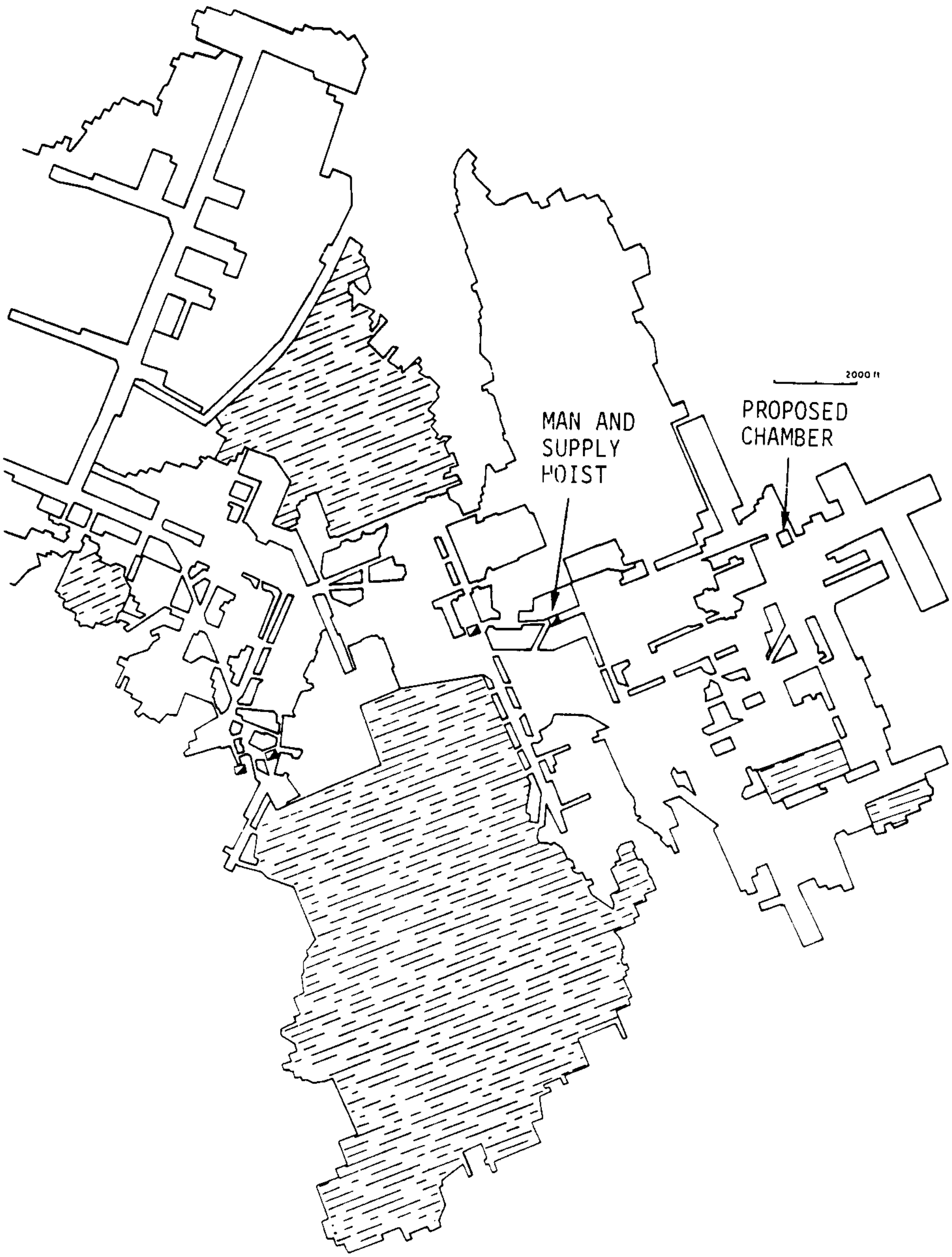
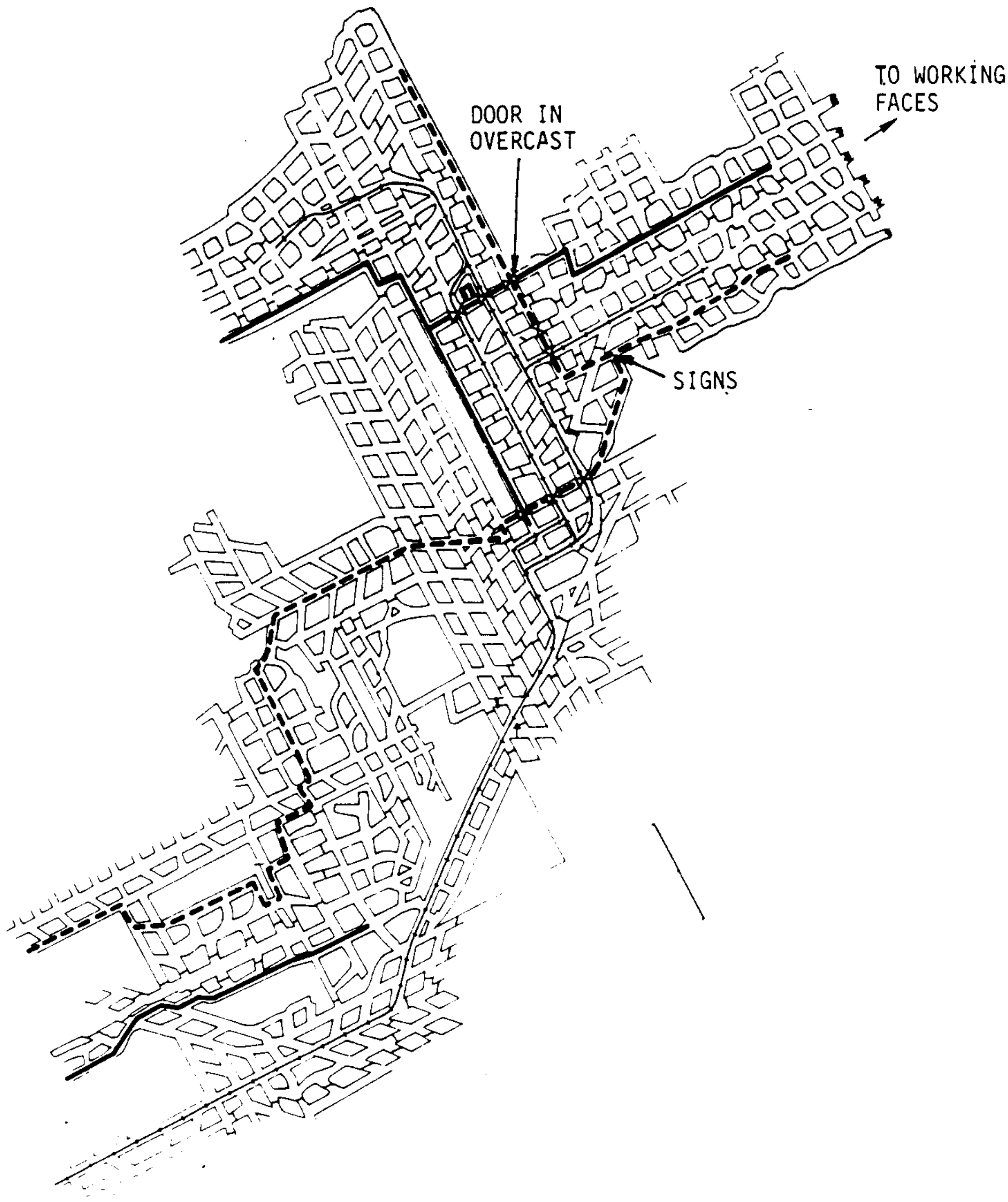
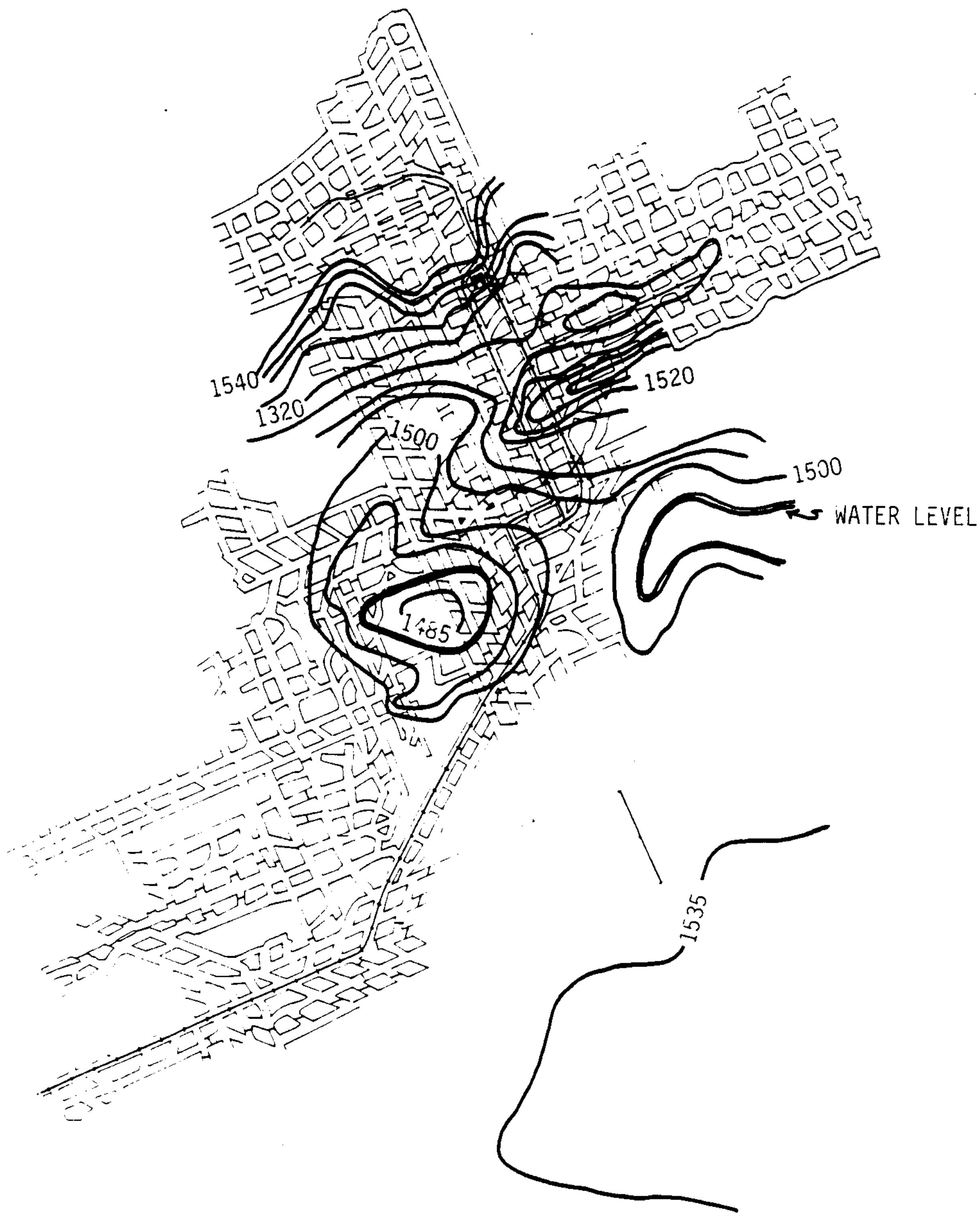


FIGURE E-1. - Mine No. 1.



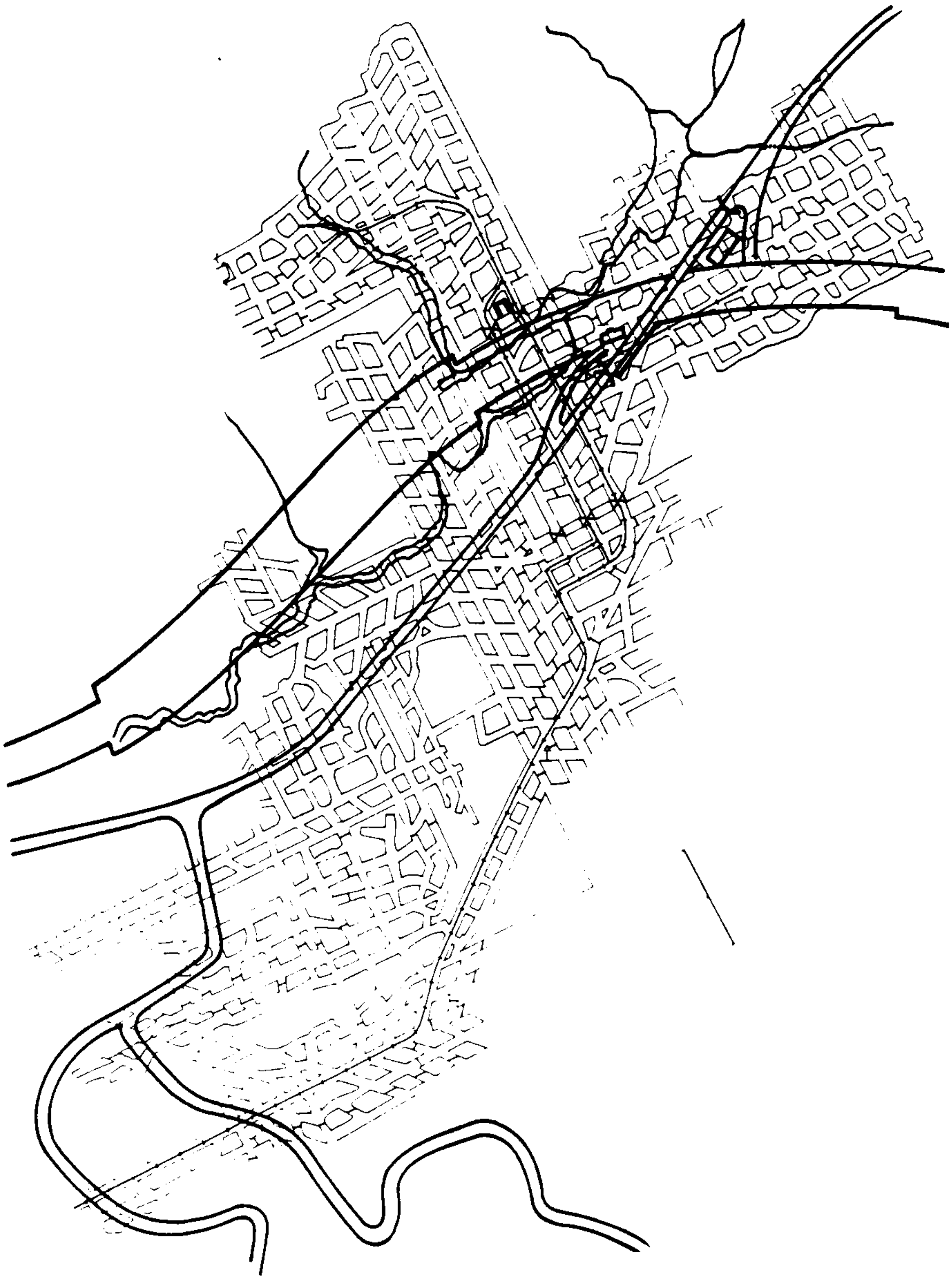
(a) CURRENTLY ACTIVE FACES AND THE INTAKE AND RETURN ESCAPEWAYS

FIGURE E-2a. - Mine No. 1.



(b) STRUCTURE CONTOURS OF THE SEAM

FIGURE E-2b. - Mine No. 1 (Continued).



(c) SURFACE FEATURES

FIGURE E-2c. - Mine No. 1 (Continued).

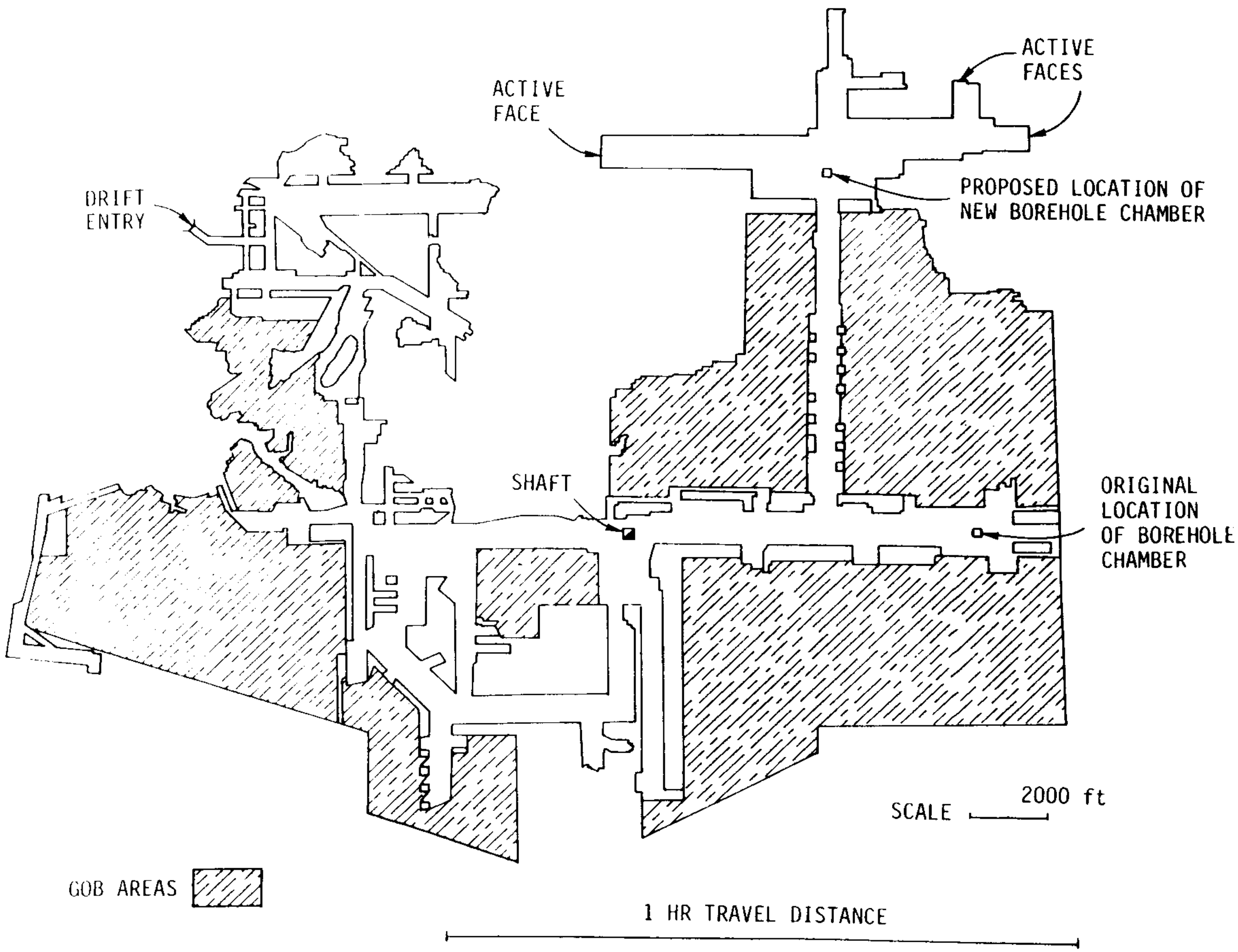


FIGURE E-3. - Mine No. 2.

Mine No. 3

Mine No. 3 (Figure E-4) is a low (42 in.) mine of the "punch" configuration. Even though the mine has multiple drift entry points, the low rate of travel (100 ft/min) makes it impossible to reach the outside from all working sections within 1 hr. The chamber is located so as to be outby the development sections, accessible from both the intake and return escapeways, and accessible by surface borehole.

Mine No. 4

Mine No. 4 (Figure E-5) is a deep, newly developed mine. Many of the working sections are more than 1 hr from a hoist. The chamber is located so as to be outby the largest number of working sections; it is slightly inby from the escape route for two of the sections. The great depth of this mine causes a borehole life support system to be substantially higher in first cost than a compressed air loop. This fact, combined with the difficulty of accurately drilling a hole to such a depth, indicates a compressed air life support system for this installation.

Mine No. 5

Mine No. 5 (Figure E-6) is a large mine with several shafts and a drift entry. All of the current and projected working sections are within 1 hr of a hoist. However, one of the shafts designated as an escapeway is an upcast shaft. Thus the possibility exists that it may not be useable in the case of an underground fire. For this reason it is suggested that a rescue chamber be installed near the bottom of this shaft.

The shaft area includes several boreholes which are used for power cables, water lines and rock dust. It is possible that an air line could be installed in one of these existing holes in order to supply air to the chamber; this would be cheaper than drilling a new borehole. However, the realtively small additional expense of a borehole, due to the moderate depth, is justified by the advantages of a separate borehole to the chamber.

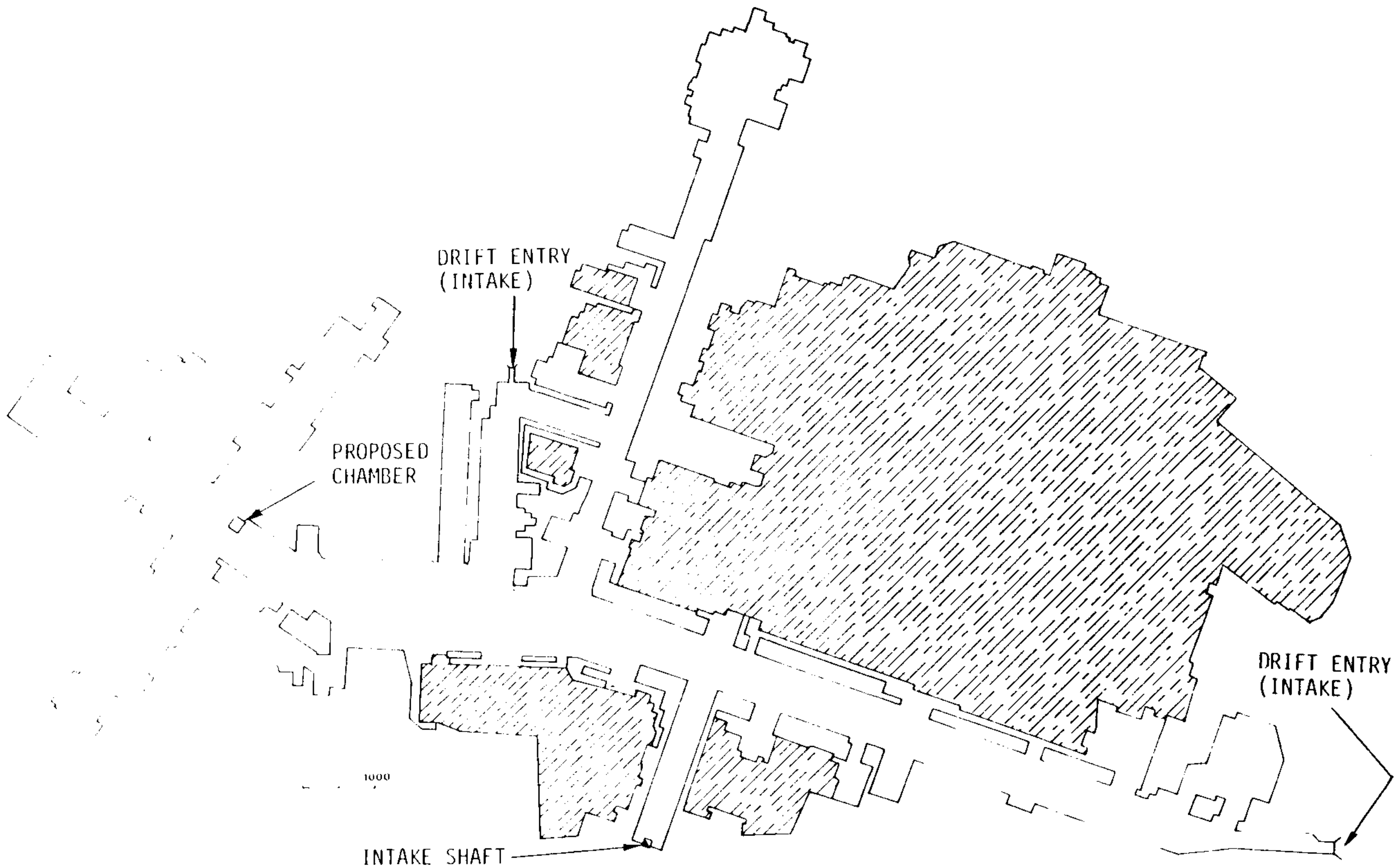


Figure E-4. - Mine No. 3.

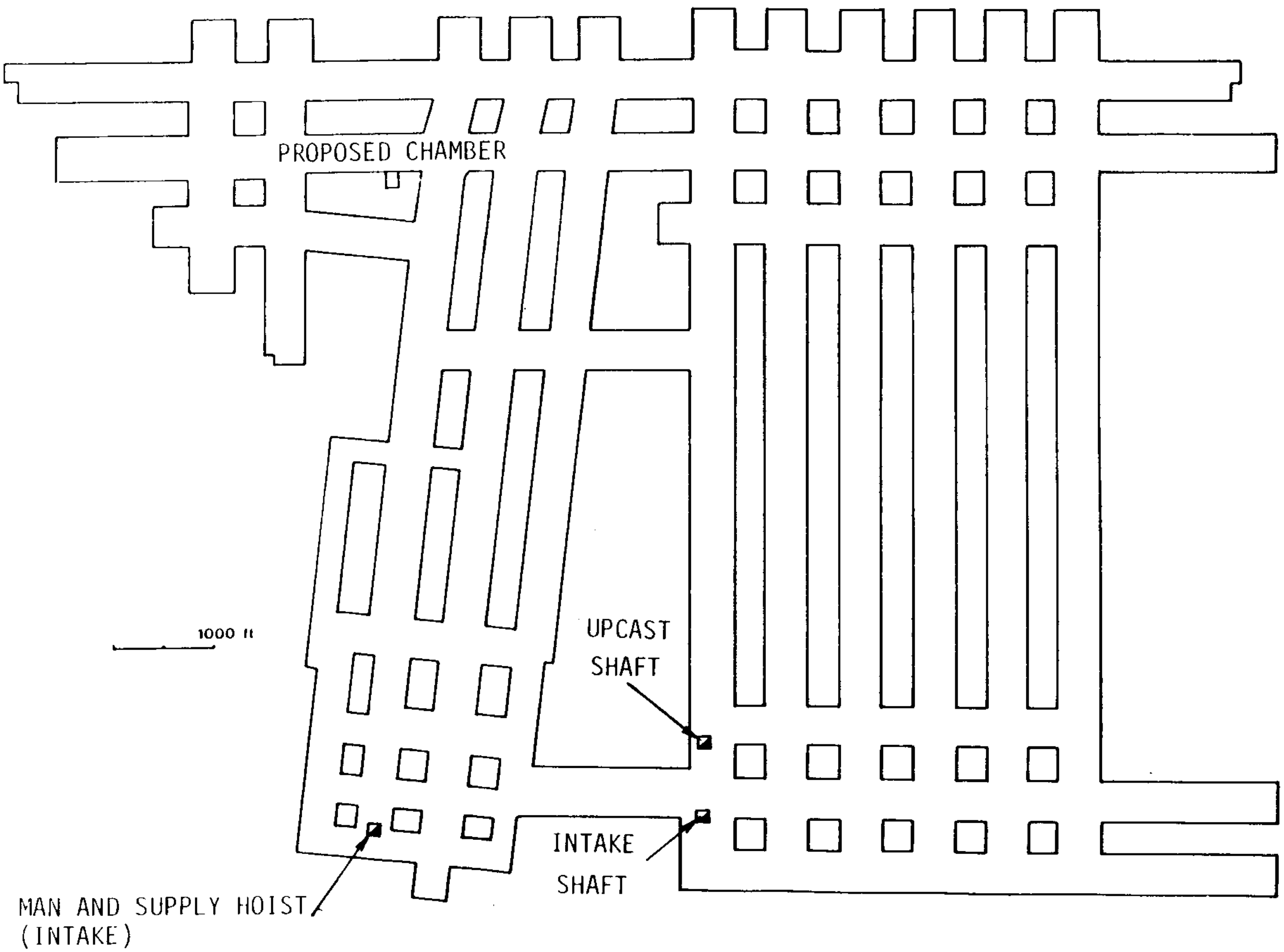


FIGURE E-5. - Mine No. 4.

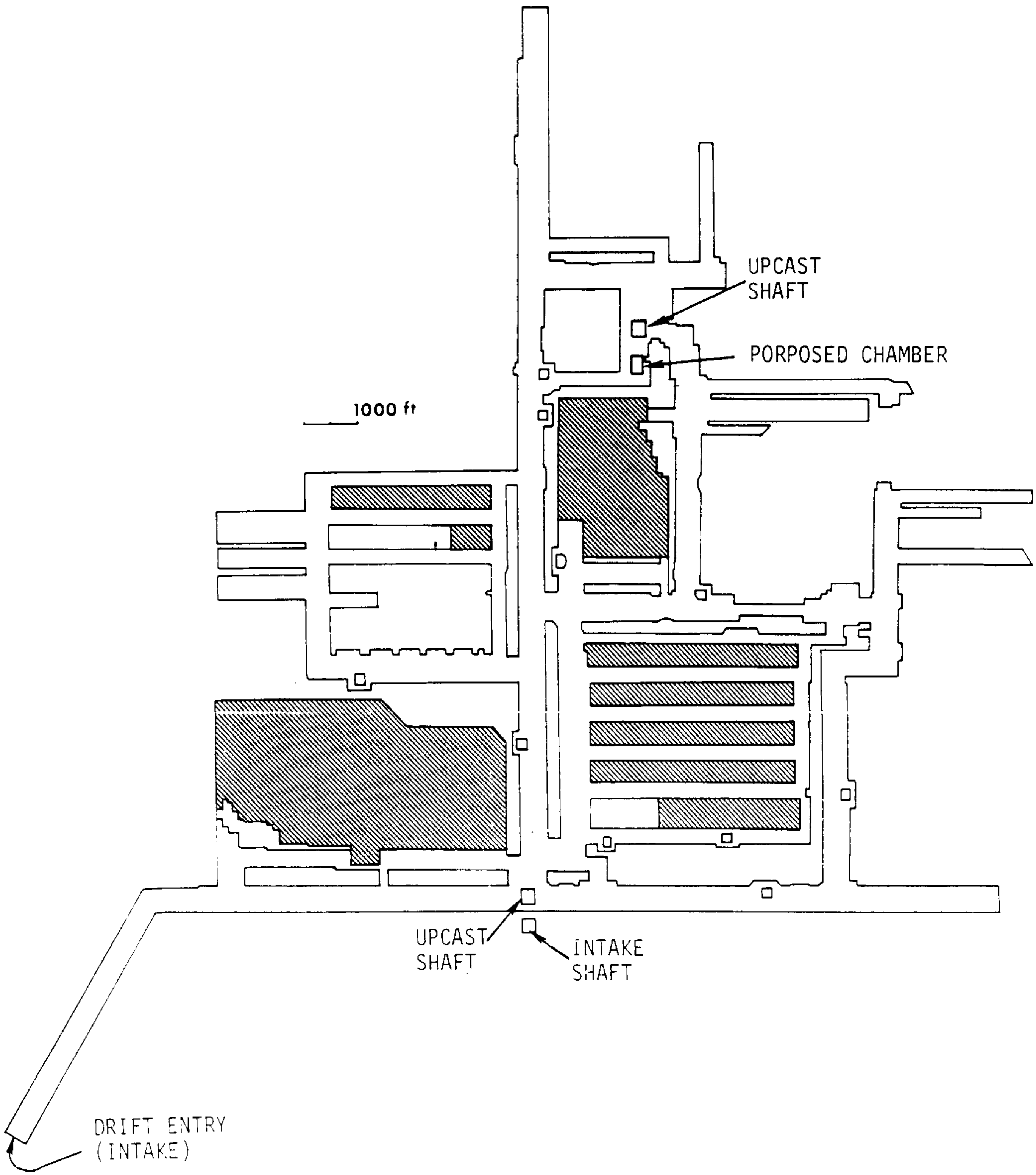


FIGURE E-6. - Mine No. 5.

APPENDIX F. PSYCHOLOGICAL ASPECTS FOR THE USE OF RESCUE CHAMBERS IN UNDERGROUND MINES

F.1 Introduction

The purpose of this Appendix is to develop hypotheses regarding the behavior or miners in the rescue chamber(s) and to suggest means to minimize potential adverse behavior. In keeping with the chamber development effort, three different chamber types, as described in Sections F.3 and F.4, are considered.

Constraints are such that the expected behavior must be derived from existing data and research; additional experiments or research to supplement existing research cannot be developed or included in this study/contract. Because existing data and research do not address the specific mining conditions of the subject rescue chamber, tentative hypotheses are advanced with the underlying assumption that in the future, hypotheses should be validated via behavioral research done under mine specific experimental conditions.

F.1.1 Objectives

The objectives are to generate plausible hypotheses concerning the behavior of miners in the subject rescue chamber(s) and to suggest means to minimize adverse behavior. Specifically, the report will:

a. Verify conclusions on behavior in Chapter 7 of June 1973 DCPA Attack Environment Manual relative to the three specified rescue chambers/conditions.

b. Discuss and suggest plausible boundaries for the potential for psychological incapacitation.* If data is available, both temporary and long-term (2-weeks), incapacitation will be discussed.

c. Discuss and suggest plausible boundaries for the effect of injured persons and the ability to cope with injured persons.

d. Discuss the ability to cope with death and the presence of bodies of the dead within the chamber.

e. Discuss and hypothesize regarding the effects of losing communication with the surface.

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* In keeping with the basic problem/intent of the report and with research data, the meaning of "potential for psychological incapacitation" will include neurotic behavior as well as incapacitation.

f. Provide suggested guidelines for recreation and exercise programs.

g. Provide an overview of the implications for the training (psychological preparation) miners should receive help to cope with the emergency/disaster.

F.1.2 Assumptions and Descriptions of Chambers

The defined rescue chambers are as follows:

a. The chamber has adequate air, food and water for at least a 2-week residence of a population of 15 persons with a minimum of 12 ft^2 each.

b The chamber is occupied by at least six individuals, but no more than 15 individuals.

c. It is highly probable that escape can be achieved within 2 weeks.

d. 2-way communications will exist to the surface.

The following optional conditions can be expected to occur, each of which may have a different impact on the type of psychological problems expected:

a. Type A: The available chamber will have a 6 in. borehole connection to the surface.

b. Type B: The available chamber will have unlimited air supply, but no food and equipment resupply capability.

c. Type C: The available chamber will have a limited (2 week) air supply and no equipment resupply capability. Communications with the surface may or may not exist.

F.2 Methodology

As depicted in Figure F-1, the program began with a thorough literature survey pertinent to psychological responses to mine disaster habitability. The research data was compiled and organized to facilitate derivation of psychological behavior in the subject rescue chamber.

The situational dimensions of isolation, deprivation and confinement were analyzed and compared with field studies of mine disasters. In as much as the laboratory and field conditions of

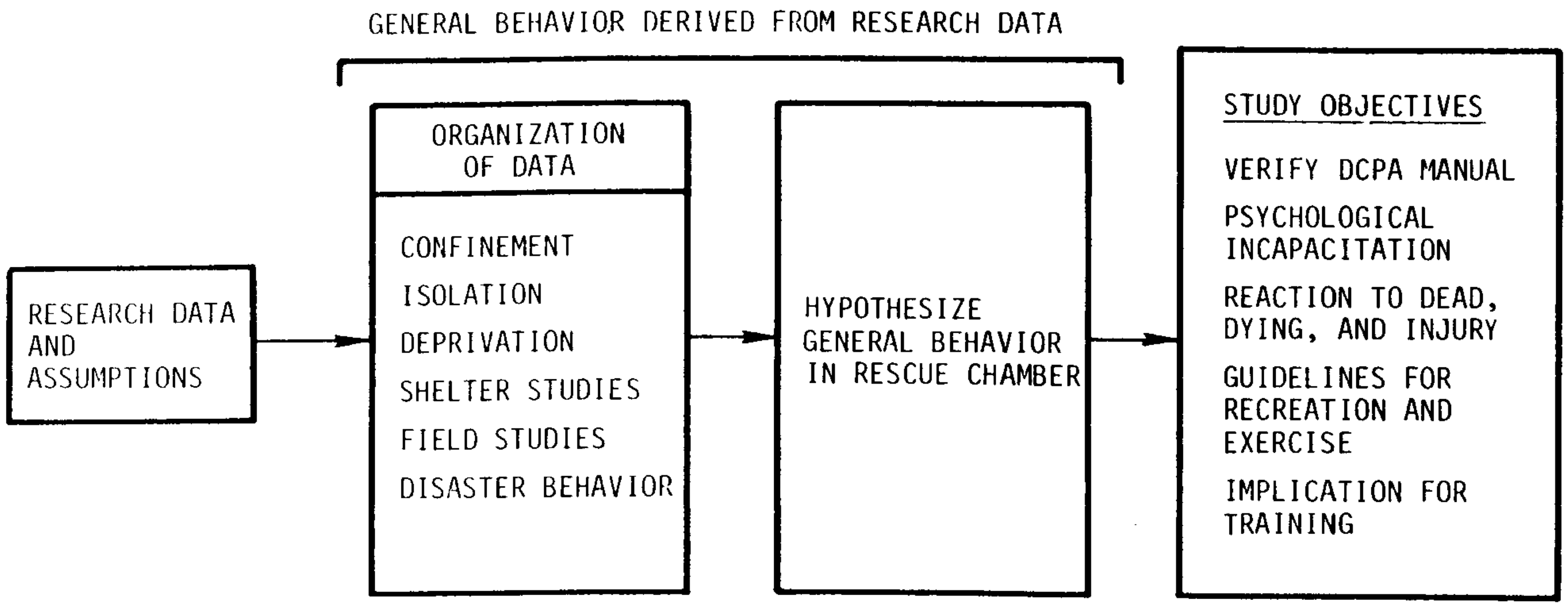

FIGURE F-1. - Methodology and report outline prior research differ greatly from the specified rescue chamber conditions, the results of this previous research were extrapolated to derive hypothesized behavior.

The study terminated with the development of hypothesized behavior. The hypotheses should be viewed as representing an opinion based on related, but substantially different, research data, a general and thorough knowledge of relevant psychological and physiological issues, and a knowledge of miners and underground mining.

Answers to the seven specific questions outlined in the Statement of Work are generated directly from these hypotheses.

This report is organized in accordance with the methodology depicted in Figure F-1 and described above.

F.3 Research Data and Assumptions

F.3.1 Literature Survey

The program began with a literature survey of applied research reports to predict psychological responses to mine disaster chamber habitability. Relevant agencies contacted to provide data base searches were:

a. Defense Documentation Center

b. National Technical Information Services

c. National Institute of Occupational Safety and Health

d. Library of Congress (Scorpio).

Agencies which provided research documents for review were:

a. National Academy of Sciences

b. Regional Director, Civil Defense

c. Defense Documentation Center

d. Library of Congress, Science Reading Room - Microfiche Files

e. George Washington University Library.

Examples of reports included were fallout shelter studies, underwater habitability studies, NASA manned spaceflight human factors research, mine disaster field studies and laboratory studies on sensory deprivation, confinement, and social isolation.

The objectives were to indicate plausible boundaries of psychological behavior, and to provide guiding principles for reducing the impact of potential problems.

F.3.2 Discussion of Validity of Data

Research data on deprivation, isolation and confinement reflects a great diversity of research questions and methodology. Studies on manned space travel, for example, are structured so as to enable generalization in most cases only to a unique set of persons (astronauts). Studies interested in underwater stress factors on personnel performance are only generalizable in most cases to the unique set of individuals assigned to these projects. The generalizability of these studies to underground mine conditions are, therefore, suspect. But, due to the limitations imposed by the contract requirements, such a review is the only plausible way that hypotheses concerning human behavior in mine environments can be developed. The reader is cautioned to carefully interpret the suggestions generated from these data in terms of their generalizability to mine parameters.

F.3.2.1 Deprivation Studies

Extrapolation of the results of these studies to miner behavior is difficult because group dynamics as an intervening variable was not subjected to analysis. One of the assumptions in the rescue chamber is that miners will not be alone when trapped. Therefore, group dynamics should have significant impact on miner behavior. Further, the deprivation encountered by the subjects studied was much more extreme than what is expected to occur with a mine disaster. In addition, the way deprivation was operationalized and experimentally varied in these studies is so uncharacteristic of what can be expected to occur with coal miners, that extrapolation seems highly questionable. Therefore though the studies were initially surveyed to gain knowledge of possible deprivation effects, the results were not included as a significant aspect of effects on miner behavior.

F.3.2.2 Isolation and Confinement Studies

Studies on confinement were briefly reviewed, and the following criterion was introduced to determine the relevance of a study to the mine parameters outlined in the Statement of Work. If a study involved more than 30 days confinement, the results based on this time frame were not included in this report. This approach was necessary to avoid drawing conclusions about behavior that were attributable to the extended confinement. Studies of prisoners of war, studies of Antarctic isolation and studies of survival in concentration camps are examples of areas that were excluded. Isolation studies thus became the focal point of this aspect of the research.

Most of the work done on isolation effects that was useful was the work done at the Navy Medical Research Institute (NMRI). The studies were a part of a continuing program called Project Argus. Despite the usefulness of this comprehensive study of isolation, confinement and deprivation effects, several difficulties appear in the methodologies. Such difficulties noted were:

a. Sampling for the experiments appears to be biased and/or from a limited population.

b. There were few replications for each of the studies.

c. The subjects were volunteers. In as much as miners will be forced to use the chambers, their attitude and orientation will be substantially different.

d. The duration of confinement for these studies was usually no more than 10 days and sometimes much less. The primary concern in this review is the effects of prolonged confinement of from 11 to 14 days.

e. These studies did not include seriously injured persons. It is expected that some miners will be injured, probably seriously, and these injuries are expected to have a significant effect on the results. The results of the field studies indicated that the presence of injured or dead persons is one of the most important stress factors.

f. The size of the groups studied and the conditions of experimentation may have significantly biased the results. The groups were usually dyads, and the conditions were laboratory conditions with strict manipulation of variables.

F.3.2.3 Shelter Studies

These studies were not primarily concerned with reactions to a disaster, but rather reactions to the effects of confinement. Conclusions cannot, therefore, be drawn from these studies concerning the expected responses of miners to disasters. The conclusions which may be drawn can apply only to the possible effects of confinement. Other limitations of these studies are a result of the selection procedures and include the following difficulties:

a. The subjects in these studies had a favorable attitude toward the conditions of the experiment. Most people think positively towards the Office of Civil Defense, and this creates a group that is significantly different in their perception of their temporary environment.

b. The possible effects of dead or inured persons on the subjects were not studied, nor were there any sick or injured subjects.

c. The subjects consisted of men, women and children. In mine disasters, children will not be present.

d. Most male subjects were in their early 20's. In field studies, older miners significantly effected the group due, perhaps, to their greater experience.

F.3.2.4 Field Studies

The two studies on previous mine disasters obtained from government sources provided the reviewers with probably the most accurate source of expectations on miner behavior. One study was of a mine disaster (explosion) in Nova Scotia in 1954, and the other was a flood in a mine in Lengede, Germany in 1963. These were studies of actual cases where miners were confined for prolonged periods of time, with most of the conditions being reviewed applicable. However, some degree of caution in interpreting these results is also suggested. They were reported after the fact, without strict control of variables possible (as is the case with field studies). Also, one study was written by psychiatrists, who interpreted the results almost solely in terms of psychodynamic process. The other study was done using a combination of psychological and sociological assumptions. The samples were relatively small for generalizations--six men were trapped in one mine cavity and twelve men were trapped in another cavity for between 6 to 8 days, in one study. In the other study, eleven men were trapped for 14 days. Finally, the mine conditions in these reports may be quite different than conditions expected with rescue chambers.

F.4 General Behavior Derived From Research Data

General behavior, including psychological, incapacitation and neurotic behavior, is affected by many dimensions and the interaction between dimensions. The rescue chambers present a unique set of dimensions which, to date, have not been studied. Therefore, related studies on different sets of confinement, isolation and deprivation, shelter studies and field studies are employed as a basis for formulating hypotheses relative to expected behavior.

F.4.1 Sensory Deprivation (SD), Isolation and Confinement

F.4.1.1 Effects of Deprivation and Isolation on Performance

Current research on the effect of deprivation and isolation on task performance is inconsistent. Some studies suggest there are definite performance decrements as a result of the stress of sensory deprivation, isolation and confinement (Bexton, W.H., Heron, W., and Scott, T.H., 1954; Heron, W., Doane, B.K., and Scott, T.H., 1956; Zubek, Puskar, Samsom, and Gowing, 1961; and Zubek, Aftanas, Hasek, Samsom, Schluderman, Wilgosh, and Winocur, 1962). In contrast to this Hanna (1960) reported that intellectual functions of subjects should not deteriorate over a 7-day period of sensory deprived confinement. Others have indicated that the amount of stress felt by the subject is the most significant determinant of the quality of task performance (Haythorne, 1966; Haythorne and Altman, 1967). According to Haythorne (1966), moderate degrees of stress impair performance. Smith (1969) summarized his review of effects of isolation and deprivation on performance by stating that little convincing evidence exists that intellectual functioning is adversely affected by confinement or isolation. The differences in findings in these studies may be due to differences in the amount of stimulation the subject actually receives while isolated or confined.

In a longitudinal study (1968-1973), stress was examined as a factor common to sensory and perceptual deprivation, isolation and confinement (Forgays, 1973). Subjects normally indicate the influence of stress in these conditions by showing low tolerance for it through early aborts, by self-report, and by physiological changes. The study was concerned with the importance of stress as a factor for each of these, and how it could perhaps be isolated. Zubeck suggested that confinement may be the more important variable (Rasmussen, 1973). Subjects were tested for responses to SD, using the water immersion technique (the most severe of the SD procedures). Stress responses to isolation and confinement were also tested. It was determined that the water immersion procedure, and therefore sensory deprivation, was more stressful than isolation or confinement.

F.4.1.2 Behavioral Symptoms of Deprivation and Confinement

There appears to be a substantial amount of evidence that the effects of stress due to SD, confinement and/or social isolation variables leads to irritability, hostility and depression (Agadzhanian, Bizin, Doronian and Kuzmetzov, 1963; Alluisi, Chiles, Hall and Hawkes, 1963; Burns and Gifford, 1961). One study (Sidney, Weinstein and others, 1967) reported that 80 percent of the subjects experienced anxiety due to confinement and isolation. Forty percent of the subjects expressed fear that there would be no one to help them if they had to leave isolation. There are some indications that such stress is affected by demographic and social background variables, such as age and isolation (Gunderson, 1963). Results from Sealab II studies indicated that later born divers from small towns adjusted better to stress factors than others.

F.4.1.3 Contagion and Territorial Behavior

It was hypothesized on one of the Argus studies (Haythorne, 1967) that since restraining influences of the larger society are less visible in isolated groups, it would be more likely for contagion of behavior to occur. Initial results were that such behavior was more likely to occur when the instigation to aggression was high, and when another person was observed by the group to aggress. It was further hypothesized that observing the aggressive behavior of another individual reduces one's restraints against such behavior, thereby increasing the probability that such behavior would occur, when instigation was high. The results appeared to support this hypothesis.

Incompatible pairs in isolation tend to withdraw socially, and to establish territorial preferences (Altman and Haythorne, 1967; Haythorne and Altman, 1967). There appears to be a developmental sequence to territorial behavior, "with fixed geographical areas and highly personal objects subject to jurisdictional control first, and more mobile, less personal objects somewhat later" (Altman and Haythorne, 1967). Incompatibility traits on dominance and affiliation result in high territoriality, whereas incompatibility on dogmatism do not (Altman and Haythorne, 1967). Related studies have reported that spatial and role relationships affect small group interpersonal dynamics (Steinzor, 1950; Sommor, 1965; Little, 1965). Group members maximize interaction potential with leaders through territorial positioning (Sommor, 1961). Little (1965) found personal distance in social relationships to be a function of feelings of "friendship."

F.4.2 Shelter Studies

Shelter studies have been oriented toward time (initial reaction, prolonged confinement, etc.) and topical dimensions (crowding, symptomatic behavior, etc.). Both groups of studies are germane to mine rescue chambers and reported herein. Because the most characteristic behaviors in shelter habitability occur in chronological order, they will be reviewed in similar fashion.

F.4.2.1 Stress Factors During Initial Stages of Shelter Habitation

Shelterees, upon first entering the shelters, exhibit confusion and disorganized behavior, usually manifested as loud noise, frequent giggling and boisterous behavior (American Institute, 1961). Initial behaviors are characterized by feelings of anxiety associated with entering an unknown environment. Studies have indicated that the most difficult period of adjustment is this initial phase, normally occurring within the first 24 to 48 hours (Raynor, 1959; Rohrer, 1968). Anxiety, caused by shelter habitability according to Rohrer, is mainly due to the following factors:

a. Not knowing what to expect in shelter living

b. Fear of contamination (in this case, gas)

c. Effect of presence of injured or dead persons

d. Phobic fears of small spaces

e. The threat of frustration

f. Anxieties over families, business, etc.

Increased anxiety and stress for some persons will likely be displaced to aggressive behavior (Rohrer, 1958-71A) or other types of psychopathology. Lawrence (1974) also reports that prolonged stress can be expected to lead to physical and psychiatric disorders, and that in some cases such frustration can lead to aggression.

As a result of increased anxiety, some withdrawal symptoms should be expected in the initial stages of shelter habitability (American Institute, 1961). A few shelterees may prefer to sit in a corner or lay on a bunk, reading or watching others, but not participating in any activities. Social withdrawal and encapsulation have also been observed in deprivation studies (Altman and Haythorne, 1967). Persons with strong predispositions to exhibit such psychiatric symptoms will probably do so, as a result of the increased anxiety (Rohrer, 1958). Based on these results, it is expected that if psychopathological symptoms are allowed to continue without any attempts on the part of leaders to control them, the individuals will probably deteriorate psychologically until they are beyond the control of the leaders, causing serious management difficulties.

F.4.2.2 Emerging Leadership

The emergence of a leader in the early stage of habitability facilitates organization (American Institute, 1961). This is particularly true in cases where the leaders have been pretrained. In the American Institute study, shelter groups willingly accepted the authority of their leaders, once the leaders actively sought to reduce the twittering and noisy vocalization that characterized initial habitability. Sherif and Harvey (1952) reported that ambiguous and anxiety-producing conditions can enhance conformity behavior. Therefore, it is important in this early phase for leaders to exhibit dominant characteristics. Alternatively, if increased anxiety during this early stage exceeds tolerable limits, informal leadership may not emerge. This might occur because the increased general anxiety may cause individuals to become preoccupied with handling their own troubles instead of concentrating their efforts on developing social organization.

Work assignments made by leaders in the American Institute study appeared to alleviate initial anxiety which was attributed to "not knowing what to expect." The first assignment in this case was the preparation of a meal. It was found that subjects exhibiting the greatest degree of anxiety were the first to volunteer for such assignments. Other studies have also indicated the importance of engaging people in functional and meaningful behavior in minimizing anxiety (Kumey, 1959; Morhs and Fritz, 1954; Rohrer, 1958). Studies conducted on longterm confinement have also been noted that group maintenance activities appear to be particularly important (Brainard, 1929; Byrd, 1930, 1938). Another study suggested that increased motivation could be channeled into an altruistic behavior, enhancing social stability.

F.4.2.3 Intra-Group Dynamics After Initial Habitation

After the initial phase of high anxiety and tension, shelteree behavior settles into a more relaxed pattern which essentially continues for the duration (1 week) (American Institute, 1961). During this phase, the shelterees willingly participate in recreational activities. Consequently, smaller recreational groups evolve, and friendship cliques form. This type of dissipation into smaller units may facilitate adjustment. Groups undergoing confinement where 24-hour schedules are maintained report that such separation helped them to maintain relationships with others (Farrell and Smith, 1964).

As this second phase continues, the need to become involved in an activity of some kind becomes very important. As the researchers reported later, "The problem of keeping busy appeared to be critical." It was found that assigning tasks that were perceived as necessary to group survival and comfort gave the subjects a sense of importance and responsibility. Other studies have demonstrated the importance superordinate goals can have in maintaining in-group cohesiveness and minimizing intra-group hostility (Sherif, 1951; Sherif and Sherif, 1953; Sherif, et al., 1955; Deutsch, 1968). Studies indicate that individuals will willingly work together as a group, for the good of the group. Results of the University of Georgia studies (Hammes, 1964, p. 40) reported that the emergence of group orientation and aggressive and empathetic actions of the leaders were the most facilitating factors in withstanding confinement difficulties. All subjects in this study apparently exhibited genuine willingness to work for the survival and comfort of the group.

The deprivation of normal social needs caused by isolation from the outside should result in the development of unique interpersonal relationships within the group. Close friendships rapidly develop (Altman, Haythorne, 1967) and emotional intimacy between some individuals occur far sooner than what would be expected in normal social relationships. Such relationships continued long after the shelter stay (AMI Study, 1963) thus indicating that these relationships are not simply due to overcompensating for the discomforts of confinement.

F.4.2.4 Responses in Later Stages of Habitation

After 2 or 3 days, the subjects become bored with the monotonous routine of shelter living. The amount of time it takes for the subjects to exhibit these characteristics varies among individuals, though it has been observed that when leaders tend to exhibit such characteristics, the group as a whole follows (American Institute Study, 1961). In all four groups, at about the same time for each of the groups, a period of "quiet resting" was observed.

The period of relaxation in the American Institute Study lasted about 1 day and was marked by a lot of sleeping and resting. The subjects in general ate little during this phase. It seemed to take longer during this phase to perform the usual activities. This type of withdrawal phase was also found in a study conducted by the West German Civil Defense Agency (1959). These studies indicate that a great deal of depression occurs at this time, with many of the subjects cross or edgy. Some shelterees complained during this phase that their continued confinement with others was becoming unbearable. Subjects in these studies once again resorted to normal activities the next day.

F.4.2.5 General Discomforts

Despite the fact that shelter life was tolerated reasonably well, there were many factors that created discomfort for shelterees. If one effect of such factors could be reduced, then it can be expected that adjustment to confinement would be facilitated. Table F-1 summarizes the sources of discomfort found in three shelter studies, including their relative importance. In examining this table, it appears that food, water for washing and sanitation purposes, sleeping conditions, boredom and interpersonal dynamics are the factors that seem most critical to shelterees feeling comfortable or uncomfortable during confinement.

F.4.2.6 Symptoms Exhibited in Shelters

Newmiller (1967) found that some of the main symptoms exhibited by shelterees as a result of confinement discomfort were headaches, body aches and nausea. A key factor noted in most shelter studies was general "frustration" (Murray, 1960, p. 71). Hammes (1964) reported most common complaints as colds, sore throats, nausea and homesickness.

Table F-1. Possible sources of rescue chamber discomforts

American Institute	HRB - Singer	MESA (9 days)
Food	Food	Noise
Water	Sleeping difficulties	Lack of water for washing
Sanitation facilities	Lack of exercise	Behavior of others
Sleeping accommodations	Boredom	Food
Communication	Inability to concentrate	Toilet facilities
Temperature	Crowding	Lack of privacy
Temperature control	Temperature; humidity	Inadequate leadership
Crowding	Lack of water for washing	Boredom
Leadership	Toilet facilities	Crowding
Management guidance	Noise	Temperature
		Inability to concentrate

F.4.2.7 Anticipation of Release

In the final phase of shelter habitability involving the last 24-36 hr, pronounced anxiety similar to the initial phase is a potential problem. Gossip among small groups or "friendship cliques" should be expected. This was particularly evident in the studies reviewed, though, with the women, and not so much with the men. There was a lot of tension, and some temper outbursts. The willingness to volunteer for work assignments was no longer present. No one appeared to particularly hungry.

The activity level in this phase was high, though the interest span was low. There was a great deal of interpersonal resentment and hostility present manifested mainly in the form of remarks and acts. The attempts on the part of leaders to reduce the tension present during this period by active participation of the group in organized activity helped to keep the tension at a minimal, acceptable level. Too much suppression of interpersonal differences, however, could lead to the development of psychosomatic ailments (Rohrer, 1961; Mullin, 1959).

F.4.3 General Disaster Behavior

Reactions to general disasters tend to follow a typical pattern. After initial impact, there is shock, but no panic. Panic in a disaster is rare and usually occurs only if escape routes appear to be closing, but not closed (Baker and Chapman). People with responsibility for others almost never panic (Baker and Chapman). For a few hours there is substantial disorganization and confusion, due to the immediate disarray. People during this phase tend to be passive, indifferent. They may express disbelief at what has occurred (Weisman, Human Adaptation, 1973). When the shock of the impact begins to wear off, the victim wonders why he was spared. "Why did I survive when so many around me died?" The victims are then troubled by what is referred to as "survival guilt." "Was there something more I could have done to help others?" Such guilt may be due to the immediate relief felt by the victim that it was people other than himself who were killed. A second feeling that strikes the victim about this time is insecurity. They begin to ponder about their vulnerability, through identification with the suffering of those around them. There is also some immediate phobia that the trauma could recur. They are struck with the suddenness and unexpectedness of death (Weisman, Human Adaptation, 1973). During this time, some may wander about in an aimless, dazed state (Weisman, Human Adaptation, 1973).

Studies of disasters have indicated that there is a relatively low rate of nonadaptive behavior present (Marks and Fritz, 1954; Wallace, 1956; and Barton, 1963). Wallace (1956) differentiated between what he described as "helpers" and "nonhelpers" in a disaster. Helpers actively participate in group activity immediately after impact. They give first aid, direct others to safety and attempt to contact sources for further help. Nonhelpers on the otherhand tend to take care of only their immediate relatives, then seek refuge. It is the nonhelpers, according to Wallace, that exhibit nonadaptive behavior.

In his report of community response to a tornado disaster, Wallace (1956) observed the following characteristics exhibited by injured persons:

a. Immediately after impact, they attempted to orient themselves by finding out where they were, how serious where their injuries, what should be done to help and how to effect rescue.

b. To extricate themselves physically, if possible. If they were unable to do so themselves, to call for help.

c. If they were able to extricate themselves, they attempted to seek help or refuge.

d. Occasionally, they would attempt to help others or give directions to others.

e. After the initial efforts of rescue and refuge were accomplished, they subsided into a dazed and apparently apathetic state.

Thus, injured persons in general are cooperative, attempting to help others in a disaster.

F.4.4 Mine Disaster Field Studies

Two recent scientific interview studies were conducted following two mine disasters. These were the Novia Scotia and Lengede disasters. In both instances, there appears to be two distinct phases; impact or escape, and survival. Each has distinct sets of behaviors, perceptions and expectations.

HYPOTHESIS 5: Miners will be visibly distrubed but not psychologically incapacitated by the presence of dead bodies. If storage and concealment of the bodies and measures for eliminating or preventing the odor of decaying bodies is not provided for, then some instances of neurotic behavior are expected to be the most serious stress producing factor, beyond the immediate threat of death.

HYPOTHESIS 6: Miners will be greatly disturbed by the suffering of fellow miners. The greater the degree of injury, the greater the effect it will have on other miners. But if adequate supplies are available to enable miners to give first aid, the anxiety felt will be moderate and tolerable. Despite the amount or seriousness of injuries, miners will not be incapacitated by such stress factors. Group standards can once again be considered a potent force for influencing the miners to tolerate substantial degrees of anxiety.

HYPOTHESIS 7: Miners will exhibit some mild psychosomatic symptoms during confinement. These will usually consist of complaints of headaches, nausea, insomnia and general malaise.

F.4.5.2 Compressed Air Chamber

This type of chamber, designated "B" in this report, includes a self-contained 2 week supply of food and water, and an unlimited air supply (compressed air). Limited power supplies and communications to the surface are assumed. Under these conditions, miners may be expected to exhibit the behaviors described in Hypotheses 1 to 7 for the Type A chamber, except at a greater level of stress, or anxiety, and with a greater frequency. In addition, miners may be expected to exhibit the following behaviors, within the parameters indicated:

HYPOTHESIS 8: Miners will be skeptical of rescue possibilities despite reassurances given them as to the progress that is being made above ground. This suspicion will be due to an inadequate frame of reference on the part of the miners that seems to occur as a result of the more stressful conditions imposed on them.

HYPOTHESIS 9: Miners are expected to neglect to adequately ration their resources, unless this behavior is successfully learned through a training program.

HYPOTHESIS 10: Anxiety levels will probably be significantly increased during the last 4 or 5 days of confinement, notwithstanding assurance from the surface that they will be rescued. The miners may manifest their displeasure in some forms of aggressive behaviors.

HYPOTHESIS 11: Most of the aggression and hostility felt during the latter days of confinement in this chamber will be directed at the outside. The miners will probably feel that not enough is being done to help them.

F.4.5.3 Self-Contained Chamber

This type of chamber, designated "C", has a 2 week supply of air, food and water, with limited power (lighting), and the possibility of no communications to the surface. Under these conditions, miners are expected to exhibit the same behaviors as they would for Chamber B, except for the following differences, and within the parameters indicated:

HYPOTHESIS 12: If communications exist, the frequency of anxiety will be greater and more intense in Chamber C than in Chambers A and B during the latter stages of confinement. In addition to the variety of behaviors stipulated above, as confinement duration reaches the last stage, there will be rapid mood fluctuations between hope and despair. Miners will, at times, doubt rescue yet never totally give up hope, even if all indications are otherwise.

If power is lost due to improper rationing, or if power is rationed in favor of communications to the point little or no lighting exists, then the added effect of darkness is hypothesized to be:

HYPOTHESIS 13: If lighting is not available, there will be increased anxiety caused by the added stress factor of darkness. Continuous darkness is expected to be extremely discomforting to the miners in general, and to neurotic types in particular. Communications to the surface is even more important psychologically in this instance than any other yet stated. Previous training is also an important factor in affecting stable reactions under these conditions. However, the added stress created by darkness is not expected to incapacitate miners, though miners who exhibit neurotic behavior may give other miners some discomfort with their behavior.

HYPOTHESIS 14: There will be reports of perceptions of visual images, with some hallucinations possible, if lighting is not available. The images will be due to the lack of lighting, whereas the hallucinations will be due to the fears of darkness felt by some of the more neurotic types, as well as fears of death and consequent wish-fulfillment (the hallucinations will probably be that of outside miners arriving to rescue them).

But informal leadership figures and an orientation toward group behavior will soon ensue. The effects of informal group standards will be the strongest deterrant against deviant behavior. As the time of rescue approaches, miners will once again become anxious, perhaps manifesting this anxiety in the form of interpersonal animosities. But such behavior is not expected to become serious management problems, and should not lead to any incapacitating states.

F.6.2 Type B - Compressed Air Chamber

From Hypotheses 1-11 in Section F.4.6.1, miners are expected to tolerate the Type B chamber reasonably well, though there will be a greater frequency and intensity of psychopathological disturbances than in Chamber A. There will also be more psychosomatic complaints. However, the effect of group processes and the influences of informal leadership qualities are expected to censure such variant responses. Adequate training will enhance these ameliorative effects. Rationing may be necessary in this chamber, but without sufficient training, it is expected that miners will fail to effectively ration their resources. Miners will be suspicious of outside activities, feeling that little is actually being done for them. Their hostility will consequently be directed mainly toward the outside. In general, however, miners are once again expected to be group-oriented, exhibiting positive behaviors overall that will facilitate group survival. No incapacitating states are anticipated.

F.6.3 Type C - Self Contained Chamber

From Hypotheses 12-14 and paragraph F.4.5, miners are expected to exhibit more sever symptoms in a Type C chamber than in A or B. In addition, miners may suffer from visual hallucinations and the false perceptions of images. Miners may neglect to ration their food, and as they approach the final days of air supply, they will exhibit extreme anxiety characteristics, manifested as despair. There may be substantial hostility felt towards the outside, as they interpret, perhaps falsely, the sounds of rescue as the sounds of hopeless random searching. Despite these grave symptoms, miners as a group will never entirely give up hope for rescue, and they are not expected to be seriously damaged psychologically, either temporarily or permanently. Some miners may need psychological counseling after rescue.

F.7 Reactions to Dead, Death and Serious Injury

The presence of bodies creates serious levels of stress for the miners. In both of the studies reviewed, miners were particularly disturbed by the odors emanating from the bodies. Many feared that the gases from the decomposing processes would poison them. A Novia Scotia miner stated it this way:

> "Oh, it was terrible...the smell (of the bodies), that is what I was scared of. The stuff might poison us, you know. The fumes of that. I was scared of that too. Of course, you can't tell what it might do to us." (p. 42)

The odor from the bodies was also clearly perceptible and greatly disturbing to the 11 miners trapped at Lengede. They expressed the same fears that they would be poisoned by inhalation of the "polluted air".

The mere presence of dead bodies and the moans and wailings on the part of the dying was responsible for most of the stress felt by the miners. Psychiatrists studying the psychological disturbances of the Lengede miners noted the following:

> "...The deaths of their fellow sufferers were not always quick, but long drawn out in some cases because some of the victims were only trapped by rock masses at first and could not be released. Groans and imploring pleas for help filled the area for days and ceased only when exhaustion or further rock falls brought death to the trapped men." (p. 12)

The report concluded by describing the deaths of fellow miners as "supremely distressing" to the trapped men. Similar sentiment was expressed by the Novia Scotia miners. It was the long agonizing process involved in dying, coupled with the feeling on the part of the healthier miners of their powerlessness to help that most disturbed the miners. A dying miner trapped by heavy roof support beams remained conscious for 2-1/2 days, moaning and pleading for help. "Oh dear, oh dear, ... I would help you if you were caught," he was reported to have said to one of the miners. He pleaded incessantly, begging any of the healthy miners within hearing distance to chop off his arm so that he could be released. But the other miners were against amputating his arm, fearing that worse trouble would result. One described the problem in the following way:

> "... (The pinned man) wanted us to cut, to cut his arm off. Well, we couldn't very well get a saw in there; well, we tried with a pack chisel, but it was too dangerous for the whole bunch of us..." (p. 41)

The man was delirious during the last 3 days of his life. He continued to plead with the group to amputate, and raved about water most of the time.

The presence of dying or injured men can be expected to affect miners differently, according to the conditions of their suffering, and the amount of help the miners can offer. The anxiety felt by the miners in the Nova Scotia incident was mainly guilt and ambivalence. In the Lengede case, the anxiety was due more to fear. The Lengede miners were subjected to a more ominous threat of death, caused by the rapid deterioration of the roof. Rocks fell continually, thus forcing each miner throughout the period of confinement to reckon with the idea that he might be the next miner killed by falling rocks. During their first sleep after their escape attempts proved futile, six miners were killed by falling rocks. For the next 14 days, the miners crouched together in terror, as the cavity in which they were trapped continued to collapse upon them. The size of their refuge diminished from 15 to 20m × 3m × 5m initially to 3m × 4m × 5m at the time of their rescue. Four additional miners were killed during the 2 weeks, all within the same immediate area of the others.

Most of the miners in both studies were thus under tremendous psychological strain, and yet, few miners exhibited any serious psycho-pathological forms of behavior. On the contrary, with the exception of one miner in each disaster studied, the miners in general showed a remarkable ability to withstand their psychological trauma. No serious pathological behavior was found among the miners in studies conducted soon after their rescue. Nor was any serious signs of long-term incapacitation noted, other than some expected resentment towards their employers. The miners in general seemed to feel no substantial psychological disturbance at all. But during the actual confinement period, many behavioral characteristics were noted, with miners exhibiting such disturbances at one time or another. The disturbances exhibited by miners in the two studies include:

a. Impulsive, irrational behavior

b. Hostility, irritability

c. Inactivity, apathy

d. Fluctuations between despair and hope

e. Repetitious concern with trivial events

f. Tearfulness, crying

g. Ambivalent frames of reference

h. Survival guilt

i. Inadequate planning

j. Hallucinations

k. Inaccurate conceptions of time

l. Feelings of bitterness towards outside

m. Suicidal tendencies.

F.8 Effects of Losing Communications with the Surface

Loss of communication is a factor in the Type C chamber only. It is assumed that communication can be readily established and maintained via the 6-in. borehole or other means in the Type A chamber. Likewise, it is assumed that the worst case condition for Chamber B would be pulsating - in morse code - the compressed airline; thus, communication will exist by definition for Chamber B. Therefore, loss of communication is applicable only to Chamber C.

Results from the AI Study (1963, p. 24) indicated that two-way communication devices are essential to adequate adaptation to prolonged shelter confinement. Studies of long-term confinement, such as those conducted by the Gunderson group, revealed the importance of short-wave radio in maintaining morale and a "feeling of belonging to a larger society" (AI, 1963, p. 14). One advantage of the two-way communications rated by the study was that it minimized the potential for defections by giving reassurances to groups distressed. Such communications were also useful in orienting the shelterees about outside events, thus tying the confined group in a social sense to the outside world, thereby minimizing the degree of loneliness. A study by Taylor, et al (1968) found that outside contacts in the form of verbal instructions for tasks, along with other forms of audio stimulations, significantly reduced the reported subjectiveness and the likelihood of defection. Rayner (1959) stated that good communications "lessen the feelings of isolation and confinement, thereby reducing problems that could stem from these sources". Haythorne (1965) discovered that isolated subjects tend to exchange more varied and intimate information than Controls. This may be due, in part, to the greater need for stimulus input. Studies have indicated that men in isolation seeking stimulation in the form of interpersonal information may create further problems by becoming "overexposed" to each other (Altman and Haythorne, 1965; Byrd, 1930; Smith, 1969). In such a case, subjects may then exhibit withdrawal behavior, thus producing an environment in which there is an even greater deprivation of stimulation (NAS/NRC, 1972). Jones (1969) states that it is not really "stimulation" as much as it is "information" that subjects in confinement seek. If this is so, then it can be expected that as the amount of information contained in a stimulus increases in familiarity, there would be a corresponding decrease in its arousal value for the sensory-deprived subject. Thus an enrichment-oriented environment that emphasizes types of stimuli that are novel, informative, and meaningful would be preferred.

In summary, if communications do not exist, the miners in the latter days will exhibit extreme anxiety, as they anticipate the inevitability of death. There will be more despair under these conditions than in all of the others, and even if they are rescued in time, some long-term psychological damage may result. Such damage will most likely be recurring nightmares and fears of going back into the mines. However, due to the irrepressible will to live that seems characteristic of man, probably due to the effect of group pressures, the miners as a group are not expected to give up hope entirely, and it is doubtful that miners subjected to these stresses will suffer either temporary or permanent incapacitation.

F.9 Suggested Guidelines for Recreation and Exercise

The following guidelines for recreation, exercise and food are recommended to reduce anxiety levels.

F.9.1 Pocket Books and Magazines

Because many people in confinement found it difficult to concentrate thoroughly, magazines with short stories were preferred (AI Study). They were easier to read and enjoy than lengthy novels.

F.9.2 Playing Cards

Cards were considered a sufficient form of recreation in the AI Study. A suggestion is to provide several varieties of cards, to reduce the monotony that might develop. Also, a large chart giving easy-to-read instructions on varieties of suggested games to play, might help to further reduce monotony and boredom. The selected leaders in the chamber should be very careful to observe signs of hostility or aggression developing. Gambling should be strictly forbidden, for it would inevitably lead to such troubles. The important point is to offer a large variety of card games for the participants to play, to reduce the eventual monotony that is expected to occur, but in doing so, to avoid generating hostility.

F.9.3 Comic Books

These were, of course, popular in shelter studies, due to the presence of children. Many adults also enjoy reading comic books, and it should be a useful form of passing time.

F.9.4 Modeling Clay, Coloring Books, Model Airplanes, Crayons

These were found to be very good time passers. Though it is very likely that miners in their free time do not normally participate in such activities, studies have demonstrated that as the length of the period of confinement increases, the need for such stimulation becomes greater. If such a variety of ways to engage oneself in time-passing activities is not provided, despite how innocuous these activities may appear, the subjects are sure to become bored, monotony is sure to ensue, and stress will consequently become a major problem. Subjects in shelter studies have in general been satisfied with the above types of recreational material.

F.9.5 Importance of Food as a Morale Factor

Even though one of the assumptions in this review is that adequate food for survival is available, the importance of food as a morale factor should not be underestimated. Because of its increased symbolic value in confinement and isolation scenarios, eating food becomes to the inhabitant a form of recreation. Crewmen aboard submarines, for example, exhibit a preoccupation with food and its preparation, making it the most important single factor maintaining the crew's morale (Baker, 1960, p. 26). The quality of the food supply could have an effect on the general morale of the group (Rohrer, 1960; Rasmussen, 1963; Murray, E.J., 1960, p. 67). Hot food has been shown to have a beneficial effect (Wohl and Boodhart, 1955). The acceptance of emergency rations seems to be a function of the particular idiosyncratic features of the individuals. Immature or maladjusted persons may even refuse to eat such rations (Tossince and Mason, 1957). Foster, Pratt and Schwartz (1955) suggested that such refusal could be overcome by group pressures.

F.10 <u>Implications for Training</u>

The expected psychological problems associated with prolonged confinement to rescue chambers are anxiety, withdrawal, apathy, aggression, hostility, depression and irrational, impulsive behavior. Miners are expected to suffer more from the immediate shock of the disaster itself, and the resultant presence of dead and injured persons, than any other variables. Initial shock and panic will be the immediate symptoms of the disaster. Disbelief, confusion and disorientation will probably be present for the first few hours. Some phobic reactions to the possible recurrence of the disaster can also be expected. The way in which miners are able to cope with this *initial* shock should determine how successful miners tolerate their confinement. After the immediate shock effects have worn off, which should not last more than a few hours, the miner will suffer some anxiety, in the form of survival guilt. The miners are expected to feel discomfort from the confinement itself, but such discomfort is expected to be superceded by the more potent effects associated with death. There will be increasing anxiety as the number of days of confinement increase, especially if the miners are in the chamber that has a limited supply of air. But this anxiety, which in extreme cases such as limited air supply and/or loss of communications can be expected to reach intolerable limits by the 13th to the 14th day, will be due more to the fear that they will not be rescued more than anything else. It is not expected that any temporary or permanent psychological incapacitation will occur. The effects of group standards upon individual behavior are expected to discourage this.

A training program which accomplishes the following is recommended:

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

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

   2. How to protect oneself from the immediate effects

   3. How to decide whether to attempt to escape or to seek refuge

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

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

   1. The 1-hr breathing devices

   2. The carbon dioxide removal agents

   3. Getting communication to the outside.

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

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

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

   2. The expected types of behavior during confinement.

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

   1. Manager selection (by experience)

   2. Supply inventory

   3. Emergency equipment review

   4. Reconnaissance

   5. Manager selection (by vote)

   6. Food, water

   7. Medical services

8. Atmosphere control

9. Sanitation services

10. Recreational services

11. Sleeping arrangements (may change)

12. Security of rescue chamber.

It is suggested that a more definitive study of training requirements be undertaken before initiating the design and development of a Rescue Chamber training program.

F.11 Glossary of Terms

Anxiety. A state of tension or stress experienced by a person that generates feelings that range from uneasiness or worry to absolute terror or anguish concerning a perceived danger. Anxiety is very closely related to *fear* in its emotive content. But though both anxiety and fear are emotional reactions to danger, with fear the danger is obvious whereas with anxiety it is not. It appears that there is a gradient quality to anxiety. That is, one might be anywhere from mildly anxious to severely anxious, depending upon the amount of stress or tension present in the organism.

Mild or Low Level Anxiety. The lowest state of tension or stress felt by an organism due to some danger present. The psychological manifestation of mild anxiety is uneasiness or worry. A person in a mild state of anxiety might be one who has seen a favorite pet struck by a car, one who has been arguing with another person, or one who has recently observed a scary movie. The person feels slightly discomforted, but with little actual physiological manifestations.

Moderate Anxiety. The state of discomfort that modules between mild anxiety and severe anxiety. Because there is no real distinction to be made between some high states of mild anxiety and low states of severe anxiety - except that the latter is always manifested in actual physiological symptoms - it was decided to use the concept here of a transitionary state, where one is more than mildly anxious, thus perhaps exhibiting some symptoms (physiological) but not quite what might be described as "severe". Some sweating might occur in this state.

Severe Anxiety. The highest state of tension or stress felt by an organism due to some danger present and manifested psychologically as terror or anguish. A person exhibiting severe anxiety might be a neurotic in an airplane who has a fear of heights, one troubled by the death of a loved one, or someone believing he or she is suffering from a heart attack. The following physiological symptoms might be observed in this state:

- Pounding heart
- Rapid breathing
- Sweating

- Feeling of faintness
- Pallor
- Jitteriness
- Diarrhea.

Anxiety in this state may be exhibited in one of two modes - either "free floating" or "phobic".

Free Floating Anxiety. Anxiety that is general in relation to a causal element - it is not tied to anything.

Phobic Anxiety. Anxiety that is elicited by a specific object or class of objects.

Neurosis. A functional disorder of the mind, without an organic cause and exhibited as either a phobic reaction to something or as free-floating anxiety.

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