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The Emergence of Leadership in a Crisis: A Study of Group Escapes From Fire in Underground Coal Mines

By Kathleen M. Kowalski, Launa G. Mallett, and Michael J. Brnich, Jr.

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This research explores the emergence of leadership in a crisis situation. Since 1988, three major fires have occurred in underground, bituminous coal mines. While all the miners managed to escape, many experienced difficulty. Subjects were 48 coal miners, from the three mines, escaping in a total of eight groups. Some groups experienced an apparent breakdown of leadership during their escape, while others witnessed the emergence of leadership.

The mission of the U.S. Bureau of Mines is to insure the health and safety of the American miner. Research into leadership during emergency escapes provides valuable information for training in prevention, escape and rescue.

In each instance, the fires were evaluated as catastrophic and evacuation was navigated under desperate conditions. The subjects fled the mine in small groups, wearing breathing apparatus. The composition of each group was determined by where the subjects were located at the time they became aware of the fire, and realized the necessity of getting to the surface as quickly as possible.

A case study method was utilized in data collection. Each subject described his escape in an open ended interview, a naturalistic inquiry format. Data were coded according to a) evidence of leadership behavior b) evidence of lack of leadership behavior c) characteristics of the individual in each group who led the subjects out of the mine.

The data then were analyzed, focusing on the dynamics of each group across the three different mines. The three sites also were compared. Attributes of the leaders who facilitated the escapes were noted and compared, as were instances of lack of leadership. The structure of the group leadership before the crisis was compared with the reality of the leadership during the crisis.

Consensus characteristics of the emerging leaders during these crises are discussed and generalizations drawn. The authors suggest questions for further investigation and topics for further inquiry into the area of leadership evolvement during crisis.

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

ft	foot	lb	pound
ft^3	cubic foot	min	minute
in	inch	st	short ton

THE EMERGENCE OF LEADERSHIP IN A CRISIS: A STUDY OF GROUP ESCAPES FROM FIRE IN UNDERGROUND COAL MINES

By Kathleen M. Kowalski,[1] Launa G. Mallett,[2] and Michael J. Brnich, Jr.[3]

ABSTRACT

This research explores the emergence of leadership in a crisis situation. The study by the U.S. Bureau of Mines focuses on three underground mine fires and the resulting evacuations. The subjects for this study are 48 coal miners, who evacuated the mines as part of eight escape groups. The subjects described their escape during an open-ended interview. Data were coded according to: (a) evidence of leadership behavior, (b) evidence of lack of leadership behavior, and (c) characteristics of the individual in each group who led the subjects out of the mine.

During analyses, attributes of the leaders, who facilitated the escapes, were noted and compared as were instances of lack of leadership. The structure of the group leadership before the crisis was compared with the reality of the leadership during the crisis. Some groups experienced an apparent breakdown of leadership during their escape, while others witnessed the emergence of leadership. Consensus characteristics of the leaders, who emerged during these crises, are discussed and generalizations drawn.

Research into leadership during emergency escapes is needed to provide information for training in prevention, escape, and rescue. The authors suggest questions for further investigation and topics for further inquiry into the area of leadership evolvement during crisis.

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INTRODUCTION

This research explores leadership behavior in a life-threatening situation, a fire in a coal mine. Underground coal mines are well known to be extremely dangerous environments. The operation of massive machinery in close, dark areas makes for a constant threat of accidents. There are, in addition, numerous tripping, water and electrical hazards, unsafe "top" resulting in roof falls, plus the threat of fire and explosions. The alarming number of fatal explosions and fires in U.S. coal mines led to the founding in 1910 of the U.S. Bureau of Mines (USBM), Department of the Interior. The continuing mission of the USBM has been to ensure the health and safety of the miners while providing an adequate mineral supply for the country. In the United States since 1949, there have been at least 18 major explosions and more than 1,000 fires in underground coal mines (*9, 12*).[4] The prevention of and escape from fires have been a major concern and research interest of the USBM.

Attempts to improve the chances of escape from fires have focused on the technological aspects of evacuation such as respiratory protection apparatus and fire fighting equipment. The USBM has addressed prevention through the analysis of equipment design and the enhancement of alarm systems. Tougher regulations have been enacted by the federal regulatory agency, the Mine Safety and Health Administration in the U.S. Department of Labor. The efforts to improve in-mine fire prevention and response have centered on "more rules"—increased regulations and "longer hoses"—improved equipment. Only limited attention has been given, however, to the behavior of persons caught in mine fires. Although research on disasters is increasing, the spotlight has been mainly on predisaster and post-disaster conditions, on gathering information to orchestrate prevention and disaster plans, and on providing services to respond to disasters. Data have been gathered mainly on natural disasters, such as hurricanes and tornadoes. Most research on behavior under the stress of evacuation has employed field or computer simulations or has been concerned with the evacuation of burning buildings.

In 1984, the USBM initiated a program of research to develop performance-based teaching and evaluation methods for assessing critical nonroutine health and safety skills. From the perspective of most miners, fires and explosions are infrequent events; little has been known about the behavior of mine personnel in these circumstances. The opportunity to learn more about this problem came in March 1988 when a major fire occurred in an underground coal mine in the eastern United States. The fire forced the evacuation of miners who were working in areas of the mine that were located beyond the site of the fire. Some 27 miners had to travel through smoke-filled passages to escape and reach fresh air; fortunately, no lives were lost. To learn from their experiences, USBM researchers subsequently interviewed 21 of these miners.

Since this 1988 fire, others have occurred in the United States in which miners were forced to escape through hostile environments. To date, 48 miners have been interviewed by USBM researchers about their escape experiences. The information, contained in more than 2,000 pages of transcribed testimony, has been analyzed in several ways. The focus of the present study is on leadership behavior during the escapes.

Leadership has been one of the most researched topics on human behavior of the 20th century. Studies have ranged from individual characteristics of leaders, to situational leadership, to interaction of leader and follower, suggesting different leadership techniques for different followers. Are there different types of leadership that may fit different kinds of situations? In a crisis situation like that examined in this study, such information about leadership may improve significantly the chances of escape.

This study examines leadership behavior in crisis. It looks at the authority structure before the fires, leadership behavior or lack of leadership during the escapes, and examines the conditions associated with the emergence of leadership. According to Bardo (*2*, p. 78), "emergent behaviors are those forms of action, and the norms, values and beliefs governing those actions, that rise out of the disaster situation." This study examines the emergent behaviors of leaders under duress.

PRIOR STUDIES OF LEADERSHIP IN CRISIS

The research on leadership during emergency situations has consisted mainly of simulation and field studies; their principal concern has been with escape from building fires. During the 1980's, the majority of the laboratory and simulation research on the behavior of leaders in crises took place in Japan.

Hayashi (*5*) created a computer simulation model to evaluate leader behavior in a fire. Although his purpose was to aid in planning disaster-prevention, his findings are relevant to this study. His simulation model was designed to judge the actions and thinking of leaders. The

[4]Italic numbers in parentheses refer to items in the list of references preceding the appendixes at the end of this report.

simulation was undertaken four times each by 101 subject-leaders. The simulation consisted of a maze containing the leader, an informal leader, and 50 evacuees. The results indicated that the leader's actions were not dictated by circumstances. Any differences in behavior were attributed to the individual characteristics of each leader. The study also showed that the worse the situation gets, the less the individual differences. Hayashi concluded that an evacuation plan should not be based or rely on circumstance, but should consider the anticipated behavior patterns of leaders.

At Osaka University in Japan, researchers T. Sugiman and J. Misumi (*16-17*) conducted field tests comparing two evacuation methods: the "Follow-Direction Method" and the "Follow-Me Method." The studies took place in an underground shopping mall with volunteer escapees and confederate leaders. In the first method, the leader indicated the direction of the exit in a loud voice and by bodily gesture moved toward the exit. In the second method, the leader told a few evacuees to follow and then actually proceeded to the exit. To make the evacuation more complicated, two exits were set up, one not visible from where the evacuees were located. In addition, the lights were turned off and a siren rang for 20 seconds before evacuation.

In the first study, the researchers found that the "Follow-Me Method" evacuated people quicker than the "Follow-Direction Method" because a multiple number of small groups formed around each leader. A follow-up study focused on leader evacuee ratio, presuming that the formation of groups would be different if there were fewer leaders. The researchers used 16 evacuees; between two and four leaders followed the two different methods and then combined them. It was concluded that when each leader had a small number of evacuees (a 1:4 ratio), the "Follow-Me Method" was more effective than the "Follow-Direction Method." With a large number of evacuees, e.g., at a 1:8 ratio, the "Follow-Me Method" was not effective because the instructions from the leader did not reach every evacuee. In that situation, combining the methods was most effective.

Misumi and Sako (*10*) looked at leader behavior in emergencies using a laboratory simulation with one accomplice leader and four naive subjects. Each subject could move his or her assigned red dot on a display. Results showed that if the leader first attempted to reduce tensions and then indicated the direction to go, the subjects followed more closely than if the sequence of behaviors was reversed. The authors concluded that panic is reduced by introducing appropriate leadership.

Other relevant research in this area has concentrated on general behavior in fires. Outside of Japan, Hodgkinson (*6*) noted that panic accompanies behavior in fires. He defines panic as nonsocial, blind, irrational behavior. His research into almost 1,000 fires, however, found that most people acted appropriately; a mere 5% behaved in such a manner as to increase risk. Johnston and Johnson (*8*) studied the behavior of the workers in the 1977 Beverly Hills Supper Club fire in Kentucky. They support the conclusion that panic is not automatic in a disastrous fire and that groups can indeed adjust to meet the increased demands of a crisis.

In England, J. D. Sime (*14*) notes that most models of escape behavior support the panic model, "every man for himself." The panic model says that people will revert to highly emotional, primitive, self-preservation behavior. Researchers generally have concluded that individuals will panic and try to save themselves at the expense of others only when a situation is extremely threatening. The panic model "assumes that escape will involve a homogeneous population of individuals concerned with self-preservation, competing with each other for limited exits" (*14*, p. 21).

An alternative model studied by Sime focused on affiliation behavior during escape from a building fire. His "Affiliative Model" predicts that "individuals with close psychological ties will attempt to escape in groups of two or more..." (*14*, p. 21). The "Affiliative Model" predicts that in life-threatening escapes individuals will be concerned not only with self-preservation, but will experience a heightened concern for other group members.

It is clear that in views of group interaction, there are two different schools of thought: **panic:** "every man for himself" versus **affiliation or attachment:** "united we are safer." During a simulation study (a French study reported in Sime (*14*)), subjects were left in a room and after a short period smoke was leaked into the room. The results showed that organized groups of sport teams responded more quickly to the appearance of the smoke than unorganized groups.

The presence of other people, and the type of group threatened, influences responses. It has been suggested that attachment or affiliative behavior has survival value (Bowlby, 1973 in Sime(*14*)). The function of attachment behavior is in gaining proximity, and consequently, protection from the threat.

Sime studied the 1973 Summerland Isle of Man fire that occurred at a large-scale seaside leisure complex in Great Britain. Of 3,000 vacationers, 50 died when a fire, started by three boys playing with matches, engulfed the Solarium area. The police collected 500 accounts of the event. In analyzing the data, Sime targeted four areas: group membership, attachment at cue (cue: signal of the fire), nature of cue (example: ambiguous, unambiguous), and affiliation at exit. The results strongly support the affiliation model. Sime concluded that

> ...in an entrapment setting people maintained as far as possible their ties with close relatives during escape. In normal evacuations people are likely to maintain primary group ties. These psychological ties will become even more important rather than disappear in a fire emergency (*14*, p. 39).

Kelley as reported in Sugiman & Misumi (*16*) demonstrated the importance of the emotional aspects of panic. Subjects were placed under a time pressure and could avoid an electric shock by depressing an escape switch that only worked if other members of the group weren't pushing theirs. The researchers showed that a sign from one or more subjects indicating they would wait for others to escape increased successful escapes for the group. Cooperation increased effective escape. Hodgkinson (*6*) recognized that the interaction between people is important when there is a choice of exits. People tend to follow the route others are using.

Familiarity in disasters seems to extend beyond affiliation and escape routes. Johnston and Johnson (*8*) hypothesized that disaster roles assumed by individuals within an organization are extensions of the ordinary, everyday roles they normally perform. Johnston and Johnson were interested in what organizational roles could be expanded to include disaster related responsibilities. They concluded that the routine roles of individuals were extended in a crisis and thus the social order maintained. Canter (*3*) echoes this thought: "The social behavior and cognitive processing of individuals stays remarkably close to what can be seen in ordinary, daily behavior" (*3*, p. 3).

Familiarity or previous information affects the ability to survive. Abe (*1*) analyzed the behavior of survivors and victims of a fire in a department store in Japan. He discussed three behavior patterns each of survivors and victims. The analysis concluded that survival behavior can be more effective with prior knowledge. The research also found that people often return to the familiar and to habit in times of crisis (e.g., they will return to a familiar area). This supports Sime's finding that the tendency of individuals and groups to head towards a familiar route is likely to increase during fires. Abe noted that, in a crisis situation, people lose flexibility. In addition, Abe found that in an unfamiliar place, under dire circumstances, many subjects decided that the only and best thing to do was to follow the person in authority. In this department store fire, this was an unfortunate decision that resulted in their death.

Although the majority of research has been on individual behavior under stress with group interaction as a secondary research focus, what happens to organizations, under stress? Driskell and Salas (*4*) suggest that organizations under stress tend to centralize authority. Decisions move to the upper levels of the hierarchy. A study of small groups under stress, however, found the opposite phenomenon: the group leaders and group members became more receptive to information from others.

The research on the concept of leadership is vast. As Warren Bennis, researcher and author observed:

> Of all the hazy and confounding areas in social psychology, leadership theory undoubtedly contends for top nomination. And, ironically, probably more has been written and less known about leadership than about any other topic in the behavioral sciences. Always it seems the concept of leadership eludes us or turns up in another form to taunt us again with its slipperiness and complexity. (Smyth *15*, p. 259).

Leadership under crisis is many times explained by discussing the heroic deeds of one individual. O. R. Holsti (*7*) wrote a chapter on crisis management. Although the focus situations were political crises, not natural disasters or fires, the observations for leadership in crisis are apropos to this study. He cites observations of leaders in action that "appear to confirm the conventional wisdom that in crisis decision making, necessity is indeed the mother of invention" (*7*, p. 117).

It is generally accepted that strong leadership is preferred. Weak leadership has been blamed for failures in the course of certain polar expeditions, and for increased friction and decreased morale in the course of fallout shelter confinement.

In a study on perceptions of leadership traits, Morris (*11*) compared adolescent and adult leaders. He concluded that "integrity and knowledge or skills, are traits of leadership highly valued" and that "effective leaders have positive identities..." (*11*, p. 725). He characterized them as self-assured, self-actualized, honest, open, and trustworthy. Another valued trait was knowledge or skills. The adults in this study considered consistency and flexibility important components of leadership, a finding which suggests a practical, pragmatic, and realistic approach to problem-solving situations.

In conclusion, the research in leadership in general has shown:

- Studying leader behavior patterns is important (*5*).
- Leaders can have a calming influence and be instrumental in helping others avoid panic (*10*).
- Panic is not automatic and indeed individuals have a tendency to follow the prevailing social order (*6, 8*).
- People tend to follow the route of others and familiar paths (*6*).
- Attachment-affiliation may have survival value (*14*).
- Cooperation contributes to successful escape (*16*).

- People lose flexibility in life-threatening situations (*1*).
- Information-knowledge can be significant to survival (*1*).

Simulation exercises on human crisis behavior raise ethical issues. Exposing subjects to the threat of electric shock, or an appropriate degree of threat to evoke the panic and fear necessary for accurate data is a concern in this type of research. Furthermore, disaster circumstances are unpredictable. Subjects who have faced some type of threat must be questioned carefully because of emotional trauma. The present study is unique in representing three authentic disasters. It focuses on the behavior and characteristics of leaders in a life-threatening crisis, an underground mine fire. The main perspective on the event is from the view of the survivors and from circumstantial data evaluated after the event.

METHODOLOGY-SUBJECTS

After learning of each of three mine fires, researchers at the USBM contacted officials from the affected companies and the United Mine Workers of America, the labor union which represented the employees. Cooperation with the USBM in an on-going study of miners' responses to underground mine fires was requested. At mines A and B union officials agreed to set up interviews with miners who had escaped the fires. One union and one management official set up the interviews conducted with those individuals who escaped the fire in mine C.

Across the three subject mines, eight separate groups of miners escaped through smoke. Forty-eight individual interviews were conducted with subject volunteers from each of these groups. Table 1 shows the number of miners in each escape group and the number interviewed.

Table 1.—Number of miners in each escape group and number in sample

Mine and group	Population N	Sample N
Mine A:		
1	10	8
2	8	6
3	10	7
Not in group	NA	1
Mine B:		
4	8	7
5	9	7
6	3	1
Not in group	NA	1
Mine C:		
7	8	5
8	9	5
Total	65	48

NA Not available.

The average age of the miners interviewed was 41.7 years. They had a mean of 16.8 years of mining experience with an average 15 years at the mine where they were working at the time of the fire. Average age and years experience for each group are shown in table 2. All of the miners included in the sample were male. One female did escape with group 3, but she chose not to participate in this study.

Table 2.—Average ages and years experience of miners who were part of escape groups (N=46)

Mine and group	Av age[1]	Av years in mining	Av years in this mine
Mine A:			
1	41.8	17.1	17.1
2	39.3	14.3	14.0
3	39.7	17.6	15.0
Mine B:			
4	41.7	17.2	16.7
5	40.3	17.6	14.4
6[2]	56.[1]	25.[1]	15.[1]
Mine C:			
7	38.8	13.9	13.9
8	40.0	14.7	13.9
Average	41.8	16.8	15.2

[1]Based on 42 miners.
[2]Only 1 person was interviewed from this group.

Data from 45 interviews were included in the analysis. The testimony of subject 8, who was part of group 1, was not available. Two of the interviews were not included in the analyses because the individuals were not part of a group escape. One of these individuals, subject 22, fought the fire in mine A. The other person, subject 38, discovered the fire in mine B. These testimonies distinguished in table 1 are listed by mine with no associated group, designated by (NA).

The sample includes miners from various job categories. Forty of the individuals were rank and file miners who worked throughout the mines. One mine inspector and five supervisors were interviewed. Data sets for group 4, group 6, group 7, and group 8, each contain one interview with a supervisor. One supervisor and a mine inspector escaped with group 4 and were interviewed. For the remaining groups, 1, 2, 3, and 5, no supervisory personnel were interviewed.

The interviews were conducted at locations convenient for the participating miners. Interviews for mine A were conducted in a room at the local union hall. Individuals who escaped mine B were interviewed at a motel close to the mine where they worked. The interviews for mine C were conducted in offices on mine property. The

interviews were completed 1 to 6 months after each fire had occurred. No one was permitted in the room during the interview except the miner and one or two USBM researchers. Each interview began with the researchers reinforcing that participation in the study was voluntary and that the miner had the option to not answer any question. Miners were also asked for permission to tape record the interviews. All subjects agreed to taping.

An interview schedule guided each interview with a series of open-ended questions and related probes. A copy of this guide is provided in appendix A. After general demographic information was recorded, the miner was asked to tell, without interruption, his story of escaping the fire. Questions were then asked so that specific details about each escape would be included. The interviews were 30 to 90 min long. The interview ended when the researcher had asked all of the questions on the interview guide and the miner did not have any additional information.

Data tapes were transcribed verbatim and entered into computer files for ease of text-based analyses. The qualitative data analysis software package The Enthnograph[5] (*13*) was used for data manipulation. This allowed large amounts of data to be coded and the codes stored in such a way that specific categories of data could be recalled during analyses.

The data were analyzed and coded for leadership characteristics, noting instances of leadership and instances of lack of leadership in each group. In addition, instances of group leadership were coded. Individuals in each group, who emerged as leaders, were studied for any characteristic behaviors or patterns of behavior. The actual leader was compared with the hierarchical leader, or "authority," to discern if they were the same individual and if not, to determine specific characteristics of that emergent leader. Finally, any particular patterns in the groups were noted and consensus behavioral characteristics of the leaders observed.

SETTINGS AT THREE MINES

A glossary of mining terms is found in appendix B. A general mine setting is discussed in appendix C for the reader unfamiliar with mining. Most underground coal mines have a distinct management and authority hierarchy. The mine superintendent is in charge of the overall operation of the mine complex including all underground and surface operations that contribute directly or indirectly to the mining and handling of coal. Assistant mine superintendents support the mine superintendents in their duties. At some underground mines, the assistant superintendent is charged with overseeing all underground operations. At least one general mine foreman reports to the assistant superintendent. The general mine foreman oversees the day-to-day underground operations at the mine and is charged with the responsibility of the general supervision of personnel and the underground workings of the mine. The supervisor is responsible for the safety and welfare of all underground employees. For each working shift at the mine, there is at least one general shift foreman (or "shift boss") who reports to the general mine foreman. The shift boss oversees all mining related activities underground during a single shift including coal extraction in the working sections plus all support services work. Each working section in the mine has a section foreman (or "face boss") who manages mining operations on his/her section, and who reports to the shift boss. In addition to these management personnel, there are other supervisors who direct specialized support work underground. These managers include, but are not limited to: (1) maintenance foreman, (2) conveyor belt installation crew foremen, (3) supply crew foremen, and (4) haulage track installation crew foremen. All of these managers report to either the shift boss or the general mine foreman.

While the three mines in this study were all underground mines, each has a distinct setting. This section describes the general setting at each of the mines. Figures 1 through 3 show for mines A, B, and C: (1) the general layout of the mine, (2) the location of the fire, (3) the initial location of the escape groups, and (4) the approximate escape routes and distances traveled for each group.

All subjects escaped under extremely difficult environmental conditions. Mine entries were dark; the only source of light was from the miners' cap lamps. In most instances, heavy smoke reduced visibility to less than 4 ft. The miners literally ran into each other. The dense smoke made it difficult to see tripping hazards and overhead obstacles.

Emergency breathing apparatus, self-contained self-rescuers (SCSR's), provided miners with a source of life-sustaining oxygen. These devices isolate miners' lungs from carbon dioxide, smoke, and other gases and provide them with a source of oxygen. Breathing through these devices, however, is unlike normal breathing. The apparatus, because of the design, produces restricted airflow. During higher levels of physical and/or emotional stress, miners require more oxygen. When miners "out breathe" the devices, they tend to feel that they cannot get enough air, this creates added tension and even panic. Under the emotional and physical distress of escape, these problems compound in an already dangerous environment.

[5]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

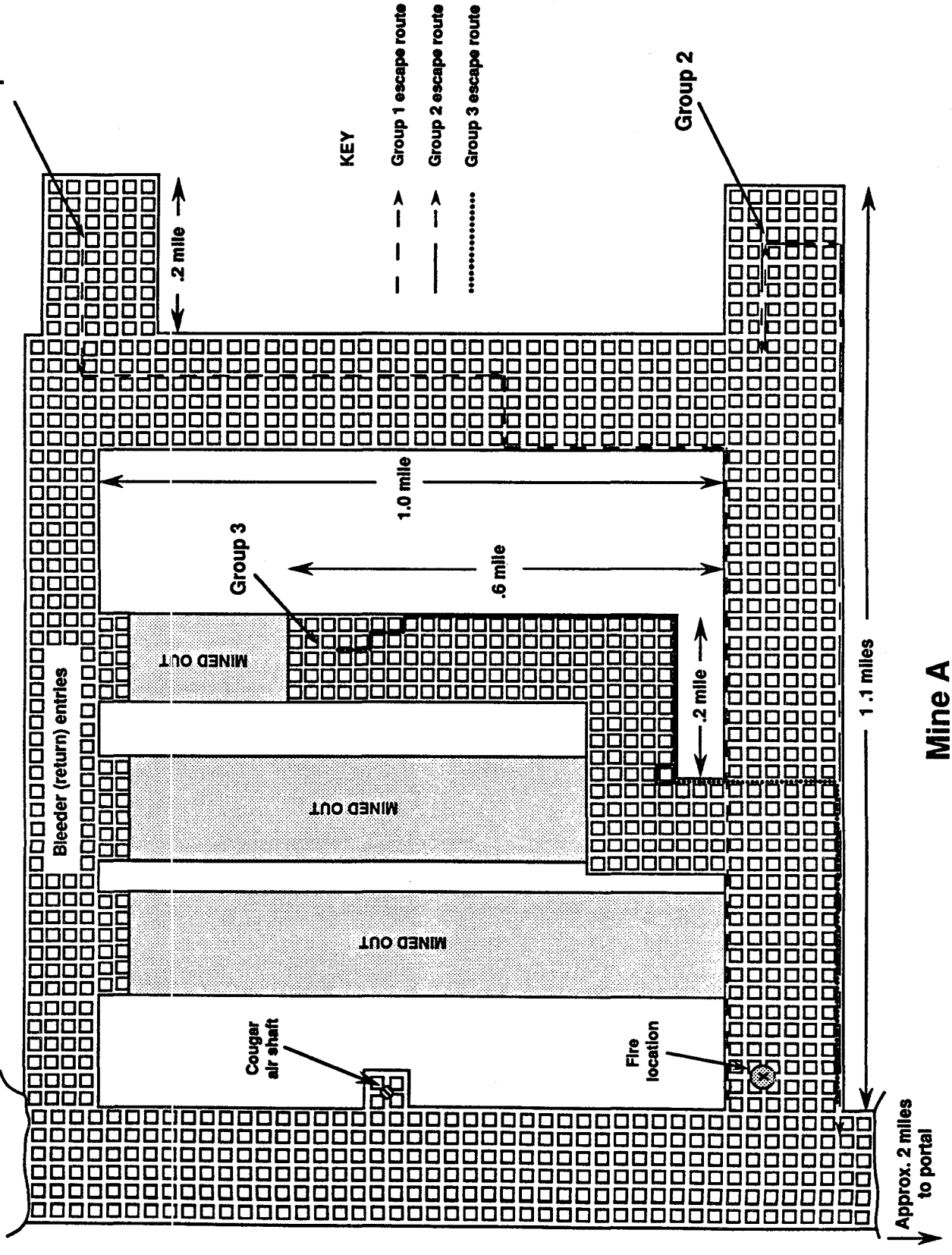

Figure 1.—Mine A.

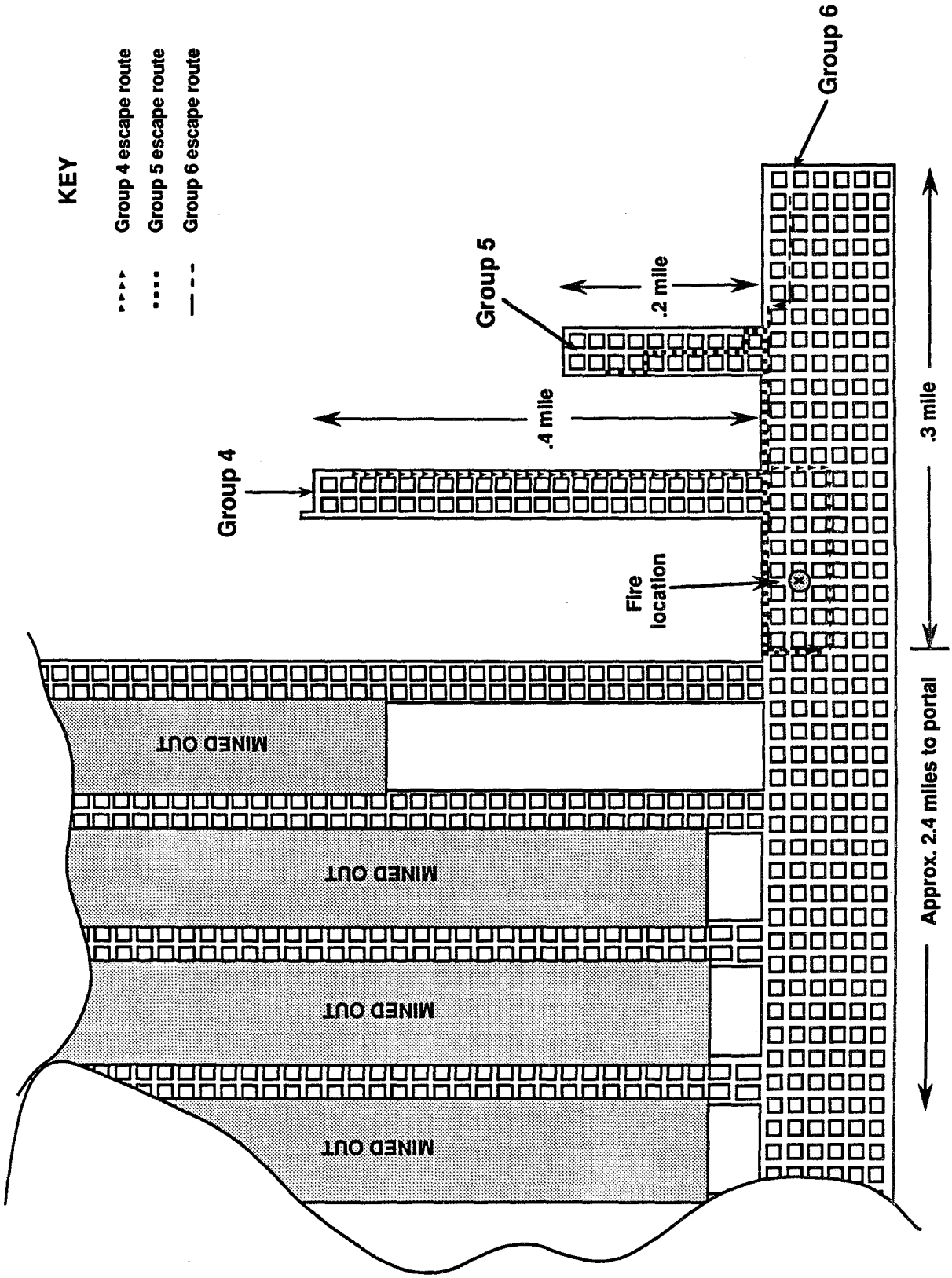

Figure 2.—Mine B.

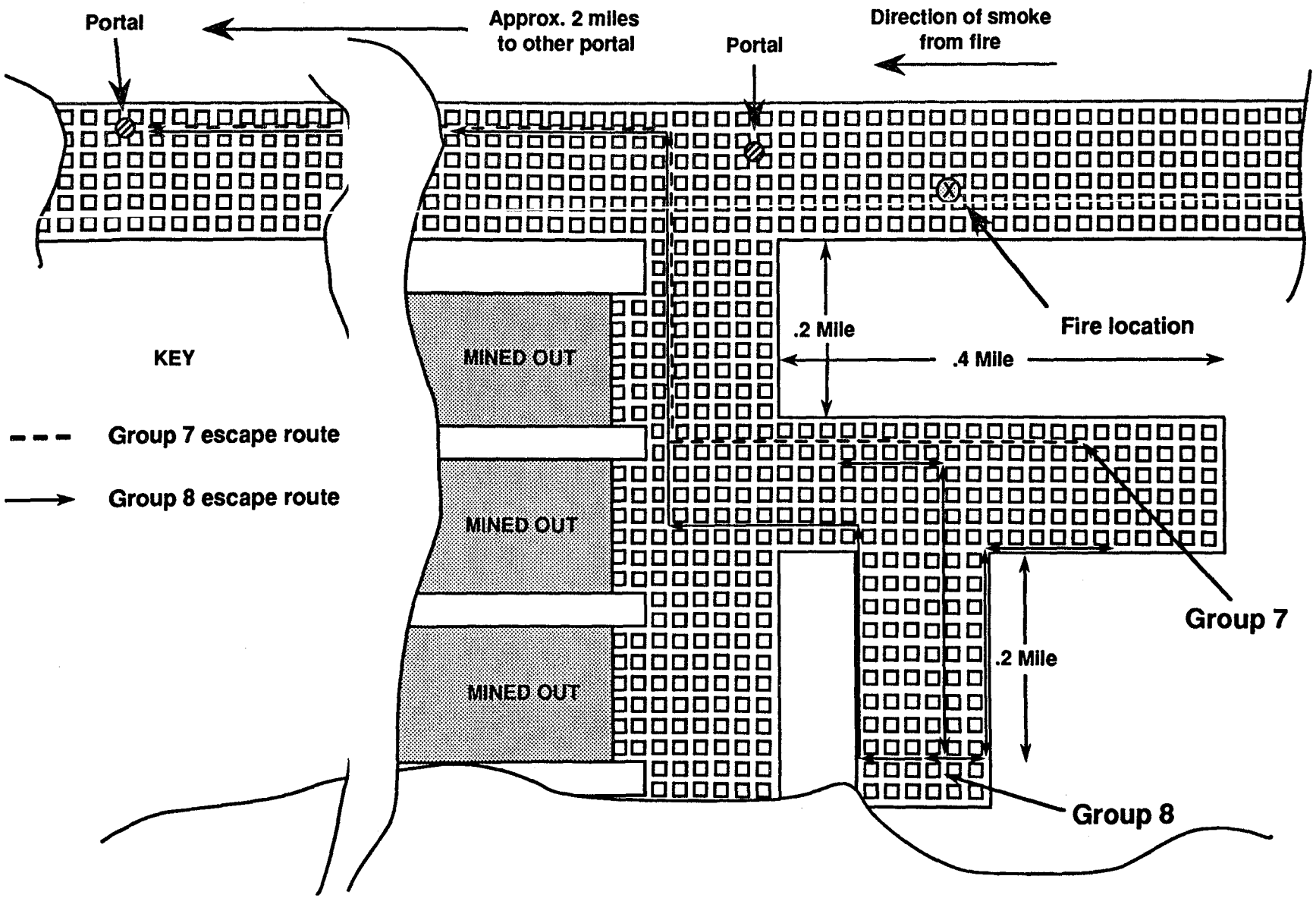

Figure 3.—Mine C.

MINE A

Mine A was an underground mine that followed a room-and-pillar mining plan utilizing continuous mining technology. This mine was opened by six air shafts into a coal seam with an average thickness of 72 in. Coal was mined on five producing sections, three development sections, and two retreat sections during two production shifts per day.

Group 1 worked on a development section with nine entries. On the day of the fire, the face boss and nine miners were working in this section of the mine. Group 2 was also working on a development section. One face boss and seven miners were assigned to this section, which consisted of 10 entries. Group 3 was working on a retreat mining section. Nine miners and one section foreman were working in this section that had nine entries. All groups were working in sections that were at least one mile past (or "inby") the fire location.

MINE B

Mine B was also an underground mine that followed a room-and-pillar mining plan utilizing continuous mining technology. This mine was opened by eight air shafts and one slope into a coal seam with an average thickness of 48 to 54 in. Coal was mined on 17 working sections during three production shifts per day.

Group 4 was mining coal on a development section with three entries. One foreman and seven miners were assigned to this section on the day of the fire. Group 5 was also working on a development section with three entries. One foreman and eight miners were assigned to this section on the day of the fire. Group 6 was conducting maintenance work on mining equipment in their working section and no coal was being mined. One maintenance foreman, a mechanic, and a mine inspector were on the section when the fire occurred. All groups were working in sections that were at least 0.25 mile inby the fire location.

MINE C

Like the others, mine C was an underground mine that followed a room-and-pillar mining plan utilizing continuous mining technology. This mine was opened with one drift and eight shafts into a coal seam with an average thickness of 66 in. Coal was mined on seven producing sections, during two production shifts per day. The fire occurred on the third shift, which was a maintenance shift. Group 7 was working on a development section with nine entries. Group 8 was in an area driven off of that main section. Both groups were working in sections that were at least 0.5 mile inby the fire location.

OBSERVATIONS

PROFILE CHARACTERISTICS

A profile of leadership in crisis emerged from the analysis of the eight escapes. The data suggest several characteristics based on the behavior of the leaders. The leader of each escape may be described as an **aware, knowledgeable** person or as an individual, who is alert to his/her environment, attentive, and discerning. This person notices things - more so than do other people. The authors believe that this quality of discernment probably is not limited to the mine environment or to crisis circumstances, but is a typical characteristic of these individuals in all circumstances. Such persons may excel at incidental learning. Each of the leaders retained information that was instrumental to the escapes. They remembered specific details and repeatedly referred to the fact that they knew what they were doing through information or deduction.

A second, generally shared characteristic of the leaders was the manner in which they took charge. In the groups where the regular authority led the subjects out of the mine, the leadership was a natural evolution of the group dynamics. It was a continuation of the social order before the disaster. A similar dynamic occurred, however, in groups where a definite leader emerged. These emerging leaders did not "muscle in and take charge," the leadership **developed in a natural way.**

Third, the leaders were **decisive, yet flexible.** They made decisions; yet if circumstances changed they adapted.

Fourth, the leaders were **open to input** from others. There is evidence that in most of the escape groups there was a "second lieutenant," an individual who offered worthwhile suggestions, support, and served as a "sounding board." In instances where there was emergent leadership, many times the leader began in a consulting function to the regular authority.

Fifth, effective leaders seemed to have a **calming** effect on their group. They were aware of others' fears and offered reassurance when it was needed. Miners in each group had **confidence** in the leader's ability to direct them to safety.

Finally, there was a **logic** to the leadership. Decisions were appropriate and congruent with the available information.

Appendix D contains technical descriptions of each of the eight escapes. The authors suggest these descriptions might be helpful to the reader as each group escape is studied. Specific details relative to leadership issues and supporting evidence for the profile discussed above follow.

GROUP 1, MINE A

Group 1 was a production crew with a new section foreman who was unfamiliar with the affected area of the mine. In fact, the night of the fire was his first night back in the mine after a 5-year absence. In addition, at least three members of the crew were new to the section. Each of the new members had many years experience in mining, but had been assigned to this crew for only 3 weeks.

The foreman, although the authority figure, did not lead the escape. His behavior was initially appropriate; he assembled everyone and called the dispatcher, the primary communications person, with the proposed escape route and he also called in when the escape route was changed. As the group entered heavy smoke, the foreman simply did not have the knowledge base to make appropriate decisions.

The group was accepting of the foreman's inability to lead in the situation because it was obvious he could not possibly have the appropriate information on his first night. "The boss, I can't blame the boss. This was the first time he was on the section in five years" (subject 6). "...it wouldn't have been (the boss's) fault, it was (his) first day in the mine" (subject 1).

It was also clear the crew was protective of this authority figure:

> The boss..."I'll say he did all he could. He did the best he could. He led us, you know, to the fresh air escapeway. He made sure we got through into the return. But as far as being well-versed in the mine, I don't know. There again, I'd really rather not have to make a statement" (subject 7).

The continuous miner operator's helper on this section was a former fireboss. The position of fireboss required him to travel throughout the mine thereby becoming familiar with the mine layout, including escapeways. As Group 1's escape progressed, the fireboss emerged as their leader. The interviews with other members of the group documented the fireboss' leadership. He began his emergence as leader by consulting with the authority figure, the section foreman, making suggestions and advising on alternative actions. He viewed himself as working *with* the foreman. When directly asked in the interview who led the group out, he responded that although probably the other members of the group would suggest he did, actually he and the foreman led the group out. Subject 4 indicated that the fireboss "was saying what we could do" and the foreman was "making the decisions." When asked if there was any confusion among the miners, subject 4 said, "It was pretty much follow (the fireboss) and the boss."

After sizing up the situation, the fireboss suggested that the group might escape by traveling through the bleeder entries to the Cougar Shaft on the other side of the mine (see figure 4). This suggestion was not accepted by the group and the fireboss chose not to push the idea. Instead he explored other possibilities with the group. His behavior at this point indicates decisiveness and flexibility of thinking in crisis. He said:

> "You know, I was thoroughly against going down it. But like I said, I knew, you know, I wasn't going to go by myself down there. If I'd have had to, I would have. If I'd just been by myself, I would have went across. But I knew half them guys would want to walk right into a bleeder. I knew they would....And so I stuck with the guys."

In short, he tried to get the miners to go deeper into the mine to explore another exit, but they had only one frame of reference - to "get out" - they could not conceptualize going further into the mine. The fireboss "wanted to go back but nobody said, yeah, let's do that. I think their main concern was, let's get out..." (subject 6).

The group entered the left return airway. At this point, the fireboss had trouble with his SCSR and told the group to go on ahead; he figured that they would know where to go from there. At that point, several members of the group got lost by following reflective markers they thought led to an escapeway, but in fact led to another part of the mine. The fireboss had to reassemble the group and told them: "...keep the stoppings to your left, ...if you don't see one, go over 'til you do find one, and then always have the stoppings to the left of you ...I told them, ignore the reflectors, because you are going to get lost." This advice is an example of this leader's awareness of the mine environment.

It was clear by the conclusion of Group 1's escape that the fireboss was in charge. When one miner did not come out into fresh air with the rest of the group, it was the fireboss who said "we will go back for him" and went back into the mine with two other miners. "You couldn't see nothing ...They (two other miners) said they wanted to go back with me. So we went back..." he told the two miners with him to hang on to a water pipe and he positioned them. Again, he took the responsibility of leader utilizing his knowledge and giving directions. Everyone in Group 1 successfully evacuated the mine.

GROUP 2, MINE A

Group 2, a production crew, was alerted to the fire, gathered together under their foreman's direction, and

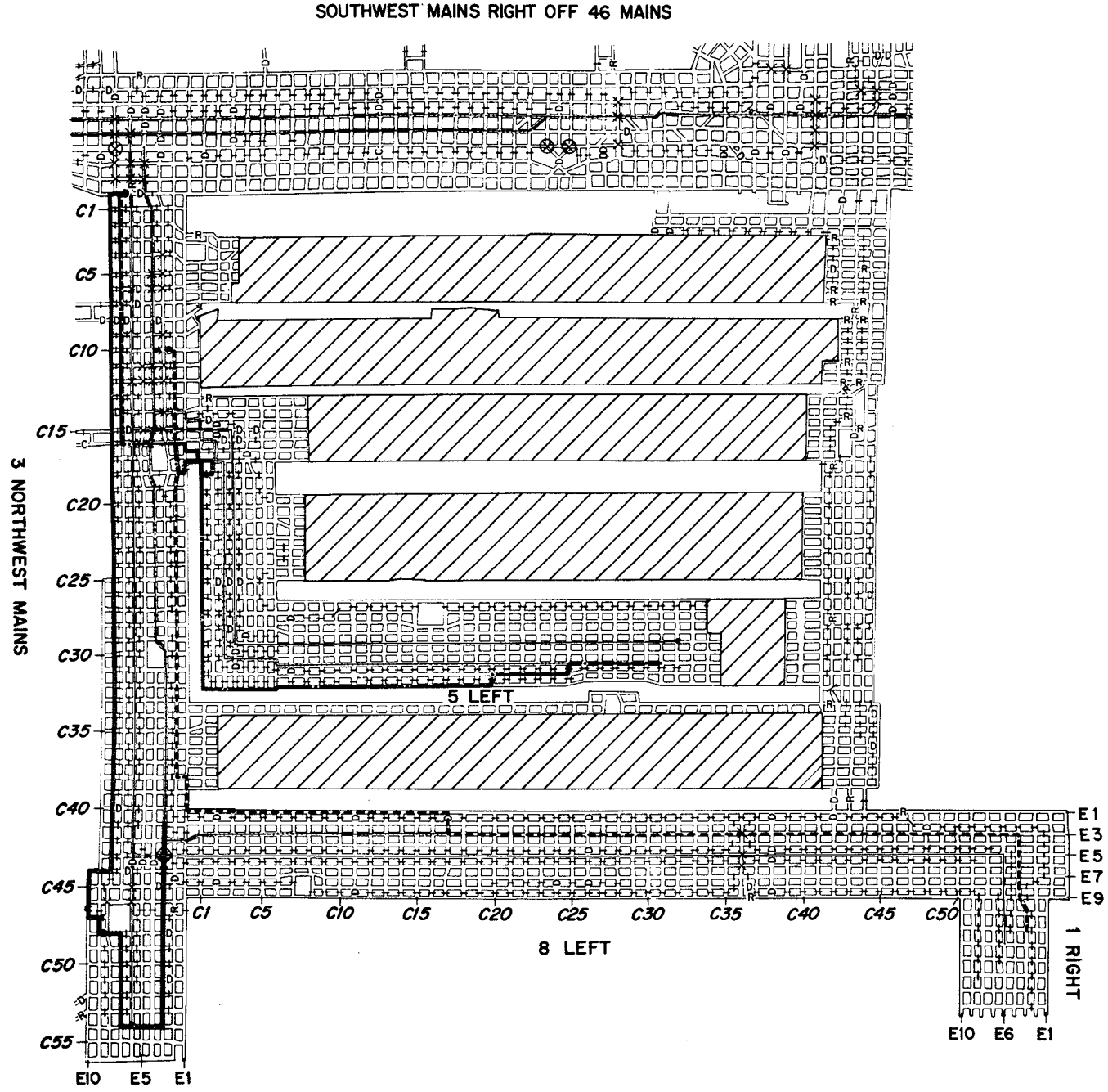

Figure 4.—Layout of mine using continuous mining technology.

rode the mantrip until they entered heavy smoke. At this time they donned their SCSR's and proceeded out of the mine on foot through the intake escapeways. This crew epitomized the "right stuff" in evacuation. Basically, they escaped without incident.

> "We were about as organized as you're going to get. We did real good. We have a mine rescue man that's been on mine rescue for years. He was with us. He's our buggy man and we had the boss and the mine rescue man set it up, the boss in front, he was in the rear. The crew was in the middle. Worked fine, no problem at all" (subject 10).

The authority figure, the section foreman was the leader and worked with the second lieutenant, an individual with mine rescue experience. The crew viewed "the boss and the other guy" as the leaders, and the two miners saw themselves as working in tandem. When asked who made the decision to put on the SCSR's when they ran into smoke the second lieutenant answered, "Well, like I say, ... maybe we hit it together, simultaneously, let's say, hey, ... we got to get these people on their oxygen now!" (subject 9).

The only problem this group experienced occurred when the miners put on their SCSR's. The leader dealt with this problem in several ways. When one miner felt his SCSR was not functioning, the foreman offered to trade. "That one guy was nervous. He didn't think his worked right. I remember the boss saying, well, do you want mine then? Because there was nothing much the matter with it. He was just being nervous" (subject 14). Another miner became panicky when his rescuer appeared not to work. The second lieutenant calmed him, blew into the apparatus to start it and said, "It's just like kissing you, you old..." (subject 13). The leader also made the group slow down so that they did not need as much oxygen and wouldn't overwork the apparatus. "...and it seemed like the harder you used, you know, it seemed like you wasn't getting the right amount of air out of them. But then (the boss) said, just slow the pace down" (subject 11). This knowledge of the operation of the SCSR's and consequent adaptability of behavior is a quality of an **aware** individual.

The leader's behavior had a calming effect on the crew. This calming was evident in the interviews with the subjects from group 2. When asked if the group stopped along the way:

> "Yeah, we stopped different times - one guy fell down. I pulled him back up. He fell down. He was a little red and hysterical there a little bit of the time. And, we stopped and the boss talked to him and calmed him down. We stopped periodically, if anybody was having problems. We'd stop and check. Not long, but long enough to talk and see where to go and calm down" (subject 10).

> "And like I said, the boss, between him and whatcha-callit, he more or less kept everybody level-headed, you know, like, well, at least not have no panic and everybody take off, you know... (subject 11).

> "The boss said, 'We got to put these on fellows (SCSR's). This is no drill. Put them on but everybody stay calm, and we'll just take our time and we'll walk out. We'll be all right" (subject 12).

> "We all stuck together real well. You know, if I got too far or (the miner who) was with me, he'd get out in front of me and if we got too far, the boss or somebody just said, take a break and the one guy was having trouble and he said you know, that he needed to rest some and we just stopped and rested with him" (subject 13).

The authority in group 2 was decisive, logical in his leadership behavior, a calming influence, and knowledgeable. All members of group 2 successfully evacuated the mine.

GROUP 3, MINE A

Most members of the production crew making up group 3 had been working together for some time. There were three new members on the section the night of the fire, but each was an experienced miner who had worked in other parts of mine A. "We had some people come and people go, but the majority had been together for at least probably two and a half years" (subject 20). In spite of their history of working as a crew, these miners did not escape as one coherent group. They spread out forming a fast sub-group, a slow sub-group, and by the end of their evacuation there were two miners in the middle.

After learning of the fire, the section foreman warned the crew and they gathered at the dinner hole. At this point, most of them did not think that they were in danger. "...That did come up, how it (the belt) could catch fire when it wasn't running. You know, but still that hasn't sunk into us that it was burning that hard" (subject 20). In contrast to other groups where the foreman attempted to calm the miners during the escape, this foreman tried to impress the seriousness of the situation on the group. According to one group member (subject 20), "... the foreman said, 'Hey, look, this is serious .... You know, we got to get out of here.' And then everybody started saying, well, maybe it is burning that hard. But it was still hard to believe it was."

Group 3 began their escape by traveling on the mantrip. When they encountered smoke, the group got off the mantrip, passed out the SCSR's, and planned on going into the intake escapeway. At this point, the miners "took off" and the group began to separate. "They started passing the self-rescuers out and everybody just started taking one and that's how—we got spread out" (subject 19). The front group saw themselves as leading the way. "So we were more or less in the front, leading the way and the foreman was back with some of the other people...We were the ones that were picking the escapeway out" (subject 20).

When the miners hit smoke in the intake escapeway, they moved to the return air course, but still had to contend with heavy smoke. They continued down the return and crossed one overcast. At a second overcast group 3 experienced fear as did no other group in mine A.

> "I was the first one there. I had like one guy on either side of me, walked up there to the overcast and I stepped right into it. And, it was like a black wall. It was like burning fifty tires and trying to walk through it...And, I said we can't go that way. So we walked out and there was some—I know there was doors in those overcasts. I said, the intake's here someplace. All we've got to do is find it. And, you'd open up the door and it'd just billow out; and you'd open up another door, and it would billow out. And that's when we had a little team meeting; that's when people really started getting tight. It was like, which way do we go?...And I remember asking the foreman as we opened up the door, it looked like it was a black river running by. That's how thick it was. And I said, 'was that the intake?' He said, 'yeah.' And its not real' registered in my head, I remember, 'it can't be! It couldn't have burned through already!" (subject 20).

The amount of smoke in the intake and other air courses led the miners to believe that all exits were blocked by fire. In this case, knowledge about the mine and its ventilation patterns hindered rather than helped those with this information. It was later discovered that a mandoor had been left open and the smoke was not following the usual mine ventilation pattern. At the time of their escape, however, the crew had no way of knowing this and logically assumed the fire was blocking all exits.

Group 3 then walked back into the mine searching for a door into another entry. Near the mouth of the section, the miners in the lead became lost. The miner operator (subject 19) said, "...we got confused and started going back into the section till we run into the first door and we just made a complete circle and come right back to that main overcast again." It is important to note the boss was not in the lead when the group got lost - the jackrabbit group in the front had run off in the wrong direction.

The group stopped, realizing that they were lost. The foreman probably figured at that point that the fire was between them and any chance of escape. With a mandoor left open, the smoke was entering areas of the mine that "made no sense." In this situation, the foreman's knowledge of the mine confused him because seeing smoke in the return indicated to him that the whole mine was on fire, or at least fire was blocking all the exits. It seems that this analysis made him too upset to make a clear decision on the direction to travel. The miner operator (subject 19) yelled at the foreman telling him to calm down so that he could think about their escape. "Then I myself told the boss—I said, (Boss), get your composure and get us out of here. We're all scared you know." Subject 19 continued, explaining that at this point the boss pulled himself together and showed his knowledge of the section and his awareness of his surroundings saying, "This pile of dirt shouldn't be here. I think he said right or left - I don't remember - but he said, This pile of dirt shouldn't be here." This information was all that was needed to point the group in the right direction.

After getting back on track, the front sub-group took off again. Subject 20 seemed to take charge of this sub-group to some degree. He was the individual who initially asked questions and made suggestions: "Can't we do this, can't we do that? and potentially could have filled the second lieutenant's role, but did not. Instead this person went with the faster miners and left the foreman and slower people behind.

As mentioned before, the front group saw themselves as leading the way; the slower group however did not see it that way. Subject 19, said, "I told them come on, why don't you guys wait for ---? One of them said, this is every man for himself. People were scared; do you know what I mean?" "Everyone was together. Then when we got to the return, why someone just took off, you know, never waited on anybody. They panicked and got scared. That's the worst thing in the world to do. Everybody should stick together..." (subject 18).

Toward the end of the escape one miner was having a great deal of difficulty and the slower group stayed behind with him.

> "I was the last one in line and this (guy), I don't know how old he is, he's probably between 55 and 60 years old. I don't know, but I could hear him starting to have trouble breathing in his device (SCSR). And, it sounded to me like he was hyper-ventilating himself. He was trying to out breathe the device. That's what it sounded like to me. I talked to myself, this man is going to go down and when I started to think that he did go down. He fell onto

> the ground and I spit out my mouthpiece on my unit and I hollered as loud as I could, I need help here. This man's down. Only two people came back. I said there was either 9 or 10 of us going out in a single file line and I was the last and I hollered as loud as I could and only two people came back. That was the boss and..." (subject 17).

This resulted in two subjects finding themselves in the middle; they did not hear subject 17 call and did not know a miner was down. These miners continued on, as did the faster group, unaware of the problem behind them. All of the miners eventually continued out to fresh air.

The section foreman, the authority, in group 3 started out in control, but eventually lost it and never recovered his group. Subject 20 characterized this man as "excitable...yeah..but he's not to the point of panic or anything like that. He still keeps his composure about it but he's kind of a high-strung guy. That would be more of a term to put on him." This subject continued later in the interview: "I do remember the boss was quite excitable and I remember the miner operator telling him, "Now, you're a foreman. Get your self together. Now where are we at?"

Instead of any one person fulfilling the role of leader, various members of the group displayed some of the characteristics of a leader. The foreman took control of the situation initially and used his knowledge to get the group back on track after they become lost. Subject 20 seemed to assume some leadership of the faster sub-group and directed them to don their SCSR's. When the foreman seemed to be losing his ability to make logical decisions, subject 19 calmed him down. At another point, subject 17 took the lead and went to explore the way over an overcast. Subject 21, one of the miners in the middle, assumed the role of assisting the other who was older and having some difficulty.

The dynamic of the escape for this group was foreshadowed when the SCSR's were passed out and people took off. Group members explained the lack of discussion saying, "...our crew, most of them have a good bit of time in the mine and it was just—as soon as we run into smoke, that was the first thing everybody thought, get into the escapeway" (subject 20). Throughout the escape, no one person was looked to as the leader. When queried, "Who was making the decisions?" the subjects of group 3 provided various answers. There was no consensus.

GROUP 4, MINE B

Group 4 consisted of a production crew plus a mine inspector. The authority figures in this escape group were the section foreman and the mine inspector. As it happened, these two people knew each other and jointly led the escape. "The boss and the inspector was there, and they were discussing which way to go - which would be the best way to get out. So they decided it would be down the belt. We all went down the belt" (subject 24). Group 4, like group 3, had a split escape, but with dissimilar dynamics and leadership characteristics. The major problem in the faster group, led by the foreman, was with breathing through the SCSR's because they were moving so fast. The slower group, led by the inspector, had a miner who experienced breathing problems and was continually falling down. Toward the end of the escape, he fell a final time, was left behind by the other miners, and later rescued.

The foreman felt and assumed responsibility for the miners, but was strengthened by the support of the inspector. An indication of how well the two miners worked together is found in both of their interviews. The inspector, when asked who was in charge:

> "...I didn't feel like I was in charge, (he) is the section foreman but anything either of us said or did, I've got a lot of respect for (him). I know (him). Anything he said I didn't question. Anything that it appeared I said, he didn't question and anything that either of us said wasn't, like I said, there was never once any talk. Even when it came down to who's going to go with the fast men and who's going to go with the slow men, there was never no discussion. It was just one of us said what we'll do, and we did it" (subject 23).

The section foreman noted:

> "Well, I'm responsible for them. I didn't want them splitting up. I was glad the inspector was there because I felt he's going to watch these people and I'm going to watch the other group... I wanted to stay in the back and know where my people are. That was my first concern. I just didn't like the idea, but didn't want them taking off the way they were. I was afraid, you know. I can't sit on them" (subject 28).

The above explanation documents that the foreman was decisive, yet flexible. Some of the miners began to take off. The foreman was concerned, yet aware enough to know how frightened the miners were. The inspector understood the dynamic too, and although against accepted "evacuation policy" of not splitting up a group, the decision to allow the faster miners to go ahead with the foreman was logical leadership.

The manner in which the inspector, the second lieutenant in the group, communicated the fire to one of the crew is evidenced in the following: "So I started to pick up my

tools. He (the inspector) said, 'leave the tools behind, don't worry about them, let's get out of here', and with his advice and his quickness and alertness, I became aware that it was serious" (subject 25). The miners who took off immediately, "they ran like deer", were stopped by the foreman who "made them wait till everybody was there so we had everybody before we started" (subject 28). Both leaders responded calmly.

It is interesting to note the behavior of the inspector when the miner in the slower group continued to fall. "I know at one point...I said let's stop and take a minute and the man is sitting there and the mechanic was still with us and I recall looking at my watch, and I thought we had been under oxygen, I believe, it was 20 min at this time and I knew we still had a ways to go." The inspector was continually evaluating the situation and reasoning alternatives, similar to the other group leaders. This same individual made a prophetic observation when the miners were first putting on their SCSR's.

> I looked around to make sure they were starting to put theirs on and when I looked over and saw the bigger man - that's about the first time I started getting a little worried because he was shaking somewhat severely, his hands were, you know, very noticeably trembling and I just thought to myself, oh boy. I said I think we are going to have trouble because he's having a hard time... (subject 23).

This miner was a large man who weighed in excess of 250 lb. When the miner went down the final time, the inspector was in a serious dilemma.

> I don't recall how far, but I know I was struggling with this man and I know he was making me tired and I hadn't had any problem up until this point but when I looked down, I realized the bags in my SCSR were flat and I know here again I thought, boy, there was no discussion about it but the section foreman and those other guys, they're probably way ahead of us by now and here I'm back here with this guy and he having all this trouble and now I'm having trouble breathing and breathing was getting harder and harder. I didn't think to look at my watch but I didn't know, had I exhausted the machine or was I running the same problems as this man? I was using more, you know, demanding more out of the machine than it was giving. I knew I was working a lot harder now and I started getting concerned about that now too and I guess we continued. I continued with this man. We finally came to a high spot and, like I said , I was still having—I was taking as much outside air in as I was out of the machine. ...I realized how this man is now because my machine is not giving me air or what but when we got to the high spot, I knew exactly where we were because from traveling the belt, I knew we were at the intake over where they had cut the overcast for the intake and the man that was having so much trouble, he's down again. He looked at (the other guy). I saw him look at (him) and he said, 'You guys go. You just leave me here.' He said, 'I can't go no more.' He said, 'I'm just going to stay here.' I looked at the other guy and I said, I got to go. I said there is no sense in me staying... I said I can't breathe now. I said I know where I'm at. I can send somebody back. I'll go out and get somebody.

In desperate circumstances this miner continued to follow a logical path. In recounting his story, the inspector noted that although he would like to have thought he was in control, he realized he was not. Each leader had taken an extra SCSR. Although the inspector was running out of oxygen, he forgot he was carrying an extra SCSR - "maybe I'd taken too much smoke." This point emphasizes the severity of the situation.

The inspector got to fresh air, saw the foreman, and told him of the miner down. The foreman said "..he's my boy.." and went back in for him. In the mean time, the miner who was down was left alone. The final person who had been trying to assist him decided he was "...not going to make it, I'm going to try and get out."

> So I started out and I was only about 100 ft from (him) when I came through the overcast and I opened the door and I saw 7 and I thought, good, this is fresh air, or this is a, you know, the way out.....So I thought, well, I'm going back in to get (him).

Actually this miner was mistaken about his location. But, while he was trying to convince the miner who was down that they could reach safety, the foreman arrived. Together they got the miner going again and out of the smoke. Everyone was then accounted for.

A major issue in this group was should they have come out together? Should the leaders have insisted, or had better control over the group to facilitate a cohesive group evacuation? The inspector responded to the inquiry with the fact that there were two individuals who could show leadership and if you have two groups, "don't hinder the one group because of the problems of the other group" (subject 23). Clearly, there was decisive leadership by both individuals in this group.

GROUP 5, MINE B

Group 5, a production crew was led out of the mine by their section foreman and "another guy." "(The foreman

is our boss. He knew - he done right. He got us on the right track and kept us on the right track. Between him and (the other guy)" (subject 35). Again, the leadership in this group was basically the authority figure with the particular assistance of one of the miners, subject 33, but with input of others. This group, after an uneven beginning, ultimately stuck together, even though there were several older miners in the group and one miner who had continual difficulties breathing from his SCSR.

After they were alerted to the smoke, they assembled and began their evacuation. Two of the miners' ran ahead. Subject 33 noted one of the miners said at this time:

> "...come on, let's go. We got to get out this way. And he took off. Well, he took off and went down like—and he was leading the pack, okay. When we got down to where the regulator was at and put the self-rescuers on, you know, that's when (the boss) took over. But that's one of the things that I told (him) later on, I says you're the boss - one thing you got to do if this ever happens again you should have a man that's in charge that's going to take his time and walk out of there slow and easy with his SCSR on..."

Subject 33 assumed the role of advisor.

One of the miners explained why the two miners took the lead initially, "...see, bratticemen know pretty much what's going on, where everything is at. I'd say the two bratticemen up there pretty much took the lead out—pretty much took us out" (subject 35). One of the bratticeman said when asked who took the lead in the group, "Well, me and my buddy, cause we knew everything, every place up there. Some of the bosses don't know their way around, and I've been in that place for 8 - near 19 years..." (subject 31). Both these subjects felt they had the knowledge to lead, yet they took off, traveling too fast for the group. They were unaware of the needs of other members of the group and the surrounding circumstances. This is not characteristic of effective leaders. The foreman stayed in the back to assist the slower miners.

At one point, the foreman left the miners to check the doors ahead. As he opened one door and he saw thick smoke:

> "Right then, panic hit, believe me. Cause all the teaching and training everything, these are all supposed to be separate splits. Well the first thing that goes through your mind is everything is burning. In my opinion, there was no sense in even trying to get (out, but) you're still thinking—so I come back, there's a bleeder pipe that goes from..." (subject 30).

This leader, although voicing his thoughts of giving up when he thought the whole mine was on fire rapidly moved on to explore alternatives, "you're still thinking."

When the foreman returned to the group, they were panicky. He felt everything was out of control at that moment and he knew the group was in trouble. The miners had decided that they would wait 10 min for him to return, indicative of the anxiety and need to "do something."

> "I told the guys, I said, you guys want to try to make it over there and before I said much more..., the bratticeman said, 'We're ahead of the smoke. Let's go.' Well right then—well, everybody seen the smoke here. That's when there was not much control, you know, everybody started just going."

Again the group spread out somewhat with the foreman staying behind with the slowest group members. The section foreman responded when one of the miners "took his self rescuer off and threw it out. (The man) said he couldn't breathe out of it, so I helped him get the little one off his belt (filter self-rescuer) and got it open. He couldn't even open that one, but he got to breathing in it" (subject 30).

The leader of this group made sure everyone was supervised during the escape by taking a position toward the back of the group. He was concerned about the slower miners and about someone going down. When the group entered fresh air everyone was accounted for.

GROUP 6, MINE B

Group 6 included three miners, a maintenance foreman and a mechanic, who usually worked together plus a mine inspector. There was only one interview from this escape group, the maintenance foreman who assumed the leadership role. The mine inspector, although an outsider, represented authority and at first exercised that authority. When appraised of the fire, the foreman initially wanted to ride out on a mantrip but the inspector said no. When asked about the inspector's reason for this, the foreman said, "Well, it could cause an explosion he said, for one thing. I mean, we were on the thing when he says no" (subject 37).

Subject 37, the authority in this group, went along with the mine inspector until they hit heavy smoke. He then decided the appropriate escape route and "they never disagreed." When they hit the heavy smoke they searched for a door in an overcast and could not find it. Subject 37 knew they had to go back and he told this to the other two miners. "I knowed where I was going here in this case, so I mean I knowed exactly where I wanted to get to..." This

was an important moment in the leadership dynamics of this group, a natural evolution based upon knowledge, logic, and decisiveness. "I mean, the inspector when I turned around and said we got to go back, he says no, and I says you can do what you want to do, I'm going back. I said you can follow me or do what you want. At that point I didn't care who followed me or who didn't. I was getting out of a heavy concentration." The next day subject 37 returned to the mine to find the door - it was there where he "knew" it should be.

The foreman did not, however, lead thinking only of his own safety. He said, "I was in the lead all the while and I mean, I knowed they were in back of me. I mean, if one of them would have dropped back, we would have gone back and got him, or tried to anyway." He was attentive to the rest of the group.

This leader had an important piece of information, he knew where the fire was. He had asked where the fire was when the dispatcher called. "I was the only one out of the guys that knowed where the fire was... and the reason for that is I took and asked (the dispatcher) where the fire was." He was the only person in all eight groups who knew the exact location of the fire and knew that the group had to go by the fire to escape. He also knew that the return was double timbered - there were two rows of posts supporting the roof. He was aware that as long as they walked between the timbers with the beltline on the left, they would go by the fire and get out.

At one point in the escape, the group heard footsteps overhead. It was Group 5. "I heard them coming over the overcast, and then I was relieved a little bit because I knowed that boss coming with that crew was real familiar with the mine. I was familiar with it, but not like him." Knowing that the other crew was going in the same direction increased his confidence. The three continued down the return aircourse to safety.

GROUP 7, MINE C

The construction foreman, the authority figure, took charge and led group 7 out of the mine. Although this group had problems, they never lost confidence in their leader and his ability to lead a successful escape. He had developed the section "so he knew which way to go.. we just followed him cause he, he knew the area" (subject 40). "I felt pretty confident though because I knew (the supervisor) had been up there for a long time walking returns and this and that and he was real familiar with the area" (subject 43). The foreman was aware and knowledgeable.

> "We were lucky because we had (him) and he just spent a whole, he probably just spent 6 months in that return, posting it and cleaning it up, so we really didn't have any trouble with the return and we basically had enough knowledge of the area" (subject 41).

The leader himself indicated that everybody "...was asking me where we were at, what direction we were headed. And with the information that I had, because the biggest part of this I set up; the ventilation, the overcast and so on, the return escapeway. And I knew first hand, you know what direction we were in, where the mandoors were at..." (subject 39).

The group's faith in the foreman continued even when some major problems were encountered early in their evacuation. When notified of the fire the foreman gathered the group together and they began their escape in three vehicles, a lead jeep, the foreman's vehicle, and a portal bus. As the group entered smoke, they experienced two vehicle wrecks, one of which actually knocked the foreman and another miner off their vehicle. The miner lost his hard hat and his cap lamp and had to escape without them. This was a problem as he continually was hitting his head on the way out. In addition, he pulled the SCSR that he was using out of its carrying case, resulting in the device having no carrying straps. To help him carry it, another miner used electrical tape to tape the SCSR to his chest. Since SCSR's tend to get very hot with use, this miner also had to contend with this discomfort.

The foreman remained aware of the condition of others in the group and responded to a miner who was having trouble with his SCSR. When the foreman said to put on the SCSR's ... "I was like shaking like a leaf, couldn't get the thing open. And he finally come up to this control and said here pop this, stick this in you mouth, and..." (subject 42).

Whereas in some of the other groups there was a second lieutenant, in this group the foreman was totally in charge.

> "I was a foreman in charge of that area, and when I said to these people what we had to do, there was no second guessing my decision. These people were counting on my knowledge that this was right and there was no second guessing it. I had no problem with these people as far as my decision. ...I didn't ask for information or input from anybody else. That was my decision that we were gonna take this course to get out" (subject 39).

The foreman was authoritarian, but not a dictator, he told the group the what and why of his decisions. He said:

> "I think that once they knew where they were, the direction that they headed, where they were going to

> come out at and get into a fresh air area, it kinda eased their minds as to knowing. Basically, they knew how long it would take to walk to these different locations and they knew that there would be communications to the surface at these locations. And it pretty much eased their minds" (subject 39).

The leadership of group 7 was decisive, informed, logical, and confident. All members of the group safely evacuated the mine.

GROUP 8, MINE C

Group 8 was not normally a working group and none of the members were involved in coal production. Members of the group typically did maintenance tasks. They were doing construction work and moving supplies. In addition, there happened to be two motormen, who usually are on their own who were in the section when notified of the fire.

Group 8 was effectively out of control most of the time during their escape. The foreman, the authority figure, was not in control and there was considerable notation of blame and emotion evidenced in the interviews of this group. The manner in which the group donned their SCSR's was indicative of the lack of leadership. When asked who decided it was time to put them on, subject 48 responded, "Well, I think everybody decided together but, you know, I already had mine on." Another miner said he kept asking, should we put these on and the foreman never answered.

The regular authority figure, the foreman proved a poor leader. As subject 47 described, "...the guys were more or less talking amongst themselves and I said, 'you know, this is real serious and this boss if we're not careful he's going to get us killed." Subject 46 was not familiar with the section and became concerned, "I can understand how people could be excited and you know, improper decisions could be made. But, you know, it kept snowballing. You know, his improper decisions that he was making, you know. I was getting more and more negative about following this man as we went." This subject later continued, "I'm not saying that I was the only person that was cognizant that (the boss) didn't know what he was doing. I believe everybody had some, you know, at some level had that feeling. But the fear level was starting to rise...." "There was a lot of confusion...the (foreman) couldn't figure out how to get into the intake escapeway... alot of the guys started getting kind of real, losing alot of confidence in him" (subject 47).

A leader did emerge however who fits the profile characteristics; he was knowledgeable and discerning, his leadership evolved, and he was responsive to others in the group. The man who emerged as leader began in the second lieutenant position, as an advisor. He "knew" based on an odor that there was something wrong. There was an odor and some smoke and he said to another miner, "turn that machine off; there is something bad wrong here." He was acutely aware and noted numerous details while continually processing information. He could "hear that the power center was on," and that confused him because he was a former maintenance foreman and he knew that the power center should not be on. He was one of the first to recognize the gravity of the situation. The rest of the group were speculating what was on fire. He knew by the amount of smoke it was not just a hanger burning. He recognized that the miners were getting upset and as he explained,

> "I am a personal friend of (the foreman) and .. the situation, I wanted to talk to (him) but I did not want other people to hear what I wanted to tell him because people were getting upset right off the get go...I was thinkin' of people I can count on .. I guess you would say that it was kind of a feeling of if you were in an airplane and you had to count on someone to hold that parachute for you could you count on that person" (subject 45).

This miner was continually evaluating the situation. A further example of this was when he discussed his concern that the miners were struggling, "If these guys start droppin', there is no way we, the three of us can pick up three other guys and carry them and get through these old workings, there's no way. So then I'm thinking well the next steps we're gonna have to start barricading ourself, that's all." When the group was in the returns in heavy smoke he told the interviewer that he was looking for footprints. He knew that the returns had to be walked periodically by the firebosses, who examine the area for hazards. He said, "when I see footprints I feel better.... Somebody was through here already, there is only one set going out. So chances are that if there was a return set of footprints, I would think somebody had to turn around because its blocked." In fact, this route did lead them to safety.

The leader of this group was conscious of the behavior of other members and careful in how he presented his advice to them. When some members of the group left their lunch buckets behind, he was concerned.

> How can I say it, being a foreman for 8 years it's hard not to say things sometime...I could see things going on that was wrong, especially the discarding (of the buckets). So I would say, "I sure wouldn't throw that away. I wouldn't say don't throw that away you don't know how long we're going to be here or what's going to happen.

The statement above characterized this miner. He presented himself as the foreman's helper during his interview, whereas the other members of the group clearly indicated their foreman was inept and that subject 45 led them out. He placed himself in a peer relationship with the group and a peer relationship with the foreman. The interview with the foreman quoted subject 45 often and was resplendent with "I should have." At one point he stated, "I plain, freely admit, I messed up. I should...." (subject 44).

DISCUSSION

A comparison of the three mine sites revealed no evidence of differences among the three sites that would be relevant to this study. There was no appreciable disparity in communication, emergency systems, fire fighting response, safety issues, or subject demographics. Leadership in the eight groups thus will be compared across mines without issue.

Among the persons who led each of the eight groups to safety, five of the group leaders were the regular person in charge (usually the section foreman) and three leaders emerged during their escapes. As described previously, analysis revealed consensus characteristics which, taken together, create a leader profile. The individuals who assumed positions of leadership during the underground mine fires fit a profile which included the following:

- Aware, knowledgeable
- Decisive, yet flexible
- Open to input from others
- Calming influence; gained follower's confidence
- Logical decision makers
- Allowed leadership to develop naturally

The reasons that leaders other than the regular authority emerged varied in each of the three groups. In group 1, it was the foreman's first night on the job. He maintained his authority in the group, but was recognized as incapable of leading because he was not familiar with the mine. In group 3, there was a split escape and no clear leader. The third emergent leader, found in group 8, took over when the hierarchal leader panicked and was ineffective in making decisions.

In examining the instances where there was a of lack of leadership from the authority figures, two characteristics emerged. First, a lack of knowledge contributed to an individual's inability to guide his group. Second, leaders "lost personal control" and thus heightened anxiety in their groups. As shown in group 1, a lack of knowledge did not necessarily result in losing authority. The lack of self-control, however, may be more likely to have such an outcome. This seems true even though no evidence of actual panic behavior was found in any of the authority figures or leaders.

Throughout this analysis support was found for the "Affiliative Model" of emergency response, as opposed to the "Panic Model." Although there was evidence of "nonsocial, blind, irrational behavior" as defined by Hodgkinson (*6*), this study found that the majority of subjects behaved appropriately and within the accepted social framework. In fact, the social structure was defended, in several instances beyond reasonable evidence to the contrary (group 8). In this group, the members initially continued to turn to the foreman after he had shown his indecision and evidenced his inability to lead the escape. This study supports previous research in concluding that panic is reduced by introducing appropriate leadership (*10*).

Effective leadership also increased the likelihood of efficient evacuation. As found in earlier research (*1, 6, 14*), the miners tended to head for a familiar route and/or follow the route others were using. In all cases, the group's first direction of travel and mode of transportation chosen were those used in routine trips out of the mine. Numerous times throughout the interviews miners mentioned following the person ahead when the familiar route became impassable. When a knowledgeable person was in the lead and the followers had confidence in that person, the evacuation proceeded much smoother.

RECOMMENDATIONS FOR FUTURE RESEARCH

The researchers suggest several areas for further inquiry. Are characteristics identified in the profile presented in this study *required* for an individual to fulfill the role of leader during a crisis situation? What if an individual has some, but not all of the noted characteristics? Some individuals identified during this study evidenced some, but not all, of the profile characteristics. Further analyses are needed to determine the fit of these individuals in the group dynamics and their contributions to the successful escapes.

Another realm of crisis behavior only mentioned in this study is the influence of leader-follower familiarity on the ability to lead. Is personal relationship in crisis leadership a component of success or failure? Analyses were not

completed to document relationships between leaders and followers prior to their escapes.

This work supports Hayashi's (5) emphasis on the study of the anticipated behavior patterns of leaders as complimentary to the study of the circumstances of disaster escape. Training for response to mine emergencies, and therefore, to other emergency situations as well, should consider the likely human behavior tendencies. Perhaps work crews should be evaluated to ensure that at least one person can and would lead the group in the event of an emergency. These potential leaders may, or may not, be the authority figure who leads during routine production.

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APPENDIX A.—INTERVIEW GUIDE

Mine Fire Interview Guide

A. Where were you when you first became aware that there might be a problem in the mine, and how did you learn of it?

- A1. Who told you?
- A2. What were you doing—did you finish?
- A3. What were your feelings at this time?
- A4. Did you think that there might be a problem in getting out of the mine?
- A5. Did you communicate with anyone—who?

B. What did you do after making sure there was a problem?

- B1. Walk with anyone—where?
- B2. Did you go anywhere to get anything after you left your equipment?
- B3. Did you pick up anything on the section?
- B4. Did you talk with anyone—what about?

C. Was there a point where the crew assembled?

- C1. Where was the assembly point?
- C2. Was this a designated point—were you trained to go to it?
- C3. What was the conversation about when you met up with the whole crew?
- C4. Does anything about the conversation stand out?
- C5. How would you describe the feeling within the crew?
- C6. Did you or anyone have any concerns about getting out?
- C7. Was there any sign of smoke at this point?

D. When did you first encounter smoke?

- D1. What was the crew's reaction?
- D2. Did someone take charge?
- D3. What was being said at this time?
- D4. Was there any confusion or indecision?
- D5. What were your thoughts at this point?

E. How was the plan of action to escape decided on?

- E1. Did the crew meet to decide the course of action?
- E2. Did anyone pass out assignments?
- E3. Was there general agreement about what to do—who disagreed—how was that handled?
- E4. What was the feeling within the crew?
- E5. Would the crew have walked out the intake without donning their SCSRs if it was smoke free?
- E6. How did you begin to go out?
- E7. How much time past between starting out and donning the SCSR?
- E8. How would you describe that period of time?
- E9. Did you at any time feel that this was a life threatening situation?

F. What was it like when you first began to don your SCSR?

- F1. Who made the decision to don?
- F2. What were the conditions—could you see?
- F3. Did anyone take a CO reading?
- F4. Did you check the apparatus?
- F5. Did you get more than one?

G. What part did you SCSR training play when you began donning the apparatus?

- G1. Which of the devices have you been trained on?
- G2. What position were you in?
- G3. Can you show us the steps you used to get the SCSR on?
- G4. Did you have any problems—did you see anyone else having problems?
- G5. Did anyone help you—did you help anyone?
- G6. Did you have confidence the SCSR would work correctly?
- G7. Did anyone experience any problems once the device was on—what were they?
- G8. How long did it take everyone to get ready to move out?

H. How did you go about actually escaping from the mine?

- H1. Who made the decision?
- H2. Did you escape alone, or in a group?
- H3. How was the escape route chosen and followed?
- H4. Were markers visible?
- H5. Were there communications along the way—what was it like?
- H6. Were there problems, especially with the SCSR?
- H7. Were you aware of any risks in taking out your mouthpiece?
- H8. Did anyone advise you not to remove the mouthpiece?

H9. How many times did you or the crew stop to rest or talk?
H10. Did you get rid of anything along the way?

I. At what points were there strategic decisions in making your escape?

I1. What were the conditions?
I2. How was decision made—who made it?
I3. Was there any disagreement—confusion?
I4. Did you feel other crews were in trouble?
I5. Where did you think the fire was?

J. Thinking back, what would have made your escape less complicated?

J1. Would you have done anything differently?
J2. Would you have taken anything else with you?
J3. Probe about walking the escapeways.
J4. Probe about SCSR donning.

APPENDIX B.—GLOSSARY OF MINING TERMS[1]

barricading - Enclosing any part of an underground mine to prevent inflow of noxious gases from a mine fire or explosion.

belt - A rubber conveyor belt used to carry material and transmit the power required to move the load being conveyed. Belt width varies from 36 inches to 72 inches. (Also: Conveyor Haulage Belt)

bleeder entries - Mine entries driven on a perimeter of a block of coal being mined and maintained as exhaust airways to remove methane promptly from the working faces to prevent buildup of high concentrations either at the face or in the main intake airways. (Also: Bleeders)

bottom - (1) The floor in any underground mining cavity; (2) The landing at the bottom of the shaft or slope.

brattice - See STOPPING.

bratticeman - In mining, a person employed to erect ventilation stoppings and doors in underground workings to control proper circulation of air to working places.

break - See CROSSCUT.

buggy - See SHUTTLE CAR.

buggyman - See SHUTTLE CAR OPERATOR.

crosscut - A tunnel, usually mined at right angles to entries, that connects two entries and permits the passage of miners and equipment between entries. (Also: BREAK, BREAKTHROUGH)

cap lamp - A rechargeable, wet cell light designed for workers who need a self-contained light that will not interfere with free use of the hands. A battery is worn on the belt while the light unit is attached to the cap.

continuous miner - An electrically powered machine that moves along on crawler tracks similar to those found on a bulldozer or military tank. The machine has a rotating drum on which cutting bits are mounted. As the drum rotates and cuts the coal, special mechanical gathering arms sweep the coal into a special conveyor mounted on the machine which channels the coal to a shuttle car or some other haulage vehicle.

continuous miner operator - A person who operates a continuous miner in an underground mine. (Also: Miner Operator)

continuous mining - Mining in which the continuous mining machine cuts or rips coal from the face and loads it into conveyors or shuttle cars in a continuous operation.

conveyor haulage belt - A moving belt that rides on rollers and on which coal is transported from the working section to the coal processing plant on the surface.

crib - A structure composed of wood timbers laid in "pigpen" fashion, that is laying flat timbers at right angles on top of each other. The timbers are stacked until the area between the bottom and roof is filled, then the crib is wedged tight. Cribs are used to support heavy roof loads or machinery.

crib block - A wood block approximately 8" x 8" x 30" used to construct a crib.

development mining - In room and pillar mining, that portion of the coal that is removed from entries as mining advances outward from the shaft toward the property boundary. (Also: Advance Mining)

dinner hole - In underground coal mining, the location (usually a crosscut) in a mining section where the crew gathers for lunch and where safety meetings are held by the foreman.

dispatcher - An employee who controls all traffic on underground haulageways and informs employees by telephone or trolley phone when to move trains, locomotives, jeeps, or mantrips.

door - See MANDOOR.

drift - A horizontal or nearly horizontal opening through the strata or coal seam used for the purpose of ventilation, drainage, and transportation of men and material, in connection with the mining of coal.

driving - The process of tunneling through or mining coal to produce entries, rooms, and crosscuts.

dump point - A place where coal is loaded into mine cars or onto conveyors; where a conveyor discharges into mine cars. (Also: Load Point)

entry - In underground coal mining, a passage used for haulage or ventilation or as a walkway. (Also: Heading)

escapeway - A predetermined passage route through which miners may leave the mine in an emergency if the ordinary exit is blocked. Generally there are two types of escapeways. They are: primary escapeway and secondary escapeway.

face - Any place in a coal mine where the work of extracting coal from its natural deposit in the earth is performed.

filter self-rescuer (FSR) - A small filtering device carried by a miner underground on his belt to provide him with immediate protection against carbon monoxide and smoke in case of a mine fire or explosion. The device is used for escape purposes only and provides protection from 30 to 60 minutes depending on mine atmosphere.

fireboss - See MINE EXAMINER.

general mine foreman - The person charged with the responsibility of the general supervision of the underground workings of a mine and the persons employed therein, and who is held responsible for the safety and welfare of all underground employees.

hanger - A special device used to suspend the electric trolley wire from the mine roof.

[1]This glossary includes definitions taken from "A Dictionary of Mining, Mineral, and Related Terms," compiled in 1968 by staff members of the U. S. Bureau of Mines and edited by P. W. Thrush.

inby - In the direction toward the working face or interior of a mine; away from the shaft, slope or drift; in the direction toward the face of an entry from the point indicated as the base or starting point.

inspector - See MINE INSPECTOR

intake - Any airway in a mine through which fresh air flows from the downcast air shaft through the workings of the mine to the faces. (Also: Intake Aircourse)

intake air - Fresh air coming into the mine which flows from the outside through the mine workings to the working faces.

jeep - A special electrically driven rail or non-rail car for underground transportation of officials, inspectors, repair, maintenance, and survey crews, and mine rescue workers.

load point - See DUMP POINT.

mandoor - A small door in a stopping to allow the passage of men. (Also: Man Door, Door)

mantrip - A special electrically driven car, either rubber tired or rail mounted, used for underground transportation of miners to their working areas. Depending on the size, a mantrip can carry from 8 to 14 miners. (Also: Portal Bus, Porta Bus)

mine examiner - A state certified supervisory mine official or certified miner who examines the mine for methane gas and other hazards before a shift comes into it and who usually makes a second examination during the shift. (Also: Fireboss)

mine inspector - A state or federal official who is employed for the purpose of examining and reporting on mines and surface plants relative to compliance with accepted mining regulations and safety practices. (Also: Coal Mine Inspector, Inspector)

motor - A low, heavy rail-mounted haulage locomotive powered by electricity and designed for pulling mine coal cars, supply cars, and other rail-mounted equipment.

motorman - In coal mining, one who operates a haulage locomotive or motor.

mouth - The end of a mining section nearest the shaft or surface (mouth of the section).

outby - Away from the face toward the pit bottom, surface, or mine entrance.

outcrop - The location where a coal seam appears at the surface.

overcast - An enclosed airway to permit one air current to pass over another. Overcasts are built of incombustible materials such as concrete, tile, or brick. Use of overcasts results in better ventilation and removes the dangers of doors left open.

pillar - The part of coal left between individual rooms and entries in room and pillar mining. Also, an area of coal left to support the overlying strata.

portal - A general term referring to any entrance to a mine.

portal bus - See MANTRIP.

post - A round, upright mine timber topped with a cap piece and wedged between the roof and mine floor to provide roof support. Also, an upright mine timber used to support horizontal roof crossbars. The length of a post depends on the height of the coal seam. By law, a post must be at least 4" in diameter. (Also: Timber)

regulator - A ventilating device, such as an opening in a wall or door, and usually placed in the return of an air split to govern the amount of air entering that portion of the mine. A simple regulator can be constructed by building a stopping with a sliding door in it across the opening to regulate the air.

rescue team - A team of miners, consisting of five to eight individuals trained in the use of breathing apparatus and in rescue operations after a mine fire or explosion.

retreat mining - The recovery or mining of pillars of coal left during initial or development mining.

return - Any airway in a mine in which vapid or contaminated air flows from the workings to the upcast shaft or fan to be evacuated out of the mine. (Also: Return Aircourse)

return air - Air which has circulated the mine workings and is flowing toward the upcast shaft or fan to be expelled out of the mine. Also, fouled or contaminated air.

rib - The side of a pillar or wall of an entry or crosscut.

roof - The rock immediately above an entry or crosscut in a coal seam. It is commonly a shale and is often carbonaceous in character and softer than similar rocks higher up in the roof strata. The roof shale may contain streaks and wisps of coaly material which tends to weaken it. (Also: Top)

roof bolt - Steel bolts, 36 to 96 inches long, that are inserted into pre-drilled holes and used to support the roof immediately above the coal seam. When the bolts are tightened, they bind together the layers of rock strata located above the opening. (Also: Pin)

roof bolter - An electrically powered, rubber-tired machine with one or more rotating drill heads that drill holes into the mine roof for the installation of roof bolts. (Also: Pinner, Pinner Machine)

roof bolter operator - In coal mining, one who operates a roof bolting machine. (Also: Pinner, Pinner Man)

roof bolting - The technique of supporting the roof of an underground mine by drilling holes into the roof and then inserting long steel bolts into the holes and tightening them to create supporting beam across the mine opening. (Also: Pinning)

room - A place abutting an entry or airway where coal has been mined and extending from the entry or airway to the face. Rooms may vary in width from 14 to 20 feet and in depth from 50 to 300 feet, depending on the depth of overburden, underground conditions, and seam thickness.

(In some areas, this term is used interchangeably with entry and crosscut.)

section - A subdivision of the mine workings under the supervision of a section foreman where coal is actively being extracted; a portion of the working area of a mine.

section foreman - A foreman who is in complete charge of a section of a mine and all operations at the working faces. (Also: Faceboss, Section Boss)

self-contained self-rescuer (SCSR) - A self-contained breathing apparatus that, when operated, provides a source of oxygen to the miner during escape from a fire.

shaft - A vertical opening through the strata that is or may be used for the purpose of ventilation, drainage, and hoisting and transportation of men and material, in connection with coal mining.

shift boss - See SHIFT FOREMAN.

shift foreman - A foreman in charge of all men working underground at a mine on any given shift. (Also: Shift Boss)

shuttle car - A rubber-tired underground haulage vehicle that can carry from six to ten tons of coal. The machine is used to transfer coal from continuous miners to the main haulage system. (Also: Buggy)

shuttle car operator - In coal mining, a person who operates an electrically powered shuttle car in a coal mine to transport coal from the point of excavation to the loading point. (Also: Buggyman)

slope - An inclined passageway driven to a coal seam from the surface that is used for the purpose of drainage, ventilation, and the hoisting and transportation of men and material, in connection with coal mining.

split - A current of air that has been separated from the main intake to ventilate a section of an underground mine. In most mines, the "fishtail" method of air splitting is used where air is brought down the center entries to the working area, split to both sides of the section and returned to the outer entries.

stopping - A permanent, airtight wall installed across mine passages, usually crosscuts, to separate air intakes from air returns or to isolate belt lines from air intakes or returns. Stoppings are frequently made of concrete blocks. Some, however, are built of steel sheet panels erected across the crosscut. (Also: Brattice)

timber - See POST.

top - See ROOF.

tramming - The movement of equipment from one location to another.

trolley wire - A wire, suspended from the mine roof, which conducts electrical power to rail mounted equipment such as locomotives, mantrips, and jeeps.

APPENDIX C.—MINING ENVIRONMENT

GENERAL MINE SETTING

A mine is broadly defined as an opening or excavation in the Earth created for the purpose of extracting minerals (*18*).[1] More specifically, a coal mine is defined as any and all parts of the property of a mining plant, on the surface or underground, which contributes, directly or indirectly, under one management to the mining or handling of coal (*18*). To clarify the following discussion of the context of this study, a glossary of mine terminology is provided as appendix B.

To extract coal from an underground mine, the coal bed (or seam) must be accessed from the surface. The term "portal" is generally given to any entrance that provides access to a coal mine. In hilly terrain, such as found in the Appalachian coalfields, the coal may "outcrop" on a hillside which would allow direct entry to the coal seam via a horizontal tunnel (or "drift") opening. At other locations where the coal does not outcrop, it may be possible to open a "slope" tunnel that angles down from the surface and intersects with the coal seam. If the coal seam is too deep for a slope to be feasible, a "shaft" must be constructed. The shaft, which may be 20 ft or more in diameter, is opened vertically from the surface to the coalbed and allows access to the seam via a large elevator. The mines which are the focus of this study have shaft openings into the coal seam.

For miners to get into a shaft mine, they must enter at the portal and travel via elevator to the mine workings. After reaching the workings, miners board some form of transportation and travel to various worksites underground. The transportation system is installed for moving workers, supplies, equipment, and coal that has been extracted.

Miners will usually travel to work areas via a self-propelled personnel carrier know as a "mantrip." Mantrips are either rubber-tired or rail-mounted vehicles that carry from 8 to 14 miners at one time. Groups of miners who work together leave the elevator at the bottom of the shaft, board the mantrip, and travel to their appointed work area in the mine which can be several miles from the portal.

Working areas of a mine where coal is extracted are called "working sections" while "working faces" are the individual places on the working section where mining activities take place. As mining activity continues, sets of parallel tunnels (or "entries") are mined through the coal seam following a predetermined plan developed by the mining engineer. This plan functions in much the same way as blueprints guide building construction workers. Mine entries typically are 16 to 20 ft wide and as high as the coal seam is thick. In the United States, the thickness to the coal seams currently mined can vary from 24 to 144 in.

The number of entries being mined in a working section will vary from 3 to 10 or more depending upon many factors. As parallel entries are mined, they are connected by perpendicular tunnels (or "crosscuts"). Like entries, crosscuts are also typically 16 to 20 ft wide and as high as the coal seam is thick. Crosscuts or "breaks" as they are sometimes called, allow workers and equipment to move between and among the entries. The walls of entries and crosscuts are called "ribs" while the ceiling above is called the "roof" or "top." The mine floor is typically called the "bottom."

As coal is mined, the working sections advance toward the boundaries of the coal property. This advancement is generally known as "development mining" and follows a "room-and-pillar" mining plan. With a room-and-pillar plan, entries and crosscuts are opened through the seam while large blocks of coal (or "pillars") are left in place to help support the mine workings. Once a mine (or a portion of it) is developed, the development sections may then become "retreat" mining sections. In retreat mining, the coal pillars, which were originally left in place for support of the mine entries and crosscuts, are themselves extracted. As these pillars are completely extracted, the mine roof they once supported collapses. **Figure 4** illustrates the layout for typical room-and-pillar development mining. **Figure C-1** shows the layout of a typical working section.

The Mining Environment

While an underground coal mine is, in some respects, like a factory, the work environment is very different. In the mine, workers must contend with work areas that can be dusty, or wet and muddy depending upon the amount of water that may be present. These work areas can be extremely confined, especially in mines where the coal seam thickness is not great. To extract coal, miners must operate large equipment in these confined work areas. The only lighting available comes from the miners' battery operated cap lamps and from localized sources on various mining machines. Miners must also deal with poor footing due to uneven and/or muddy bottom. In short, miners must do their jobs in an environment that is harsh and dangerous.

[1]Italic numbers in parentheses refer to items in the list of references preceding the appendixes at the end of this report.

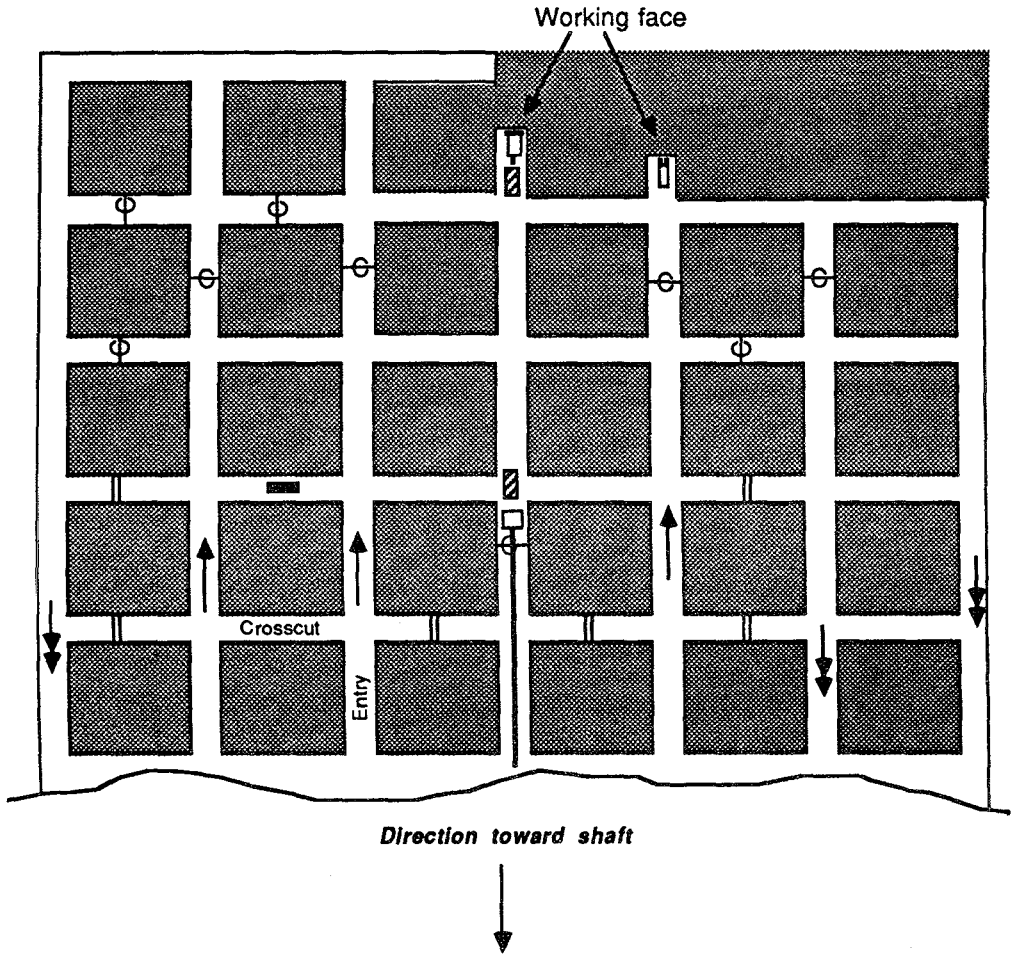

Figure C-1.—Layout of typical working section using continuous mining technology.

The Mining Process

In the United States, most development mining following a room-and-pillar plan uses "continuous mining" technology. Continuous mining incorporates two operation cycles at the working face which include: (1) cutting and loading of coal; and (2) support of the mine roof above the entry or crosscut. With continuous mining, operations progress sequentially at each face on a working section. First, an area from which coal has already been extracted (commonly called a "cut"), must have its roof supported. Typically the roof is "bolted" by one or two miners who operate a "roof bolter." A roof bolter is a rubber-tired, electrically powered machine with a rotating drill head that drills holes into the mine roof. Steel bolts (48 to 96 in long) are then inserted into these holes, and when tightened, bind together the layers of rock strata located above the cut. This, in effect, creates a supporting beam

between the coal pillars and across the entries and crosscuts, thus preventing the roof from collapsing.

After a cut is bolted, the "continuous miner" is driven (or "trammed") into the face to begin cutting and loading coal. A continuous miner is an electrically powered machine that moves along on crawler tracks similar to those found on a bull dozer. The machine has a rotating drum (or "ripper head") about 10 ft wide and 3 ft in diameter on which cutting bits are mounted. The continuous miner is trammed up to the face and begins to cut the coal. As the ripper head rotates and cuts the coal from the face, a pair of mechanical gathering arms, located beneath the ripper head sweeps the dislodged coal onto a special conveyor mounted on the continuous miner. This conveyor moves the coal to the rear of the machine where it is dumped into a shuttle car (or "buggy"), which is a rubber-tired, electrically powered haulage vehicle that can carry 6 to 10 st of coal. Usually, two buggies transport coal from the face to the mining section's conveyor belt dumping point. From the dumping point on the working section, the coal is then transported via a series of conveyor haulage belts out of the mine.

Fresh air must be supplied to all working areas of a mine. Air is drawn into the mine from the outside by one or more propeller-type fans that can be as large as 8 ft in diameter and capable of moving several 100,000 ft^3 of air per minute. Mine entries serve as "intake" (or fresh) and "return" air courses and channel the air through the mine to all working locations. Intake and return air courses are separated by concrete block walls (or "stoppings") that are erected in the crosscuts between the entries. Where intake and return aircourses must cross each other, air bridges or overcasts are used. **Figure C-2** illustrates an overcast. Air moving through the mine and sweeping across the working faces carries away smoke, dust, and accumulations of methane gas. These intake and return aircourse also function as escapeways for miners in the event of a fire or other type of emergency. Federal mining law requires that underground mines must maintain two separate and distinct travelable passageways designated as escapeways from each working section. At least one of these two escapeways must be located in fresh air.

A Typical Work Crew

Work crews on a mining section are usually comprised of from 8 to 10 individuals. A typical crew might consist of: (1) one foreman; (2) one continuous miner operator and a helper; (3) two roof bolting machine operators; (4) two shuttle car operators; and (5) one mechanic. In addition to the miners needed on each working section for the purpose of producing coal, many more support personnel, who are scattered throughout the labyrinth of underground entries, are needed to help maintain the many subsystems found in the mine. Work performed by these support personnel includes building and maintaining stoppings, installing supplemental roof supports, cleaning coal spillage around and under conveyor haulage belts, moving supplies, maintaining electrical installations, and conducting hazard inspections. Generally, these support workers perform the various tasks singly or in small crews, usually without direct contact with other miners, supervisors, or the outside.

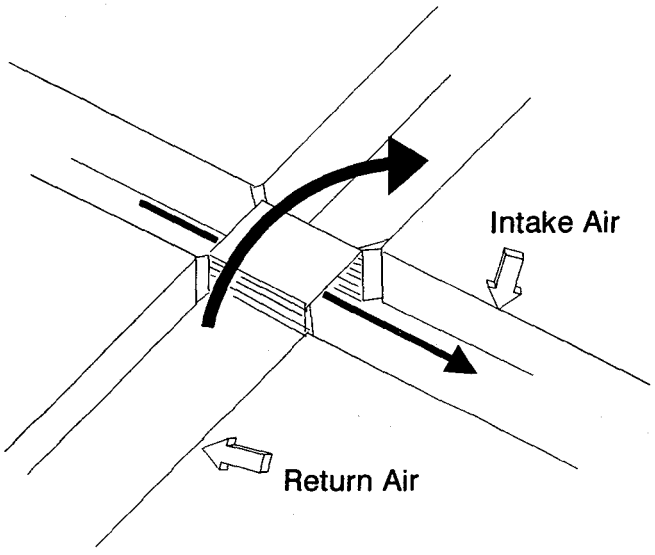

Figure C-2.—Example of overcast.

APPENDIX D.—GROUP ESCAPE ROUTES

Description of approximate escape routes taken by the groups follow. Refer to the mine maps given as figures 1, 2, and 3.

Group 1

This group boarded the rail mounted mantrip and started to come out of the mine. They traveled nearly 0.7 mile before encountering smoke. At this point the crew stopped the mantrip, got out, and began walking off in different directions. The foreman and another miner got the crew back together. After reassembling, the crew decided to go to the intake escapeway and walk the rest of the way out of the mine. After getting into the intake escapeway, the crew traveled about 500 ft on foot before encountering smoke in this escapeway. The crew then moved into the left side return entry where they confronted smoke again. After putting on their rescue breathing apparatus, group 1 continued for about 0.3 mile before turning right. After turning right, this crew continued to move through the smoke filled return entry for another 0.8 mile before finally getting past the location of the fire and reaching clear air.

Group 2

This group boarded the rail mounted mantrip and started to come out of the mine. The crew traveled about 0.1 mile in the mantrip before encountering smoke. At this point, the crew stopped the mantrip, got out, and decided to move to the intake escapeway and continue to egress the mine on foot. The crew traveled about 0.1 mile on foot in the intake escapeway before encountering smoke. Upon being confronted with smoke, the crew moved to the right return entry to continue their escape. After traveling several hundred feet more in the return entry, this group encountered smoke again. At this point, the group put on their rescue breathing apparatus and continued their escape, traveling about 0.4 mile in the return before turning right. After turning right, the group traveled another 0.2 mile in the smoke-filled return entry. At this point, the group became disoriented in the smoke and began to go the wrong way by walking back toward the working section. The group traveled about 200 ft in the wrong direction before a miner in the group realized that they were going back into the mine. At this point, the group turned around, and continued to egress the mine, traveling an additional 0.4 mile before passing the location of the fire and reaching clear air.

Group 3

This group boarded the rail mounted mantrip and started to come out of the mine. The crew traveled about 0.1 mile in the mantrip before encountering smoke. At this point, the crew stopped the mantrip and decided to go back to the section. The crew rode the mantrip back to the section, got off the mantrip, proceed to the intake escapeway, and began walking out. This group walked about 500 ft before encountering smoke in the intake escapeway. The crew then moved into the right side return entry and continued to proceed out of the mine. After moving into the return entry, this group walked several hundred feet more before running into smoke in the return. At this point, the miners put on their rescue breathing apparatus and then continued on foot about 1 mile through smoke before passing the location of the fire and reaching clear air.

Group 4

The foreman and mechanic with this group noticed smoke coming up the intake escapeway. This crew assembled at the section power center. This group elected not to follow the intake escapeway since it was already filled with smoke. Similarly, the miners chose to avoid the alternate escapeway in the return air course since they knew that it would be filled with smoke. The crew decided to escape via the mine entry in which the conveyor haulage belt was located since they believed that this entry should have clear air. This group walked the belt entry for about 600 ft when they encountered smoke. Group 4 traveled for about 0.4 mile in heavy smoke to the point where the conveyor belt entry intersected with the main supply haulage track. Here, the group turned right and moved into the haulage entry and followed the main haulage entry for about 0.1 mile until they were past the fire location and in clear air.

Group 5

This group assembled at the rescue breathing apparatus storage station in the number 1 intake entry. The group traveled on foot several hundred feet, and after being confronted with heavy smoke, moved into the belt conveyor entry where the smoke was lighter. This group traveled about 400 ft on foot in the belt entry until they hit heavy smoke again. At this point, the group moved into the alternate escapeway entry and proceeded to travel the

section and main return aircourse through smoke for about 0.25 mile before passing the fire location and reaching clear air.

Group 6

These miners assembled at the beginning of the intake escapeway on the working section. After putting on their rescue breathing apparatus, this group traveled on foot for about 700 ft in the intake escapeway before being confronted with heavy smoke. At this point, the group moved to the alternate escapeway where the smoke was lighter. After moving to the alternate escapeway, the group continued to travel on foot for about 0.25 mile before passing the location of the fire and reaching clear air.

Group 7

Because the primary escapeway was filled with smoke, this group decided to follow the alternate escapeway out of the section. These miners got into the alternate escapeway in the left return air course of the section and traveled this escapeway on foot for about 0.3 mile. The crew then made a right turn and followed the escapeway for another 0.25 mile. At this point, the group turned left and continued on foot for about 1 mile before reaching fresh air.

Group 8

These miners gathered at the beginning of the primary escapeway and proceeded to travel this escapeway on foot about 0.3 mile before being confronted with heavy smoke. Upon hitting heavy smoke, the crew turned around and followed the primary escapeway back to the section. After returning to the section, the group then got in the section's left return air course. The group followed the left return air course for about 0.2 mile before realizing that they were not in a designated escapeway. The group turned around and followed this air course back to the section. At this point, the group crossed the section and made their way into the right return airway (the designated alternate escapeway) and followed it for 0.1 mile before turning left. After turning left, the group continued on foot through the alternate escapeway for about 0.2 mile before turning right. After turning right, the group continued on foot for another 0.3 mile before turning left into the main alternate escapeway. After turning into the main alternate escapeway, the crew continued for about 1 mile before reaching clear air.

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