INITIAL STUDY OF BURIED COMMUNICATION CABLE FOR UNDERGROUND MINES

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ABSTRACT

The objective of this project was to perform a preliminary study to determine the desirability/practicality of burying the communication cables in underground mines in order to protect them from the effects of fires and explosions.

We conducted discussions with Government and industry specialists on the physics of mine fires and explosions, mine disaster fighting, rescue, and investigation activities, and on mine operations. In addition, we examined published experimental work and selected detailed MSHA accident reports on fires and explosions in underground mines.

We found the overall desirability/practicality of cable burial must be regarded at this time as highly questionable, because of its benefit limitations to special scenarios, its practical operational shortcomings, and the availability of alternative cable protection options.

A. OBJECTIVE

Fires and explosions in underground mines can be life-threatening emergencies. During such emergencies, reliable communication links could play vital roles in saving lives and in combating the spread of the emergency condition. However, under such conditions, communication links may become disabled at the very time at which they need to be used for alerting others of the emergency and for coordinating emergency response activities.

The objective of this project was to perform a preliminary study to determine whether or not it is desirable or practical to bury the communication cable in underground mines in order to protect it from the effects of fires and explosions.

B. APPROACH

The overall objective of this preliminary study was accomplished by assessing:

- the need for protecting the communication cable from the hostile environmental effects of fires and explosions,
- and the considerations that affect the practical implementation of cable burial.

To assess the need for burying the communication cable, we examined a number of issues concerning the likelihood of cable involvement in a mine fire or an explosion, the extent of cable involvement, the likelihood of loss of communication to endangered miners due to cable damage, and the consequences of such loss of communication in terms of added risk to the miners.

We conducted discussions with Bureau of Mines technical staff, Mining Safety and Health Administration (MSHA) personnel and industry specialists, associated with the physics of mine fires and explosions, with mine disaster fighting, rescue, and investigation activities, and with mine operations. In addition, we examined published reports on mine fires and explosions. As a result, we obtained verbal and written information on the various communication needs, statistics on fire and explosion accidents in mining, quantitative descriptions of physical conditions measured during controlled fire and explosion experiments, and practical cable installation considerations. However, we found that no one had examined and reported on involvement of the communication cable. Accordingly, it became important to the outcome of this study that we review detailed MSHA accident reports for selected major fires and explosions to assess the nature and severity of cable involvement, and the potential benefits obtainable from burial. Although the obtaining and reviewing of key accident reports caused some delays and reallocations of project efforts, these activities proved to be vital to the findings of this initial study.

The available information was, by and large, widely dispersed, incomplete, and not in a form lending itself to ready and specific application to the buried cable problem. It became evident that the effort required to evaluate this information in detail would be significantly greater than originally allocated to this study. Therefore, as a result of budgetary limitations, the U.S. Bureau of Mines and Arthur D. Little, Inc. agreed to capture the main results of this initial study in the form of a summary data report instead of a formal final report. This report summarizes our main findings, conclusions and recommendations. They are based on preliminary evaluations of the assembled data and the application of professional judgment. The statistical, physical and operational data evaluated during the study are summarized in four Appendices.

C. FINDINGS

1. Examination of the general statistical accident data for mine fires and explosions revealed that the overall number of accidents involving injury or death appeared to be somewhat limited compared to overall casualties in underground mines. The average number of deaths per year from mine fires is relatively low and remaining steady, while the average number of injuries per year from mine fires is low and decreasing. For an eight year period in the 1970's, the average numbers for fires are approximately 5 injuries and 2 deaths per year. The number of injuries and deaths per year from mine explosions in the 1970's, averaged over the same eight year period, is about 3 to 5 times that for fires, respectively. However, the number of yearly injuries due to explosions has decreased by a factor of about 5 since the early 1970's. For the same eight year period, the average number of 10 deaths per year from explosions is the result of averaging a few high death toll explosions with many low death toll incidents (see Appendix I).

2. Based on a more detailed review of detailed accident data, we were able to identify the most important accident scenarios for mine fires and explosions to be examined with regard to the nature of communication cable involvement and the cable's potential utility for saving lives. Electrically-initiated fires, both on working sections and those associated with vehicular movements along the electric rail haulageways, were found to be the most important sources of major mine fires. Spark induced methane ignitions in the immediate face areas of working sections were found to be the most important causes of major mine explosions (see Appendix I).

3. In the detailed examination of the scenarios and the mine accident reports, we found no specifically-reported need for cable burial. Furthermore, benefits to be derived from such burial appeared to be quite limited and constrained to specific scenarios. For mine

fires, it appears that the most important scenario is a major fire along a main haulageway. Such a fire could endanger many miners located inby the fire. For mine explosions, it was more difficult to identify a key benefiting scenario. In each case, the potential benefits to be gained from cable burial still appear, at first glance, to be quite limited, especially in view of the potential problems associated with cable burial and the presence of alternative solutions for cable protection (see Appendices II and III).

4. The practical problems can be grouped into two major categories: one associated with its utilization on working sections, and the second with its utilization on haulageways. On sections, the greatest hazard will be to miners in the immediate face area, where it is impractical to extend a buried cable for up to 15 days after mining, because of ground movement problems during this 15 day period. Furthermore, pager phone communications up to the face become academic for methane explosions in which everyone in the area can be killed immediately. It is also of questionable utility for fires, because the overriding need is for direct face-to-face personal communication between the miners on the section shortly after the fire is discovered. Along the main haulageways, burial becomes a bit more attractive because of the permanence of these main travel routes. However, buried cable must function over long periods in the face of water, acidity and ground movement, perhaps for the life of the haulageway. Therefore, burial will require more expensive and difficult installation and maintenance procedures in the form of trenching equipment, types of cable and splices, troubleshooting, and repair. On the positive side, a buried cable installation would be less susceptible to roof falls and other mechanical accidents in haulageways. Finally, although a survivable buried cable could be available for use by rescue and recovery teams, questions remain as to whether long standing concerns about sparking hazards at the exposed pager phones would in fact still prohibit use of the phone system by such teams (see Appendix IV).

5. In view of the practical problems associated with burial, and the apparent survival of communication cables for significant times in many mine fires and explosion accidents, we believe that several alternative solutions to cable burial may provide sufficient protection in most accident situations. These potential alternative solutions include:

- cable loop-back through parallel tunnels or other passages,
- repositioning of the cable away from the immediate roof area, where fires tend to spread more rapidly, to a more favorable side wall (rib) location in the tunnel,
- use of a heavier duty or better insulated communication cable, or
- perhaps even covering the cable on the floor of the tunnel instead of burying it.

Although each of these methods admittedly provides less absolute protection under the most extreme accident circumstances, each also requires less drastic departures from present mine practices. Finally, the needs of rescue and recovery teams will probably be best satisfied by new medium frequency portable radio equipment recently developed under Bureau of Mines sponsorship (see Appendix IV).

D. CONCLUSIONS

Although cable burial should improve the long-term availability of pager phone communications during mine fire and explosion emergencies, this may not necessarily lead to corresponding benefits in the form of fewer injuries and fatalities during these emergencies. This initial study, which included a review of detailed accident reports of past emergencies, has revealed:

- that cables did survive long enough to permit communications with endangered miners in some major emergencies,

- no cases where deaths or injuries were reported as being directly attributed to failure of the communication cable,

- no cases where we could easily infer that lives were in fact lost as a result of cable failure, and

- some fire cases where deaths could be attributed to inadequate familiarity with emergency warning and response procedures, and to inadequate emergency breathing devices.

In summary, we have found that burial of the communication cable is <u>not generally</u> needed, although cable burial can conceivably be useful in a specific scenario, such as a major haulageway fire.

The overall desirability (need)/practicality (feasibility) of cable burial must be regarded at this time as highly questionable, both because of its benefit limitations to special scenarios, and its practical operational shortcomings. This questionability becomes particularly apparent where alternative cable protection options, offering somewhat lower protection but also less dramatic actions, are available for consideration. Furthermore, it also appears that improved emergency response procedures and emergency breathing devices could have a bearing on the number of potential fatalities from mine fires.

E. RECOMMENDATIONS

In view of our findings and conclusions in this preliminary study, we make the following recommendations:

- Before requiring any major changes in cable installation and protection practice in underground mines,
  - -- identify and define specific scenarios where some form of cable protection could be beneficial,
  - -- perform cost/benefit analyses for various cable protection and miner protection alternatives, and
  - -- document the favorable and practical alternatives, if any, in guideline form.
- Evaluate the need for more effective emergency response training.

APPENDIX I

GENERAL MINE ACCIDENT STATISTICS

A major objective of this study was to assess the need for burying the communication cable to protect it from the hostile environmental effects of fires and explosions. This need will depend on a number of factors such as the frequency of occurrence of fires and explosions in mines, the degree of involvement of the cable, the likelihood of losing the communication capability, and its impact on the endangered miners.

This appendix presents summary information and data related primarily to the first of these factors. To identify statistics and general trends on coal mine fires and explosions, we reviewed the literature and talked with knowledgeable MSHA staff.

A. FREQUENCY OF COAL MINE FIRES

We searched the literature and found that the Allen Corporation (Orlando, Florida) was conducting a detailed study of coal mine fires, under the sponsorship of the Bureau of Mines (Denver Federal Center).

The Allen Corporation study consists of developing an annotated bibliography for over 1200 coal fires covering the period from 1950 to 1977. (Explosions were excluded unless initiated by these fires.) Data were collected from MSHA fire reports, periodicals and interviews of mine safety directors. The data were categorized into reportable fires (at least one-half hour duration or injury), non-reportable fires and opinion data. (The latter two were based on the interviews.)

The data were analyzed by time trends, state, ignition source, burning substance, location, equipment, detection, duration, injuries, fatalities and successful extinguishing agents. A qualitative ranking of the importance of these factors is given in Table I-1 for underground mine fires involving injuries and fatalities. The study concluded that the overwhelming majority of fires are of electrical origin. Underground fires occur mostly outby the face, at the working face and along haulageways. A number of recommendations were made, none of which called for improving the communication cables.

The number of fires in each year is plotted in Figure I-1 for the period of 1950 to 1977, along with the corresponding number of tons of coal produced. There is a noticeable upward trend in the number of fires in the 1950's, followed by a downward trend in the late 1960's, and a leveling-off in the 1970's. However, coal production was fairly constant over this period, so that the number of fires per million short tons of coal mined per year followed the same trend as the number of fires, and ranged from approximately 0.2 to 0.03 fires per million short tons per year.

The frequency distribution of various casualty levels is given in Table I-2 covering both injuries and deaths. The results are given for two time periods: 1970-1977 and 1953-1977. This separation of time periods is made because the number of fires are generally lower in the 1970's as indicated in Figure I-1. Table I-2 also gives the total number of fires during these periods and their breakdown in terms of with or without casualties.

Note that the number of fires resulting in a casualty is a small fraction of the total number of fires: about 7 to 8% for injuries and 3 to 4% for deaths. The estimated arithmetic average numbers of casualties per year from fires for these periods are: 5 to 9 for injuries and about 2 to 3 for deaths. These numbers provide an upper bound on the potential benefits to mine fire casualties to be gained by improving the availability of the mine pager phone communication system through cable burial. The actual benefits are likely to be lower since improved communications may have little or no effects on some of these casualties.

TABLE I-1

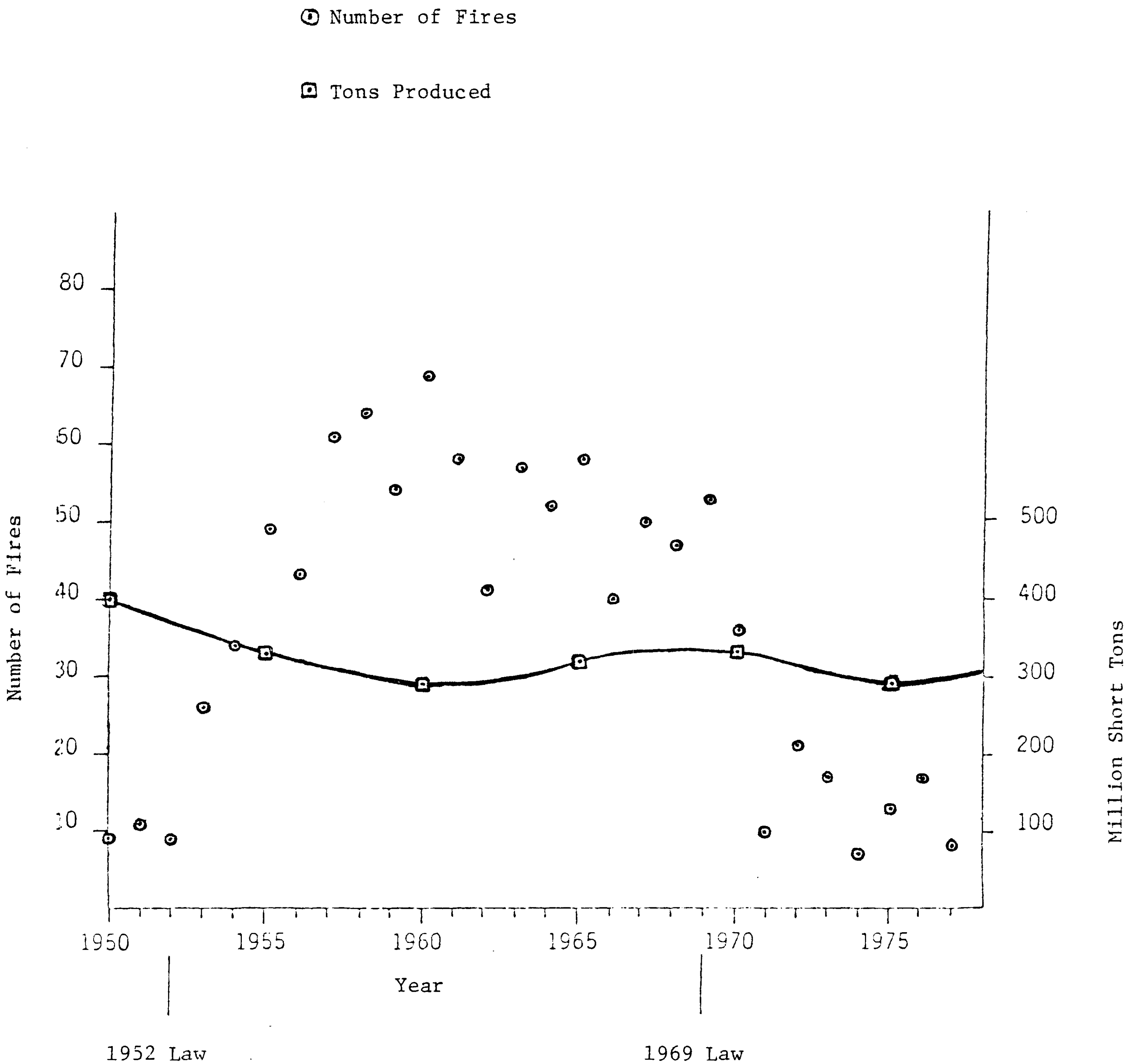
MAJOR ALLEN CORP. STUDY RESULTS FOR

UNDERGROUND COAL MINES

Category	Reportable Fires			Non-Reportable Fires	
	Incident Descriptions			Incident Descriptions	Opinion Data
	Overall	Injury	Fatal	Overall	Overall
Ignition Source	Electrical, Spontaneous, Welding	Electrical, Welding	Electrical	Electrical, Friction	Electrical, Friction, Spontaneous
Burning Substance	Wiring Insulation, Coal, Rubber			Wiring Insulation, Coal	Wiring Insulation, Coal, Grease
Equipment Involved	Belt, Cutter, Locomotive	Welding Equipment		Conveyor Belt, Shuttle Car, Scoop Tram	Conveyor Belt, Shuttle Car, Locomotive
Location	Outby Face, Working Face, Haulageway	Outby Face, Haulageway	Outby Face, Working Face	Main Haul-ageway, Haulageway	
Successful Extinguish-ing Agent	Water, Dry Chemical, Rock Dust			Portable Extinguisher, Water, Power Disconnect	

Note: Items in descending order of significance in each box of matrix.

Ref: Allen Corp. of America "An Annotated Bibliography of Coal Mine Fire Reports, Vol 1, Final Report, BoM Contract J0275008, 15 Feb. 1979.



Source: Allen Corp. Final Report, Vol. I, 15 Feb. 1979

Figure I-1

Trends Over Time for Occurence of Underground Fires

TABLE I-2

FREQUENCY DISTRIBUTION OF VARIOUS CASUALTY LEVELS IN COAL MINE FIRES*

	Injuries				Deaths			
	1970 - 1977		1953 - 1977		1970 - 1977		1953 - 1977	
Number of Casualties/fire	No.	%	No.	%	No.	%	No.	%
1	6	4.7	41	4.2	3	2.3	16	1.6
2-5	1**	0.8	33	3.3	1[ff]	0.8	5	0.5
6-10	4[f]	1.6	7	0.7	1[fff]	0.8	2	0.2
10+	0	0.0	1	0.1	0	0.0	2	0.2
Fires with casualties	9	7.1	82	8.3	5	3.9	25	2.5
Fires without casualties	119	92.9	904	91.7	123	96.1	961	97.5
TOTALS	128	100%	986	100%	128	100%	986	100%
Arithmetic average number of casualties per year	5.4		8.6		1.9		2.8	

*Source: Allen Corp. Final Report, Vol. I & II, 15 Feb. 1979, and Arthur D. Little, Inc.

**5 injuries

[f] 6 and 10 injuries, 2 each

[ff] 3 fatalities

[fff] 9 fatalities

B. FREQUENCY OF SEVERE COAL MINE EXPLOSIONS

We also searched the literature for information on coal mine explosions. We found an old report covering a detailed review of all incidents between 1910-1958.* More recent similar studies were being conducted by George Price of MSHA and John Nagy (formerly of MSHA). These reports were due to be completed after the completion of this study. Accordingly, we obtained some general results through telephone conversations and a meeting with George Price and Edward Kawenski of MSHA, Bruceton, PA. These results are summarized below:

1. Methane ignitions are very common in mines--about 100 ignitions per year. They occur near the face due to the friction generated when continuous mining machines hit a hard surface such as sandstone. Most of these "ignitions" cause no damage, due to the limited availability of methane or coal dust. On the other hand, a few develop into devastating explosions. It is noteworthy that an explosion involving methane alone is not likely to ignite the coal seam, while that involving coal dust may ignite it. (This is generally true for Pittsburgh seam coal.)

2. In the period of 1959-1979, there were 918 underground casualty-involving explosions, leading to 353 deaths and 453 injuries. Of these explosions, 16 were major ones involving 294 deaths. In 1970-1979, there were 10 explosions causing 79 deaths. The date, location and number of casualties for each of these major explosions are given in Appendix II.

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*Humphrey, H. B., "Historical Summary of Coal Mine Explosions in the United States," 1810-1958, Bureau of Mines Bulletin 586, 1960.

3. The explosions involving injuries in 1970-1979 are very numerous. However, the total number of injuries/year has been decreasing as shown below:

Year	Total Number of Injuries/Year
1970	29
1971	12
1972	28
1973	3
1974	5
1975	6
1976	9
1977	6
1978	6
1979	9
1980 (incomplete)	5
Total	118

4. The accident investigation reports on these explosions are not likely to have any information on the conditions of the cable after the explosion. However, there seems to be agreement between Price, Kawenski and Nagy that the cables will generally not survive in the explosion area. They are likely to be torn loose and burned. This was based on both judgment and some recollection of specific fires.

5. Nagy reported that some 20 years ago they used to bury cables during fire tests in the experimental mine at PMSRC. They found it easier to bury the cables in the mine rib than the mine floor because the former is much softer. They used a

cutting machine to cut a 6-inch wide and 6-inch deep slot in the rib. This was done very frequently but was not documented to the best of Nagy's knowledge. (In an operating mine environment, burial in the rib becomes impractical because of the presence of crosscut tunnels.)

C. COMPARISON WITH OTHER MINE ACCIDENTS

The data presented above is summarized below to compare the risk of fatalities from fire and explosions over the following periods.

	1970-77 Fires	1970-79 Explosions	1970-78 All Accidents
Fatalities	15	79	∿1000
Injuries	43	113	-

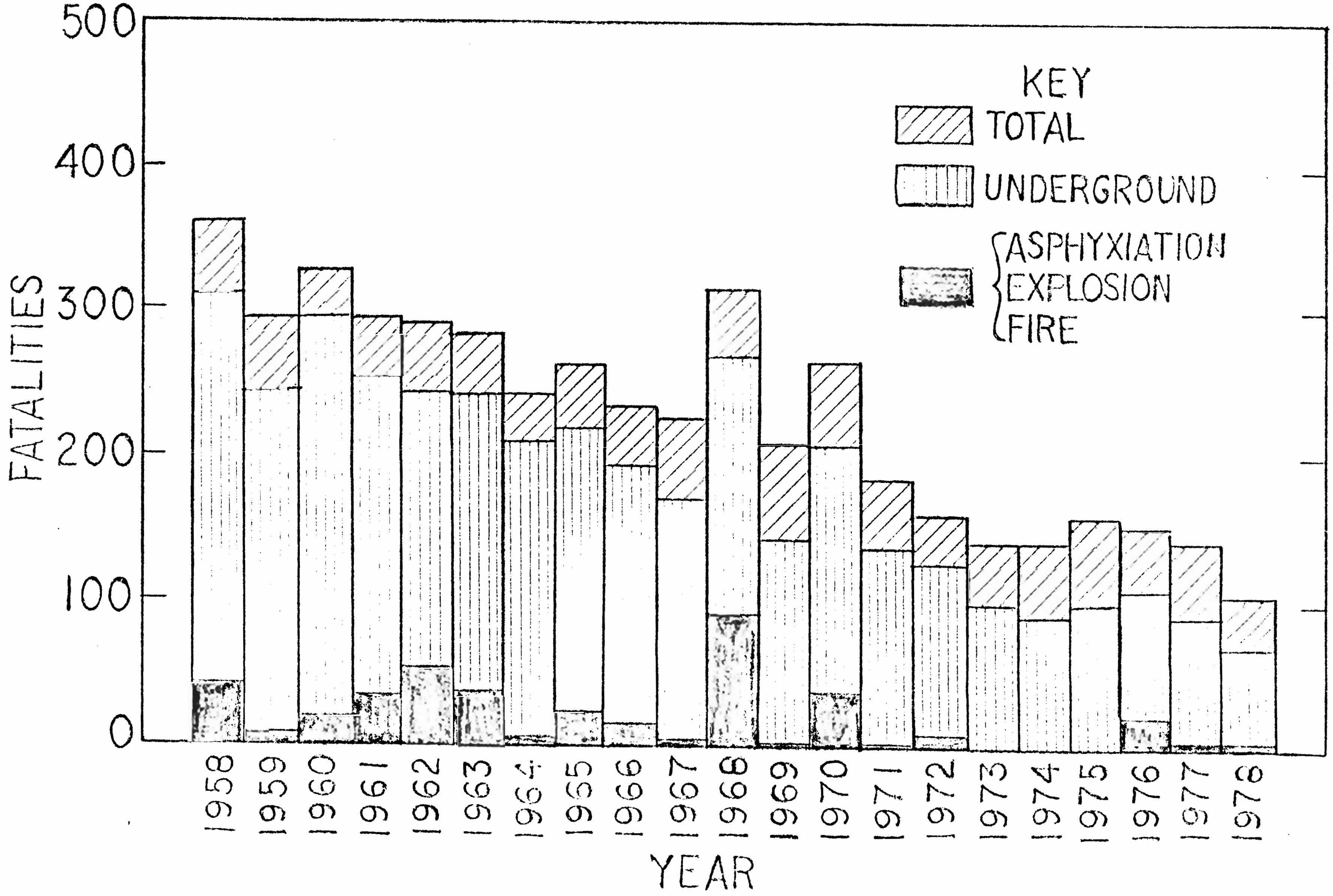
We also give the corresponding values for all accidents in underground mines. Note that, on the average, fires and explosions constitute a small percentage of the total number of accident casualties. Figure I-2 prepared by G. Price of MSHA presents the mine fatality data in summary bar graph form for the 21 year period from 1958 to 1978. It illustrates the general decline in overall mining fatalities, and the reduced contributions made in the 1970's by fires and explosions on the average. However, it also indicates that the number of fatalities from fires and explosions can still become significant in any particular year as a result of a few severe incidents.

In view of these trends, it became necessary to examine in detail MSHA accident reports for major fires and explosions to assess the degree to which cable burial might improve miner survival rates. Appendix II provides summary information and data from this review.

FIGURE I-2

SUMMARY OF MINE FATALITY DATA (COAL)

1958 to 1978



Source: G. Price, MSHA - Bruceton

APPENDIX II

MSHA ACCIDENT REPORTS FOR MINE FIRES AND EXPLOSIONS

A. NEED FOR MINE ACCIDENT REPORT REVIEW

The miner casualty numbers presented in Appendix I provide an upper bound on the casualties that could potentially be reduced by a survivable communications system. The actual benefits will of course be lower, since some or all of the casualties may remain unaffected by communications links. This, together with the decreasing frequency of occurrence of fires and explosions involving casualties, made it important to examine detailed MSHA accident reports describing the circumstances and outcomes of selected key fires and explosions in which casualties did occur. Such a review could help identify the role and utility, if any, of the communication cable in affecting outcomes in terms of lives saved or lost.

MSHA mine accident reports are published in more limited quantities than other government documents, and they are not stored in a central repository. They are generally kept at various MSHA district offices, and not always in districts where the accidents occurred. In addition, there are two locations where special collections of certain accident reports have been accumulated; namely mine fire accident reports at the Allen Corporation in Orlando, Florida, and mine explosion reports at the MSHA office in Bruceton, PA. To obtain printed copies of the reports, it became necessary to contact the MSHA Office of Public Information in Washington, and to follow up with a formal letter request to that office.

Thirty-three accident reports covering selected coal mine fires and explosions and metal/non-metal mine fires from the period 1970 to 1979 were requested. The requested list of reports is shown in Table II-1.

TABLE II-1

LIST OF SELECTED MINE FIRE AND EXPLOSION ACCIDENTS
REQUESTED FROM MSHA OFFICE OF PUBLIC INFORMATION

DATE OF ACCIDENT	MINE NAME	MINE LOCATION
Coal Mine Fires		
✓ 4/24/70	Olga Mine	Coalwood, W.Virginia
8/10/70	Itmann No. 3	Itmann, W. Virginia
✓ 3/26/71	Nemacolin Mine	Nemacolin, Pennsylvania
✓ 7/22/72	Blacksville No. 1	Blacksville, W. Virginia
✓ 9/29/73	Pyro Mine No. 2	Sullivan, Kentucky
✓ 8/31/74	Jane No. 1 and 2	Elderton, Pannsylvania
6/11/75	Powhatan No. 6	Beallsville, Ohio
✓ 11/14/75	No. 3 Mine(Itmann Coal Co.)	Itmann, W. Virginia
✓ 10/3/77	Franklin High-wall Mine	New Athens, Ohio
Coal Mine Explosions		
✓ 4/2/70	Compass No. 3	Dola, W. Virginia
✓ 4/10/70	Homer City	Homer City, Pennsylvania
✓ 11/30/70	Pyro No. 2	Sullivan, Kentucky
12/30/70	No. 15 and 16 (Finley Coal Co.)	Hurricane Creek, Kentucky
✓ 12/16/72	Itmann No. 3	Itmann, W. Virginia
✓ 9/25/73	No. 4	Vansant, Virginia
3/11/76	Scotia(Blue Diamond Coal Co.)	Kentucky
3/19/76	Scotia	Kentucky
✓ 5/13/76	Mulga	Mulga, Alabama
✓ 7/7/77	No. 2	St. Charles, Virginia
Metal/Non-Metal Mine Fires		
9/27/70	Lakeshore	Cassagrande,Arizona
✓ 1/20/71	Star Mine	Burke, Idaho
✓ 5/2/72	Sunshine	Kellogg, Idaho
✓ 4/23/73	Lisbon	LaSal, Utah
✓ 8/17/73	Lakeshore	Cassagrande, Arizona
✓ 6/2/74	Sherwood	Iron River, Michigan
✓ 12/4/75	Pilot Knob	Pilot Knob, Missouri
✓ 2/11/76	Buick Mine & Mill Facility	Ross, Missouri
✓ 4/16/77	Cabin Creek	Mayesville, Kentucky
✓ 6/3/77	Alchem Trona	GreenRiver, Wyoming
✓ 10/3/77	Eagle	Gilman, Colorado
✓ 1/28/78	U.S. Engergy Corp. Project 74	Caycee, Wyoming
✓ 6/8/79	Belle Isle (Cargill, Inc.)	Calumet, Lousiana

✓Reports received

Check marks on the table indicate which reports were eventually received. Reports on the metal and non-metal mine accidents were obtained in about one month. The coal mine accident reports took about three months to arrive.

B. VISITS FOR EXAMINATION OF ACCIDENT REPORTS

To expedite the accident information review and analysis process, we visited the Allen Corporation in Orlando, Florida. The visit was made to get a timely preview of the environmental and operational conditions surrounding serious mine fire accidents. The visit was made by R. Lagace and A. Moussa of Arthur D. Little, Inc., who met with R. Baker and C. Duncan of the Allen Corporation. Twenty-two coal mine fire reports and five metal/non-metal fire reports dating back to 1952 were selected and examined in detail.

Reading the reports on-site at an early date gave us the advantage of quickly obtaining several "snapshots" of the actual conditions and outcomes related to cable and miner survival for these accidents. Summary information and impressions for each mine accident examined were recorded on a dictating machine, and accompanied where necessary by brief notes and sketches, for later transcription and analysis.

Our examination of the fire accident reports convinced us that the fire dynamics in relationship to the location of the cable and miners, and the operational dynamics of the miners and supervisors directly and indirectly involved with the fire, may be even more important than maximum physical stresses that could be imposed on communication cables. For example, in some cases the communication cable was not involved and not a factor in the emergency events, while in others it survived beyond the time that it was needed, and was used to communicate with endangered miners. For many of the reports it was somewhat tedious and difficult to extract information on cable involvement and damage, because accident inspection teams have not been particularly concerned with the communication cables.

We also expedited the review and analysis process for the MSHA mine explosion accident reports by visiting the MSHA office in Bruceton, PA. This visit was made by R. Lagace and A. Moussa of Arthur D. Little, Inc., who met with E. Kawenski, G. Price, and R. Reynolds of MSHA. Fifteen major mine explosion reports dating back to 1959 were selected from their files. As in the case of the fire reports, the review process was somewhat difficult and tedious, and included the dictation of summary information and impressions, accompanied by brief sketches and notes, for later transcription and analysis.

The review difficulties are due to the need to extract in a short time period, information related to cable survival and its potential impact on miner survival, from reports that vary in style and content, and are typically not concerned with damage to cables. Not withstanding these difficulties, the review and analysis of the MSHA fire and explosion accident reports were successful and of critical importance to this buried cable study.

C. PRELIMINARY ANALYSIS OF MSHA ACCIDENT REPORTS

Tables II-2, II-3, and II-4 list the MSHA accident reports reviewed by Arthur D. Little, Inc. for coal mine fires, metal and nonmetal mine fires, and mine explosions, respectively. The tables also indicate those reports for which summaries were dictated during the review process. Nearly all the reports reviewed were selected from the files of the Allen Corporation and MSHA Bruceton during the preview visits of R. Lagace and A. Moussa. Most of the reports requested from the MSHA Office of Public Information arrived too late in the project to be fully utilized.

TABLE II-2

LIST OF MSHA ACCIDENT REPORTS OF
MAJOR & MINOR UNDERGROUND COAL MINE FIRES

REVIEWED BY ARTHUR D. LITTLE, INC.

(Tablulated information excerpted from Allen Corp., Final Report, Vol. II)

Date	Mine Name and Company	Location	Fire Description	Fatalities	Injured	ADL Dictated Summary
12/13/52	No. 3 Elkhorn Mine Pond Creek Pocahontas	Evanston, Kentucky	Fire caused by friction of belt drive pulleys turning against a stalled belt. Area was sealed.	4	0	*
5/06/54	Pursglove No. 15 Christopher Coal Co.	Pursglove, W. Virginia	Fire occurred when roof fall pulled trolley wire on rail igniting coal and clothing on men. Area sealed.	0	10	*
8/04/55	Vesta No. 5 Jones & Laughlin Steel Corp.	Vestaburg, Pennsylvania	Fire of undetermined origin occurred on locomotive. Possibly main resistor overheated. Water, rock dust, and power used to extinguish the fire.	0	2	
10/05/57	Crescent Mine Nashville Coal,	Central City, Kentucky	Fire caused by fall of roof which shorted light line and ignited timber. Water, rock dust, and powder applied to extinguish fire.	0	3	

TABLE II-2 (Continued)

Date	Mine Name and Company	Location	Fire Description	Fatalities	Injured	ADL Dictated Summary
10/14/58	Turner No. 5 Left Beaver Coal	Drift, Kentucky	Fire caused by short circuit in trailing cable on locomotive ignited the cable. Nip removed and fire went out.	1	0	
11/04/58	Hubbard Mine Greensburg-Connellsville Coal & Coke Co.	McKeesport, Pennsylvania	Fire supposedly caused by arcs of locomotive on rails which ignited oil and acetylene gas. Water and rock dust applied	0	2	
3/08/60	No. 22 Mine Island Creek Coal	Holden, W. Virginia	Fire of undetermined origin discovered. Burning timber and coal contained by sealing area.	18	0	*
11/27/61	Springfield No. 6 Cambria Clear-field Mining Co.	Westover, Pennsylvania	Fire caused by friction ignited coal and dust. Rock dust put the fire out.	1	0	
1/29/63	Orient No. 5 Freeman Coal Mining Corp.	Benton, Illinois	Fire of undetermined origin discovered on belt entry. Seals erected to contain burning coal, timber, belt and dust.	3	4	*
10/05/63	No. 28 Mine National Coal Mining Co.	Verdunville, W. Virginia	Fire supposedly caused by friction ignited coal and belt. Water and rock dust put fire out.	0	3	

TABLE II-2 (Continued)

Date	Mine Name and Company	Location	Fire Description	Fatalities	Injured	ADL Dictated Summary
4/14/64	Zeigler No. 3 Bell & Zoller	Zeigler, Illinois	Fire caused by short circuit in locomotive ignited it and timbers. Water and rock dust applied.	1	0	
7/24/65	Arkwright No. 1 Christopher Coal Co.	Mona, W. Virginia	Fire was caused by phase to phase fault. Seals erected.	2	0	
10/16/65	Mars No. 2 Clinchfield Coal	Wilsonburg, W. Virginia	Fire caused by short on miner ignited hydraulic fluid, coal, and rubber. Water and CO2 put fire out.	7	0	*
11/13/65	No. 3 Mine Dean Coal Co.	Leivasy, W. Virginia	Fire of undetermined origin discovered by shaft portal. Water and rock dust applied to burning timber and coals and belt.	0	3	
12/28/65	Nemacolin Mine Buckeye Coal Co.	Nemacolin, Pennsylvania	Fire caused by short circuit in trolly pole cable which ignited cable, trolly pole, and cab of locomotive. Powder applied.	1	0	*
5/02/66	Keystone No. 1 Eastern Asso-ociated Coal Corp.	Keystone, W. Virginia	Fire caused by short in pump power cables ignited same. Fire self-extinguishing.	0	3	

TABLE II-2 (Continued)

Date	Mine Name and Company	Location	Fire Description	Fatalities	Injured	ADL Dictated Summary
7/21/66	Forge Slope Glen Nan Coal Co.	Newport Township Pennsylvania	Fire caused by sparks from torch ignited timbers and plank liners at top of air shaft.	0	34	*
12/12/68	No. 8-B Mine Buffalo Mining Co.	Saunders, W. Virginia	Fire caused by short circuit in splice on blet power cable and belt, hydraulic fluid, coal, dust, hoses, and wooden crib ignited. Rock dust and extinguishers applied.	3	0	*
3/26/71	Nemacolin Mine Buckeye Coal Co.	Nemacolin, Pennsylvania	Trolley wire fell and contacted grounding clamp on rail which ignited coal. Water and nitrogen applied to extinguish fire.	3	0	*
7/22/72	Blacksville No. 1 Consolidation Coal	Blacksville, W. Virginia	Fire occurred when miner contacted trolley wires igniting insulation, hydraulic fluid, and coal. mine was sealed.	9	0	*
7/11/73	Powhatan No. 6 Nacco Mining Co.	Beallsville, Ohio	Fire caused by short circuit in trolley wire ignited insulation, coal, and hose on compressor. Powder extinguished the fire.	0	10	*
8/31/74	Jane Nos. 1 & 2 Rochester & Pittsburgh Coal Co.	Elderton, Pennsylvania	Fire caused when trolley wire contacted leveling bar on bolter and arc ignited insulation, hydraulic fluid, and clothing. Powder applied to fire.	1	1	*

TABLE II-2 (Continued)

Date	Mine Name and Company	Location	Fire Description	Fatalities	Injured	ADL Dictated Summary
10/03/77	Franklin High-wall Mine Consolidated Coal	New Athens, Ohio	Fire caused when ram car ran over charging cable while battery being charged and cable ignited. Powder extinguished the fire.	0	6	

TABLE II-3

LIST OF MSHA ACCIDENT REPORTS OF

UNDERGROUND METAL AND NON METAL MINE FIRES

REVIEWED BY ARTHUR D. LITTLE, INC.

Date	Mine	Location	Mineral	Fatalities	Injured	ADL Dictated Summary
3/5/68	Belle Isle	St. Mary Parish Louisiana	Salt	21	0	*
2/9/71	Star	Drukee, Idaho	Lead-Zinc	2	0	*
5/2/72	Sunshine	Kellogg, Idaho	Silver	91	0	
4/16/77	Cabin Creek	Maysville, Kentucky	Limestone	0	11	*
8/17/77	Lake Shore	Casa Grande, Arizona	Copper	2	0	*

TABLE II-4

LIST OF MAJOR MINE EXPLOSIONS

1959 to 1979

Date of Explosion	Mine*	Company	State	Number of Fatalities	Cause of Explosion	Reviewed by ADL Team
2/23/59	No. 1 Mine	Phillips & West Coal Co.	Tennessee	9	Explosion-CH_4	√
3/2/61	Viking Mine	Viking Coal Corp.	Indiana	22	Explosion-CH_4	√
1/10/62	Mine No. 2	Blue Blaze Coal Co.	Illinois	11	Explosion-CH_4	√
12/6/62	Robena No. 3 Mine	U. S. Steel Corp.	Pennsylvania	37	Explosion-CH_4	√
4/25/63	Compass No. 2 Mine	Clinchfield Coal Co.	West Virginia	22	Explosion-CH_4	√
12/16/63	No. 2 Mine	Carbon Fuel Company	Utah	9	Explosion	√
5/24/65	No. 2A Mine	Cili Kline Coal Company	Tennessee	5	Exp-osion-CH_4	√
10/16/65	Mars No. 2 Mine	Clinchfield Coal Co.	West Virginia	7	Fire & Explosion-CH_4	†
12/28/65	Dutch Creek No. 2	Mid-continent Coal & Coke	Colorado	9	Explosion-CH_4	√
6/1/66	Dora No. 2 Mine	Doverspike Brothers, Inc.	Pennsylvania	5	Suffocation	**
7/23/66	Siltix	The New River Company	West Virginia	7	Explosion-CH_4	√
8/7/68	River Queen	Peabody Coal Company	Kentucky	9	Explosion of explosives	√
1/20/68	Consol No. 9 Mine	Mountaineer Coal Co.	West Virginia	78	Explosion-CH_4	**
12/30/70	Nos. 15 - 16	Finley Coal Co.	Kentucky	38	Coal Dust Explosion	√
7/22/72	Blacksville No. 1	Consolidation Coal Co.	West Virginia	9	Mine Fire	†
12/16/72	Itmann No. 3	Itmann Coal Company	West Virginia	5	Explosion-CH_4	√
3/9-11/76	Scotia Mine	Scotia Coal Company	Kentucky	26	2 ExplosionsCH_4	**
6/8/79	Belle Isle Mine	Cargill, Inc.	Louisiana	5	Explosion-CH_4	√

†Reviewed as a mine fire in this study

*All coal mines, except for Belle Isle (Salt)

**Report not available

√Including dictated summary, with the exception of 6/8/79 Belle Isle Mine

Source: MSHA and Arthur D. Little, Inc.

The following criteria were used to decide which MSHA fire and explosion accident reports would be selected for review.

- o Fires that resulted in fatalities or several injuries, and occurred in a location that could involve a communication cable. Of particular concern were fires of an electrical origin, since communication cables are generally in the vicinity of electrical cables, especially along main and section haulageways.

- o Major explosions that involved five or more fatalities since these are classified as mine disasters.

More fires than explosions were examined because explosions tend to occur more frequently on sections, and mainly in the face areas where communication cables are not usually located.

Tables II-5 and II-6 present the results of our preliminary review and analysis of the fire and explosion accident reports, respectively. They represent our initial attempts, within the constraints of this project, to characterize the dynamics of the physical and operational events of mine fires and explosions, and the potential impacts on the role of mine communication cable survival in reducing miner fatalities and injuries. To our knowledge, Tables II-5 and II-6 are the first time that such characteristics have been tabulated in this manner for a large number of mine fires and explosions. It should also be noted that the various factors we studied and tabulated were not intended to be comprehensive, but to illustrate various key indicators and trends of significance to this initial assessment of the feasibility and utility of cable burial.

TABLE II-5

PRELIMINARY ASSESSMENT OF COMMUNICATIONS IMPACT ON MINE FIRE OUTCOMES

LEGEND

Fire-Cause, Features

E = Electrical
TC = Trailing Cable
TW = Trolley Wire
HF = Hydraulic Fluid
ET = Equipment Transport
SC = Short Circuit
FB = Feeder Breaker
AT = Oxy-Acetylene Torch
W = Wood Timbers
TP = Trolley Pole Cable
R = Rectifier
F = Friction
U = Unknown
RF = Roof Fall
LL = Light Line
RS = Rock Slide
DL = Diesel Loader
TI = Transformer Insulation
SP = Spontaneous Combustion

Location

H = Haulageway
S = Section
B = Beltway
T = Transformer Area
AS = Air Shaft
AA = Abandoned Area

Severity

Mi = Minor
Ma = Major

Cause-Death/Injury

S = Smoke
T = Toxic Gases
B = Burns
Dr = Drowning
D = Dehydration

General

Y = Yes
N = No
? = Uncertain/Do Not Know
< = Less than
> = Greater than
Hosp = Hospital
DOA = Dead on Arrival
- = Not Applicable
Comm = Communications
Hdw = Hardware

Source: Arthur D. Little, Inc.

TABLE II-5

MINE FIRES

Fire Date	Mine Name	Fatalities	Injuries	Fire-Cause, Features	Location	Severity	Cause-Death	Cause-Injury	Self-Rescuer Inadeq.	Self-Rescuer Used?	Fire Duration (Est.)	Miner Survival Time (Est.)	Wire Comm Used?	Comm. Hdw. Survival for Time Needed?	Comm. Hdw. Factor in Saving Lives?	Comm. Hdw. Damage Factor in Death/Inj.?	Comm. Messages Factor in Death/Inj.?	Inad. Emerg. Responses Factor in Death/Inj.?	Cable Burial Improve Outcome?	Comments/Footnotes
Coal Mines																				
10/3/77	Franklin Highwall	0	6	E TC	S	Mi	-	S	-	N	4-5 min.	-	?	Y	?	N	N	Y?	N	
10/31/74	Jane 1 & 2	1	1	E TW HF	H	Mi	B	B	-	-	15 min.	Hosp. 22 days	Y	Y	Y?	N	N	N	N	Miner roof bolting under live trolley wire
7/11/73	Powhatan No. 6	0	10	E TW ET	H	Mi	-	S	?	?	65 min.	-	Y	Y	Y	N	N	?	N	
7/22/72	Blacksville No. 1	9	0	E TW ET	H	Ma	S/T	-	Y	Y & N	>week (sealed)	45-90 min.	Y	Y	?	N	Y	Y	N	Fire report delayed 30min. Escape order delayed 45-60 min.
3/26/71	Nemacolin	3	0	E TW TC	S	Ma	S/T Dr	-	?	?	>week (sealed)	15-30 min.	Y	Y	Y	N	N	Y	N	Cables near floor survived 1 drowning during fire fighting
12/12/68	No. 8B	3	0	E SC FB	S	Ma	S/T	-	-	-	75 min.	few min	N	N	N	N	N	Y?	N	Phone engulfed in flames, Don't put phone near equipment.
7/21/66	Forge Slope	0	34	AT W	AS	Mi	-	S	?	?	4 hr	-	Y	Y	Y	N	N	?	N	
5/2/66	Keystone No. 1	0	3	E SC	H	Mi	-	S	?	?	<1 hr	-	N	Y	Y	N	N	N?	N	
12/28/65	Nemacolin	1	0	E TP SC	H	Mi	B	-	-	-	<1 hr	Hosp. 2 days	Y	Y	Y	N	N	N?	N	Could have been major if vehicle not following train.
10/16/65	Mars No. 2	7	0	E TW ET	H	Ma	S/T	-	-	N	1-4 hr	<60 min (1~24 hr)*	Y	Y?	Y?	?	?	Y	?	No dispatcher. Attempt to alert inby miners delayed 15-30 min. *1 miner found unconscious after 22 hr, DOA at hosp.

TABLE II-5
(Continued)

Fire Date	Mine Name	Fatalities	Injuries	Fire-Cause, Features	Location	Severity	Cause-Death	Cause-Injury	Self-Rescuer Inadeq.	Self-Rescuer Used?	Fire Duration(Est.)	Miner Survival Time (Est.)	Wire Comm Used?	Comm.Hdw.Survival for Time Needed?	Comm.Hdw.Factor in Saving Lives?	Comm.Hdw.Damage Factor in Death/Inj?	Comm.Messages Factor in Death/Inj?	Inad.Emerg.Responses Factor in Death?	Cable Burial Improve Outcome?	Comments/Footnotes
Coal Mines																				
7/24/65	Arkwright No.1	2	0	E R	H	Mi	S/T	–	–	N	<12 hr	1<t<11 hr (~2 hr)	Y	Y	?	N	Y	Y*	N	*2 miners remained inby fire without self rescuers
10/5/63	No. 28	0	3	F	B	Mi	–	S	?	?	<1 hr	–	N	Y	N	N	N	?	N	
1/29/63	Orient No. 5	3	4	U	B/H	Ma	S/T	S	?	?	~week	1-2 hr	Y	Y/N*	Y	N?	?	Y	N*	*Survived 45-90 min.,if longer may have improved fire fighting
3/8/60	No. 22	18	0	U	H	Ma	S/T	–	?	?	Many hrs	<2 hr?	Y*	Y*?	?	?	?	Y	?	*Appears trolley comm. used, pager comm. not mentioned, possibly damaged; examined memo, not accident rept.
11/4/58	Hubbard	0	2	E	H	Mi	–	S	–?	–?	<1 hr?	–	N	Y	N	N	N	?	N	
10/14/58	Turner No. 5	1	0	E SC TC	S	Mi	S/T	–	–?	–?	<1 hr?	few min	N	Y	N	N	N	Y	N	Miner panic and movement into smoke area
10/5/57	Crescent	0	3	E RF LL	?	Mi	–	S	–?	–?	<1 hr?	–	N	Y	N	N	N	?	N	
8/4/55	Vesta No. 5	0	2	E SC TP	H	Mi	–	S?	–?	–?	<1 hr?	–	N	Y	N	N	N	?	N	
5/6/55	Pursglove No. 15	0	10	E TW RF	H	Ma	–	B/S	–?	–?	~week (sealed)	–	Y	Y?	?	N?	N	Y?	N?	

TABLE II-5
(Continued)

Fire Date	Mine Name	Fatalities	Injuries	Fire-Cause, Features	Location	Severity	Cause-Death	Cause-Injury	Self-Rescuer Inadeq.	Self-Rescuer Used?	Fire Duration (Est.)	Miner Survival Time (Est.)	Wire Comm Used?	Comm. Hdw. Survival for Time Needed?	Comm. Hdw. Factor in Saving Lives	Comm. Hdw. Damage Factor in Death/Inj.?	Comm. Messages Factor in Death/Inj.?	Inad. Emerg. Responses Factor in Death/Inj.?	Cable Burial Improve Outcome?	Comments/Footnotes
Coal Mines																				
12/13/52	No. 3 Elkhorn	4	0	F	B	Ma	S/T	-	-?	-?	>week (sealed)	few min	N	?	N	N	N	?	N	Miners quickly overtaken and overcome by smoke
Metal and Non-Metal Mines																				
8/17/77	Lakeshore (Copper)	2	0	RS DL	S	Ml	T/D	-	?	?	>week?	few hrs to days	N	-?	N	N	N	?	N	2 miners trapped behind rock slide found dead after 8 days
4/16/77	Cabin Creek (Limestone)	0	11	E TI	T	Mi	-	S	Y & N	Y & N	5.5 hrs	-	N	N	N	?	N	?	N	AC powered phones failed with power failure, Emerg. sound powered phones in-operable
5/2/72	Sunshine (Silver)	91	0	SP	AA	Ma	S/T	-	Y & N	Y & N	>10 days (sealed)	2,7 days 91, <few hrs.	Y	Y*	Y?	N*	N?*	Y	N	*Mine wire comm ineffective due to traffic overload 2 miners rescued after 7 days
2/9/71	Star (Lead-Zinc)	2	0	AT	-	Ml	S/T	-	?	?	3 hr	<3 hrs	Y	?	?	N?	N	?	N?	
2/5/68	Belle Isle (Salt)	21	0	AT?	AS	Ma	S/T	-	?	?	?	<1 hr	Y	N*	N	?	N	N?	N	*Survived for alert to surface. Miners trapped by fire at only exit shaft.

TABLE II-6

PRELIMINARY ASSESSMENT OF COMMUNICATIONS

IMPACT OF OUTCOMES OF MAJOR MINE EXPLOSIONS

LEGEND

Explosion - Cause, Features

M = Methane Gas

CD = Coal Dust

BO = Gas Blowout

E = Electrical

S = Spark

T = Trolley Wire

B = Blasting

TC = Trolley Cable

CL = Cigarette Lighter

C = Cigarette

Location

S = Section

H = Haulageway

LP = Load Point

F = Face Area

Severity

High

Moderate

Low

Explosion Forces & Flame Front Extent

M = Whole Mine

S = Section

P = Panel

MH = Main Haulageway

< = Less than

> = Greater than

Fatality Locations

I = Ignition Area

B = Beyond Ignition Area

M = Whole Mine

Cause-Death/Injury

E = Explosion Forces

B = Burns

A = Asphyxiation

T = Toxic Cases

F = Fall

Survival Times

Inst. = Instantaneous Death

General

Y = Yes

N = No

? = Uncertain/Do Not Know

- = Not Applicable

Comm = Communications

Hdw - Hardware

Source: Arthur D. Little, Inc.

TABLE II-6

MINE EXPLOSIONS

(Major)

Explosion Date	Mine Name	Fatalities	Injuries	Cause-Explosion	Location	Severity	Expl. Forces-Extent	Flame Front-Extent	Fatality Locations	Cause-Death	Cause-Injury	Escape Movements of Killed Miners (Est.)	Survival Times of Killed Miners (Est.)	Survivors in Affected Areas	Wire Comm Used?	Comm Hdw. Survival for Time Needed?	Comm Hdw. Factor in Saving Lives?	Comm Hdw. Damage Factor in Death/Inj?	Comm Messages Factor in Death/Inj?	Cable Burial Improve Outcome?	Comments/Footnotes
6/8/79	Belle Isle (Salt)	5	3+	M BO ES	H	H	M	<M	M	E A/T	B/F	0 to 100's ft	Inst, sec/min	17*	Y*	Y/N*	Y	N	N	N	*Comm at: shaft No.1 survived and used; shaft No. 2 destroyed, so pounding and shouting successfully used.
Coal Mines																					
12/16/72	Itmann No. 3	5	3**	M TS	S/H	L	S	<S	I	E/B	B	Few, 10's, 100's ft	Inst. sec/min	3*	Y*	Y*?	N	N	N	N	*Trolley comm to expl. area w/o response; to other areas ok, **3 survivors at expl. site eventually unconscious
12/30/70	No. 15 and 16	38	1	CD B	S LP	H	M	<M	I & M	E-33 A/T -5	E-1*	0 to 100/140 ft	Inst, sec/min	1*	N	N?	N	N	N	N	*One survivor located at mine portal, Self-rescuers stored in chests
8/7/68	River Queen	9	2**	CD B	S F	M	>S	S	I	E,B A	E	0 to 10's ft	Inst/ few sec	2**	Y*	Y*?	Y	N	N	N	*Comm response from all but explos. area, **2 miners knocked down ~2000 ft from explos, rest of mine unaffected
7/23/66	Siltix	7	1**	M TCS	S F	L	>S	S	I	E,B A	E,B	0	Inst.to 1-2 hr	12*	Y*	Y*?	Y*	N	N	N	*Comm to adj. sections and rest of mine possible and used to evacuate mine, **1 miner found unconscious in explos. area, 11 in adj.sec barricaded and rescued.
12/28/65	Dutch Creek No. 2	9	0	M/ CD TCS	S F	M	>P	>S	I	E,B A	-	0 to 10's ft	Inst/ sec.	0	Y*	Y*?	Y*	N	N	N	*No reply from explos. section, Comm to rest of mine used to evacuate

TABLE 11-6

(Continued)

Explosion Date	Mine Name	Fatalities	Injuries	Cause-Explosion	Location	Severity	Expl. Forces-Extent	Flame Front-Extent	Fatality Locations	Cause-Death	Cause-Injury	Escape Movements of Killed Miners (Est.)	Survival Times of Killed Miners (Est.)	Survivors in Affected Areas	Wire Comm Used?	Comm Hdw. Survival for Time Needed?	Comm Hdw. Factor in Saving Lives?	Comm Hdw. Damage Factor in Death/Inj?	Comm Messages Factor in Death/Inj	Cable Burial Improve Outcome?	Comments/Footnotes
Coal Mines 5/24/65	No. 2A	5	0	M/ CD CL	S F	H	M	<M	I	E/B	-	0	Inst/ sec	0*	N?	?	N	N	N	N	*All in mine perished, no one on surface to receive comm even if tried
12/16/63	No. 2 Mine	9	1**	M/ CD ES	S F	M	>S	S	I	E/B T	E	0 to 10's ft	Inst/ sec	1**	Y*	Y*?	Y*	N	N	N	*Comm to rest of mine used to evacuate,**Miner injured beyond ignition area and escaped
4/25/63	Compass No. 2	22**	0	M/ CD ES	S F	M	>S	>S	I & B	E/B	-	0 to 10's ft?	Inst/ sec	0**	Y*	Y*	Y*	N	N	N?	*Comm. to 2 unaffected area ok, **All miners killed on 3 sections
12/6/62	Robena No. 3	37*	0	M/ CD S	S F	H	P MH	P MH	I & B	E	-	0 to 10's ft?	Inst/ sec.	0*	N?*	N?*	N?*	N	N	N	*Extremely destructive explos. and inst. or near inst. death to all miners on a large section/panel; rest of mine not affected.
1/10/62	Mine No. 2	11	0	M/ CD ES	S	H	M	>S	I & M	B,A	-	?	Inst/ sec?	0*	Y*	?	N	N	N	N	*All in mine perished, no comm.response from mine
3/2/61	Viking	22	0	M/ CD S	S	H	S	>S	I & B	E,A	-	0 to 10's ft	Inst/ sec.	0	Y*	Y/N*	Y?*	N	N	N	*No reply received from explos. area, phone at jct w/mains disabled, Portal phone used to alert/evacuate miners in unaffected areas
2/23/59	No. 1	9*	0	M ES or C	S H	L	>S	S	I	B,A	-	0 to 10's ft	Inst/ sec.	0*	N?	?	N	N	N	N	*All in mine perished

Although the detailed information summarized in Tables II-5 and II-6 is preliminary and incomplete, several trends and characteristics can be detected and some important conclusions can be drawn. For example, consider the question: Would cable burial have improved the casualty outcomes for the reviewed mine fire and explosion accidents? For many cases, the answer was a clear "No." In no cases, was the answer a clear "Yes". In few cases, the answer was uncertain and most of these were for haulageway fires. Thus, more detailed analyses of these reports are required to resolve the issue.

A second finding relates to the utility of cable survival, through burial, during mine methane and/or coal dust explosions. In such cases it appears that cable survival is a moot point. Namely, the miners in the area of the explosion are almost invariably killed, if not instantly, within a few minutes, leaving no one alive to use any survivable communication system. The reports also indicate that if the explosion is due to methane ignition only, the cables appear to survive even in the explosion area. On the other hand, a violent coal dust explosion is highly destructive to everyone and everything, including cables, in the explosion area and beyond. However, beyond the working section containing the explosion, the cables appear to survive, thereby allowing communications to continue in the unaffected parts of the mine.

A third observation is related to likely survival times, for the miners exposed to the dangers. For serious fires, the survival times have been mainly on the order of minutes to a couple of hours, and typically much shorter than the durations of the fires. For major explosions, the survival times have been mainly seconds to a few minutes for miners in the explosion area. Furthermore, in two major mine fires, miners were found dead wearing their self-rescuers, an indication that the CO-type, self rescuers apparently did not provide adequate protection against deadly combustion products. For some of the other fires, more detailed investigations of the accident reports are required to resolve uncertainties regarding the utilization and effectiveness of the self-rescuers during the fire. The new MSHA regulation requiring the use of emergency breathing devices that supply oxygen to the miners is aimed at providing adequate protection to miners exposed to all hazardous atmospheres during mine emergencies.

A fourth observation is that in several mine fires, deaths and injuries occurred because of inadequate emergency responses by supervisory personnel or the miners themselves. These include a variety of actions, such as delays in notifying miners inby the fire of the dangers, inappropriate advice to inby miners, and returning to dangerous areas to retrieve equipment. Improvements in this area should be possible through the establishment of practical emergency procedures and associated training and drills.

Several other important findings and conclusions concerning mine fires and explosions could be obtained from a more comprehensive analysis of the accident reports and the factors tabulated in Tables II-5 and II-6. More comprehensive analyses are not required for this initial study, but the Bureau of Mines may want to consider the applicability of such analyses to its post disaster or environmental monitoring programs.

A final observation is included here concerning fires in coal mines that leave a layer of highly volatile roof coal to prevent roof shale exposure and spalling, a common practice in the Pittsburgh seam. It appears that once ignited, the roof coal continues to burn and the fire spreads rapidly along the roof. Furthermore, it appears that the burning of the thin layer (6" to 10") of roof coal could allow the fire to spread into adjacent entries by passing right over the thin cinder block barriers erected in crosscuts. This of course would defeat the effectiveness of the barrier as a restraint to fire propagation and the containment of noxious fumes. Therefore, it may be possible to avoid this problem in a simple manner during the construction of new barriers; namely, by taking down the 6" to 12" of roof coal at the barrier, and installing cinder blocks up to the roof material above the coal. This hypothesis on the spread of fires over barriers by means of the roof coal, and its potential solution, should be practical to check by straightforward experiments in a fire gallery.

APPENDIX III

SUMMARIES OF FOUR SELECTED MINE FIRES AND EXPLOSIONS

This Appendix presents summaries of four mine fires and explosions selected to illustrate the representative types of physical and operational dynamics that affect the survivability of endangered miners and communication cables.

A. SUMMARY OF MAJOR HAULAGEWAY FIRE
BLACKSVILLE NO. 1 COAL MINE FIRE ON 7/22/72

This was an electrically initiated fire which resulted in nine (9) fatalities and no injuries. The Blacksville fire is a good example of a track haulageway fire involving a trolley wire. The fire rapidly got out of control and generated large quantities of smoke and toxic combustion products that were carried by the ventilation system to men working on sections inby the fire. The fatalities occurred because of inadvertent delays in the sounding of the alarm (escape) instructions after the initiation of the fire. This extended delay prevented the successful egress from the mine of the men working on sections inby the fire because of the rapid spread of the fire and combustion products to the escape routes taken by these men.

The fire started during the movement of a continuous mining machine along the haulageway on a Saturday maintenance shift when the machine boom came into contact with the trolley wire, causing a flash fire around 7:30 pm (T start). Fire fighting with local extinguishers began immediately, but was ineffective. Trolley wire voltage was not disconnected for several minutes after fire initiation. Initial communication with the dispatcher was attempted almost immediately after fire initiation via the towing locomotive's trolley carrier phone. No reply was received.

Five to ten minutes later (T report-1) the dispatcher was informed of the fire from a nearby pager phone, and of the need for additional help. It was not until 8:00pm, about half an hour after fire initiation, that the dispatcher was told by pager phone to inform the miners in the inby A-2 section to expect smoke on the A-2 section, and to remain near the pager phone (T report-2). No information was relayed as to location of the fire or direction from which the smoke was coming.

At approximately 8:15, the man on A-2 section informed (T report-3) the dispatcher of the worsening smoke situation, and at that time (T alarm-1) was told by the dispatcher to leave the mine. However, the dispatcher did not give the man on A-2 any details concerning the fire, nor did he ask the miner of his intended direction of travel out of the mine.

At approximately this same time (T report-4), a vehicle operator on inby Section A-3 informed the dispatcher of loss of trolley wire power. At about 8:30 pm (T alarm-2), the foreman called A-3 section from the pager phone outby the fire to ask if miners on A-3 had detected smoke. Upon reply that no smoke was detected, they were told to assemble all the men with their self rescuers, and to leave the mine immediately by way of the returns escapeway. All miners still at the fire location exited the mine at about 8:45 pm because the fire went out of control.

The reasonable conclusion of the investigating team was that the work crews in the inby Sections A-2 and A-3 would have escaped to safe areas through established escapeways if they had received timely and adequate instructions to evacuate. However, the time the men were told to leave, the fire had burned to the point where the integrity of the escapeway system may have been destroyed, thereby trapping the miners from Sections A-2 and A-3.

The rapid spread of the fire was caused by two factors. The first was the high percentage of volatile matter in the Pittsburgh coal seam. The volatility ratio was .46 as compared to .12 which is considered high. The second was the 6 to 10 inches of coal left on the roof to support the unconsolidated carbonaceous shale above the coal. This top coal burns very rapidly, and was a major factor in the rapid advance of the fire into surrounding areas such as adjacent entries and escapeways. This coal was ignited by the burning lubricants and hydraulic fluids on the mining machine, which were ignited by coming into contact with the trolley wire.

A key observation from the standpoint of communication cable survival for this mine was the fact that the pager phone system integrity was maintained at least one hour after the start of the fire; right up until the general alarm and escape command was given to all miners inby the fire location. From the report text, without the aid of a map, we deduced that the pager phone line was installed on the wide side of the track haulageway, as is a common practice in mines. Therefore, the cable survived in the haulageway in which the fire occurred and developed during this period. The investigative report gave no other indication that further communications were attempted either to or from the miners in sections A-2 and A-3 after they were given the alarm to evacuate. The miners from Section A-3 were found dead with their self rescuers on in the No. 8 heading return air escapeway between Sections A-2 and A-3 along 3-North main inby the fire. The miners from A-2 section were found dead along the A-2 section beltway nearly halfway out of the section.

The miners located directly inby the machine who were involved in the machine movement and fire fighting escaped from the inby area, when threatened by extensive smoke, by using a crosscut to a parallel entry to pass around the fire to the outby side of the machine. Heavy roof involvement of the fire occurred, resulting in roof collapse by Monday. The fire started on the Saturday evening maintenance shift, and all people were evacuated for the last time on Monday just after an explosion around 2 pm. The mine was eventually sealed.

In summary:

o The following key times were determined:

T start is known (at approximate 7:30 pm)
T detection = T start

T report-1 about 5-10 minutes after T detect (to dispatcher)

T report-2 about 30 minutes after T detect (to dispatcher and Section A-2)

T report-3 about 45 minutes after T detect (to dispatcher from Section A-2)

T alarm-1 about 45 minutes after T detect (to A-2 from dispatcher)

T report-4 about 45 minutes after T detect (to dispatcher from A-3)

T alarm-2 about 1 hour after T detect (to A-3 from foreman)

T evacuate about 1-1/4 hour after T detect (fire fighting team)

- The pager phone line survived in the fire haulageway up to, and for an unknown time after, the time (1 hour after T start) which all the miners inby the fire were told to leave the mine.

- The roof coal was heavily involved in the fire and was perhaps the region of the greatest concentration and spreading of the fire.

- Miners working in the sections inby, the fire would probably have been saved if an alarm to evacuate the inby areas had been given soon after report of the fire. Effective emergency response procedures need to be adopted by coal miners, and mine personnel need to be properly trained and drilled in these procedures.

B. SUMMARY OF MAJOR SECTION FIRE
NEMACOLIN COAL MINE FIRE ON 3/26/71

This was an electrically initiated fire which resulted in three (3) fatalities and no injuries. The fire occurred in a development section on 118 'Mains Straight', and required that the miners on two threatened sections be given an alarm to escape. The sections included the one in which the fire occurred, and the adjacent section called 118 'Mains Left' perpendicular to 'Mains Straight.'

The fire started unnoticed within 2-1/2 hours of start of the morning shift, in a section track entry containing an air compressor. This entry was 2 entries away from a track entry with loaded cars, and 3, 4, and 5 entries from miners operating roof bolting equipment and operating a continuous miner. Detection of the fire may have taken long, perhaps as long as 2-1/2 hours or as short as 1/4 to 1/2 hour. However, once discovered, its presence was reported to the dispatcher via the pager phone at the junction of 'Mains Straight' and 'Mains Left' within minutes.

The dispatcher was informed of the fire, was requested to send additional help, and was told to inform workers in the adjacent 'Mains Left' section to leave the mine (which they did safely). DC power was cut off to the fire area via two trolley wire cut-out switches within minutes of the discovery by the section foreman. Workers in the section with the fire were also informed and directed to exit the section within minutes of fire discovery; with the exception of a roving mason, whose location in the section was unknown. (He was later found dead in an entry on the opposite side of the fire from the rest of the men.) This on-section alarm was made by voice and personal contact with each individual.

None of the three fatalities were caused by failure to use, or non-performance of, the pager phone communication system in existence at this time. However, if an emergency warning system utilizing a howler siren-type alarm incorporated in the pager phone system had been installed, even the roving mason might have been alerted and possibly saved. The second fatality occurred because one of the roof bolt operators, once safe, returned to his machine to retrieve his flame safety lamp before escaping. He never returned. The third fatality, by drowning, occurred several days later during flooding and sealing operations.

The clue leading to fire discovery at this mine was loss of air pressure by the roof bolt stopeing machine located three entries away from the air compressor. Once smoke was subsequently discovered in the number 2 entry by the stoper operator, the effects of the fire, particularly in terms of smoke (initially yellow in this case) and other combustion productions, spread rapidly through the section. This created a very hazardous situation requiring the evacuation of all section personnel before ascertaining the final location of the mason.

Though there seems to be some questions as to the exact cause of the fire, it appears that the principal factor was the replacement of a 200 amp fuse on a trailing cable nipped to the dc trolley wire with a 300 amp fuse. This apparently led to the deterioration of the trailing cable to the compressor, and to the electrical failure of this cable and the mechanical/electrical failure of a trolley wire support near the nip point. These failures occurred during the morning shift. The 200 amp fuse had been replaced by a 300 amp fuse on the midnight shift of the previous day by another stoper operator.

The following key investigative observations were made regarding the nature of the fire and the survivability of trailing cables and power cables within the number 2 entry in which the fire started.

First, it was found that the fire was mostly concentrated along, or confined to, the roof areas of the entry, and had commenced between the nip point and the compressor. Burning was also indicated along the roof, and in some loaded coal cars, in the number 4 entry, and in the crosscuts between entries 3 and 4. Machinery and equipment in the fire entries did not reveal any signs of being on fire, another indication of the fire's confinement to the roof coal in the entries. This is further supported by the fact that sections of trailing cable and power cables suspended from the roof were destroyed by the heat and flame, while sections of cables on or near the mine floor showed no evidence of heat or flame. Evidence also indicated that control cables on a car spotter, presumably in entry 4, developed a short circuit due to the destruction of the cable insulation by flame and heat.

A final observation of importance is concerned with the hydraulic hoses on the compressor. The sides of the hoses facing the fire were charred and blistered, while the sides of the hoses facing away from the fire showed no evidence of charing or blistering. Similarly, sections of the hoses shielded from the fire by parts of the compressor were not damaged. We believe that the charing and blistering in these cases were caused by radiative transfer and not by contact with the flames.

In summary:

- The following key times were determined:

  T start of fire is unknown,
  T fire detection is uncertain (maybe as short as 1/4 to 1/2 hour, to as long as 2-1/2 hours after T start),
  T fire report to dispatcher was within about 10 minutes of initial detection,
  T alarm to men was within about 5 minutes of T report.

- The pager phone cable extending outby the 118 'Mains Left' and 'Mains Straight' junction phone survived up to and beyond the time (about 15-30 minutes after fire detection) when the miners left both threatened sections of the mine. Phone cable located close to the source of the fire on 'Mains Straight' section eventually burned, time unknown.

- The fire was primarily confined to (at least for some time), and spread by, the roof coal in the entries involved.

- A general alarm howler system might have saved at most one person.

C. SUMMARY OF MAJOR SECTION EXPLOSION
FINLEY NO. 15 AND 16 COAL MINES EXPLOSION ON 12/30/70

This was a coal dust explosion which killed 38 of the 39 men who were underground at the time. No. 15 and 16 are drift mines side by side, together forming a "T", each mine consisting of approximately 1/2 of a vertically bisected "T". The explosion was initiated in mine No. 16, at a boom hole being blasted for a load point on the left side of the top leg of the "T". The investigation showed 14 of the 17 men in mine No. 16 were killed instantly by the explosion, while 3 others may have moved a short distance of at most 100 feet from their work site before dying, presumably from asphyxiation or carbon monoxide poisoning. Nineteen out of the 21 men in mine No. 15 were apparently killed instantly by the explosion, while the other two may have moved a short distance of about 140 feet before dying, presumably from asphyxiation or carbon monoxide poisoning, shortly after the explosion. The lone survivor was located at the portal of the belt entry of the No. 15 drift mine. He was injured only slightly by the explosive force and debris coming from the mine.

Both blast and flame fronts occurred during this explosion. The primary damage was caused by the force of the blast. The forces involved from the explosion were substantial, blowing out a large number of concrete stoppings throughout the mine. The explosion forces extended throughout the whole mine workings and out the portals, while the flame front extended over approximately 80% of the mine workings. The top of "T" was about 1,750 feet long while the base of the "T" was about 2,000 feet long at this mine. Although not stated, it appears that the force of the blast would have ruptured or severed nearby communication cables in light of the substantial destruction observed by the investigating team. However, even if the communication cables did survive, the severity of the coal dust explosion was such that no miners survived to use them.

Self-rescuers were not carried by the men, however, 21 MSA one-hour self-rescuers were stored in a metal container in No. 16 mine. There were no self-rescuers stored in mine No. 15, but 16 of them were stored in a trailer on the surface. Investigation showed more than 60 concrete block stoppings were completely or partially blown out, equipment moved, belt-conveyor structures damaged, and explosion doors blown open.

The conclusion of the investigating team was that the explosion occurred when coal dust was thrown into suspension and ignited during the blasting of roof rock for a loading point (boom hole). Excessive accumulations of coal dust, and inadequate applications of rock dust, in parts of No. 15 and 16 mines permitted the explosion to propagate throughout both mines. The geometric configuration of the mines also allowed the forces to expand rapidly from the point of origin, and to become less intense while traveling toward the surface. Rock dust applications in the main entries assisted in damping the explosion as it traveled toward the surface. Evidence indicated that the flame front spread to within 23 pillars of the mouth of the drift mine, but extensive burning did not occur after the explosion.

In summary, this was a violent coal dust explosion that extended throughout this relatively small drift mine. Although not stated, we assume that the excessive forces would have destroyed communication cables in the vicinity of the explosion. Furthermore, if the communication cables had survived, the force of the blast was such that the instantaneous and near-instantaneous deaths of all miners would have prevented the use of such communication cables after this type of severe explosion. The lone survivor was located at the mine portal, and thus did not need to communicate via the mine pager phone cable.

D. SUMMARY OF A MINOR SECTION EXPLOSION SILTIX COAL MINE EXPLOSION ON 7/23/66

This was a methane gas explosion that claimed the lives of seven out of the eight men working on a development section at the end of 2-Left Mains of the Siltix mine. The layout of this part of the mine can be visualized as a crucifix-shaped cross formed by 2-Left Mains, and the 6-Left and 6-Right working sections perpendicular to 2-Left Mains, with the 2-Left Mains development section forming the top part of the cross.

The flames extended about 700 feet beyond the explosion ignition source in 2-Left Mains section, down to the beginning of the junction between 2-Left Mains and the 6-Left and 6-Right sections. The explosion forces extended to about 1700 feet beyond the ignition source, but were greatly attenuated after reaching the junction of the 6-Left and 6-Right sections. All evidence indicated that the explosion was a relatively weak methane gas explosion. Coal dust entered into the explosion's propagation only to a minor degree. The explosion was caused by ignition of a body of methane by an electrical spark from a shuttle car trailing cable during the morning of a normal day shift. Men working on both 6-Left and 6-Right sections communicated with the mine superintendent who was located at the underground motor pit, via the mine pager phone line which remained intact during and after the explosion. A miner shoveling coal onto the belt at the junction of 2-Left Mains and 6-Left section was blown over by the blast and tossed about 60 feet. Upon recovery, he moved to the 6-Left junction pager phone and also notified the mine superintendent of the occurrence.

Miners on 6-Left section felt an unusually strong blast of wind, and saw dust suspended in the air afterwards. The mine foreman, who was on the 6-Left section, instructed the 6-Left section foreman to assemble his men at the section phone while he attempted to learn what had happened. Once assembled at the phone, communication was established via pager phone with the mine superintendent, who asked the section foreman to ascertain what happened. The section foreman walked outby the phone about 1000 feet, returned after he noted nothing unusual, and recalled the superintendent. The superintendent informed the section foreman of the explosion in 2-Left Mains, and instructed him to take his crew out of the mine by the 6-Left fresh air entry. These men encountered smoke approximately 1000 feet outby the phone, and switched over to a return airway, where they also encountered smoke upon reaching the No. 1 entry of 2-Left Mains. Their escape being blocked, they returned to a suitable place in No. 2 entry of 6-Left section, and constructed a barricade in a crosscut. Eleven men entered the barricade, where they remained until they were rescued in good condition approximately 45 minutes later.

The section foreman and 10 men working on 6-Right section were not affected by the explosion. This crew was instructed from the surface by pager phone to deenergize their equipment and come to the surface, which they did. They arrived at the surface without incident shortly before the miners in 6-Left section barricaded themselves.

Only one miner survived on the section where the explosion occurred. The four men nearest to the explosion were badly burned and died quickly. The lone survivor, a shuttle car operator, was found by the rescue team about 200 feet from the explosion lying on the ground behind his shuttle car. After the initial blast and flames, the section did not burn very much, which accounts in part for the miner's fortunate survival. However, in spite of his survival, he was in no condition to utilize the section's pager phone communications, if it had also survived (unknown).

As the superintendent proceeded towards 2-Left Mains after being informed of the explosion, he encountered smoke and dust about 500 feet inby the mouth of the 2-Left Mains. This smoke and dust became extremely dense as he approached the affected sections. Therefore, the chief electrician was sent to the mouth of 2-Left Mains to deenergize all power circuits. The superintendent and other miners then advanced to the 6-Right junction, and continued to reestablish the ventilation on their way to the affected sections. The last body of the victims was found around 5 p.m. the day of the explosion, and all bodies and members of the recovery crew were removed from the mine by 6:15 p.m.

In summary, this was primarily a weak methane gas explosion caused by electrical sparks together with bad ventilation which resulted in a gas build up in the face area. The main forces and flame effects were essentially confined to the section. Pager phone cables outside the section were not destroyed, thereby allowing communications to and from adjacent sections 6-Left and 6-Right by mine supervisory personnel. These communications allowed the men in those sections to be alerted and instructed to leave the mine shortly after the explosion. No mention was made of the survivability of communications within the section where the explosion occurred.

This is an example of an explosion which kills or incapacitates all miners on the section where it occurs, but whose destructive effects remain essentially confined to that section. Thus, miners and communication equipment outside the section may not be threatened, at least initially, and are able to function in a way that permits effective alert and escape activities. However, survivability of the communication facilities within the explosion section becomes moot in cases such as these when no miners are alive or able to use them.

APPENDIX IV

METHODOLOGY FOR CALCULATING CABLE BURIAL DEPTHS FOR ADVERSE ENVIRONMENTS

The practical feasibility of cable burial depends to a large extent on the burial depth required to protect the cable from the adverse physical environment of fire and explosions. In the early phase of this study, we outlined a methodology for determining this burial depth as a function of the physical environmental conditions in the tunnel.

During the course of the study, however, we found that the survival time over which the cable must function was not defined, and had to be estimated from a detailed review of historical mine accident reports. Secondly, it became increasingly evident that the overall need for cable burial was questionable. Accordingly, it was necessary to direct more of the effort towards assessing the specific needs, if any, for cable burial or for some less dramatic form of cable protection.

This appendix summarizes the approach or methodology we formulated for defining cable burial depths to achieve various degrees of survivability under different environmental stress conditions. This methodology can be used and integrated into a detailed cost/benefit analysis that the Bureau of Mines may wish to undertake in the future concerning cable protection.

A. APPROACH

The methodology is discussed for the case of thermal stress from a fire. It can also be applied to different types of stress from an explosion and from normal operating environments.

In fires, the heat output builds up to a maximum value and then decreases as the fire burns out. Some of this heat is transferred to the mine floor and is transmitted through it to a buried cable. As the cable insulation is heated, it may undergo physical and chemical changes depending mainly on the temperature reached. The burial depth, at which the cable will remain functional, can be determined as follows:

First, one can characterize the thermal exposure expected from various types of fires that may occur in mines. For each fire, this can be represented as a constant heat flux level imposed over a given duration. The magnitude of the heat flux can be obtained from the experiments conducted by PRC, and its duration from review of MSHA accident data. Note that each fire type may be associated with a range of heat fluxes and exposure durations. This is illustrated in Figure IV-1, where we indicate qualitatively the region where each fire type may be plotted. The indicated fire categories, which are described in the following section, were obtained from PRC mine fire investigators.

Second, one can characterize the thermal endurance response of the cable to these thermal exposures, for various burial depths or other means of protection. This is portrayed qualitatively by three curves for three burial depths in Figure IV-1. Each curve gives the maximum exposure duration that can be withstood without cable functional damage, for a given heat flux impinging on the mine floor. These curves can be obtained by a heat conduction analysis through the mine floor material to the cable, along with a criterion for functional damage of the cable insulation. This criterion may be the melting of the insulation, or some other manifestation of the thermal aging process. The primary thermal aging mechanism is oxidation for most materials used in mine communication cables.

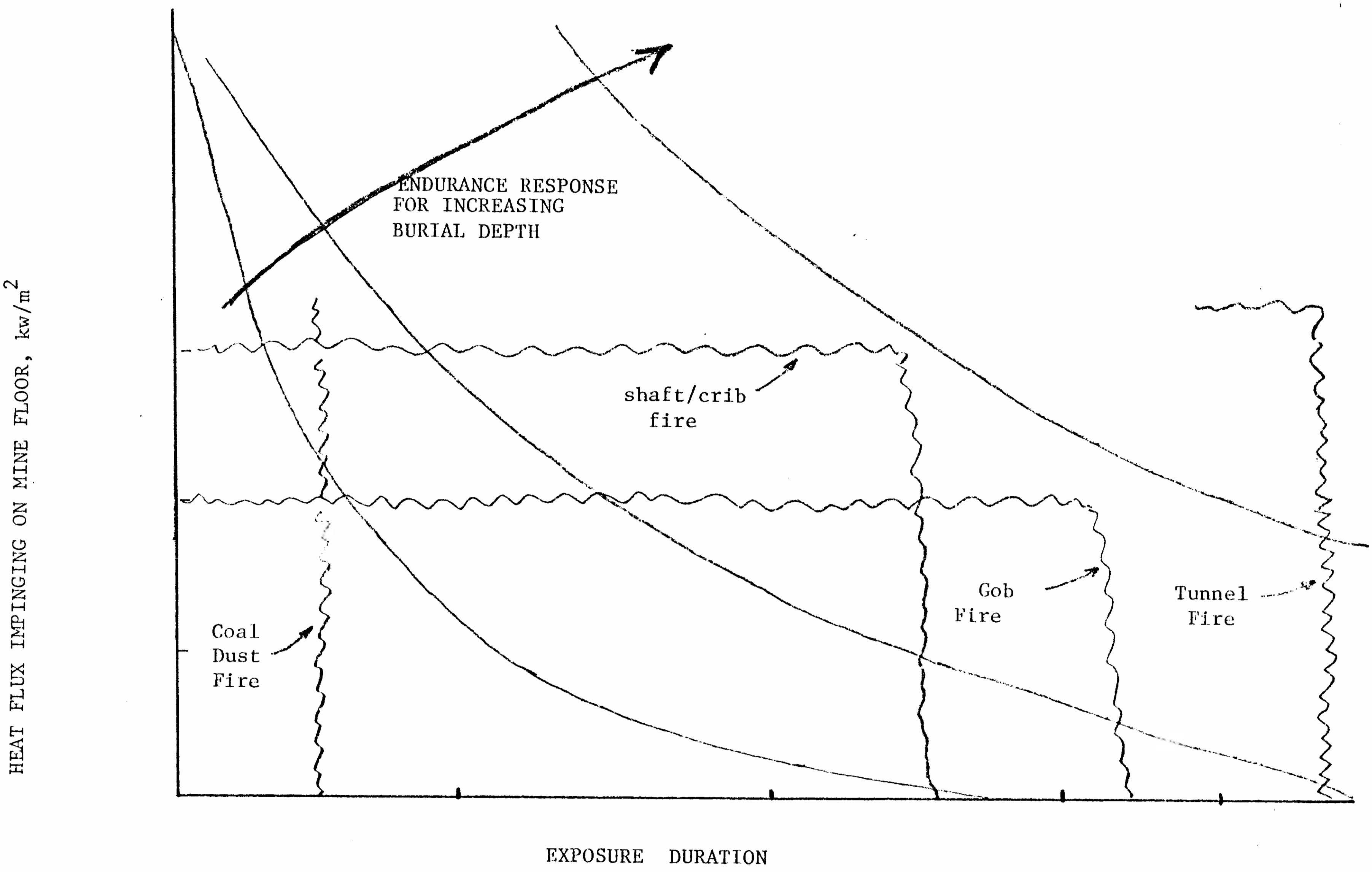


Figure IV-1 Qaulitative Characterization of Buried Cable Thermal Exposure and Endurance

Third, by comparing the thermal exposure and the cable endurance, one can determine the minimum burial depth required for each fire type. Note that a feasibility index (such as cost) can be attached to each burial depth curve. Furthermore, a probability estimate may be associated with each fire type or heat flux--duration level. This could be obtained from review of detailed accident data. Thus, cost and benefit could be traded off using Figure IV-1 or some modification thereof.

B. PHYSICAL CHARACTERIZATION OF FIRES AND EXPLOSIONS

We had a number of discussions with the staff of the Bureau of Mines associated with mine fire and explosion physics. These discussions identified the major categories or types of mine fires/explosions for which experimental data have been obtained.

- A gob fire involving a heap of mixed coal, wood and other materials, formed by roof collapse.
- A shaft fire involving the wood structure of an air shaft.
- A tunnel fire involving the coal.
- A crib fire involving the wood cribs which support the roof.
- A methane explosion.
- A coal dust explosion.

The Figure IV-1 sketch provides a qualitative comparison of the fire categories with respect to the relative ranges of expected flux levels and time durations.

We collected and reviewed various reports describing comprehensive experimental investigations at the Bureau of Mines for these fires/explosions (Ref. 1-9). In these investigations, the heat flux from the fires has been measured or estimated. A heat flux value that is often quoted for a tunnel fire that is well developed is 2 cal/cm^2 (80 kW/m^2), a severe thermal environment. For explosion tests utilizing natural gas (mainly methane or natural gas/coal dust mixtures, unsteady deflagration was observed. The maximum static pressure and wind speed reached in these tests were approximately 20 psi and 800 fps, respectively. This could subject the cables to a severe mechanical stress.

The frequency distribution of the duration of actual mine fires is shown in Table IV-1 obtained from data in the Allen Corporation study.* Note that approximately 65 to 70% of the fires last 4 hours or less. In recent years only about 20% lasted more than 24 hours. This gives some reference points for the required duration of cable survival (if survival is needed). In reality, the required cable survival time depends more on whether, and how long, affected miners are endangered. Thus, it can be significantly different from the values in Table IV-1. Finally, duration of the pressure pulse in an explosion is on the order of a second, and the need for cable survival also depends on the presence of surviving miners in the vicinity of the explosion. Therefore, more realistic information on the need for cable survival and the corresponding survival durations had to be obtained by analyzing the emergency activities and fire and explosion dynamics described in MSHA accident reports (see Appendix II).

C. THERMAL PROPERTIES OF CABLES

The thermal endurance of communication cables depends on the thermal aging of the cable insulation materials. Many cables used in

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* Op.cit, Appendix I.

TABLE IV-1

FREQUENCY DISTRIBUTION OF VARIOUS MINE FIRE DURATIONS*

Duration	1970 - 1977 No.	1970 - 1977 % of Total	1970 - 1977 Cumulative % within maximum time**	1953 - 1977 No.	1953 - 1977 % of Total	1953 - 1977 Cumulative % within maximum time**
0 - 1/4 Hr.	28	21.7	23	118	12.0	16
1/4 - 1/2 Hr.	12	9.3	33	83	8.4	28
1/2 - 1 Hr.	11	8.5	42	100	10.1	42
1 - 4 Hrs.	28	21.7	65	206	20.9	70
4 -24 Hrs.	15	11.6	77	131	13.3	88
24+ Hrs.	28	21.7	100	86	8.7	100
Unspecified or Unknown	7	5.4		262	26.6	
TOTALS	129	100%		986	100%	

*Source: Allen Corp. Final Report, Vol I. 15 Feb. 1979, and Arthur D. Little, Inc.

**The frequencies of the fires of known duration have been proportionally increased to include the fires of unknown durations.

mines are constructed of materials that are prone to aging by oxidation at elevated temperatures. These materials include cellulose, rubber, polyvinyl chloride, polyvinyl acetal, acrylic resins, and polyamides.

The IEEE has established a thermal classification system for insulating materials that is shown in Table IV-2. The class assignments are based on the results of thermal aging tests. The temperature for each class indicates the operating temperature limit for which the material will achieve an expected lifetime. As the temperature rises above this value, the cable lifetime will generally be shortened according to the logarithmic relationship:

$$\text{Log } L = A + B/T$$

where

L = life in hours

T = absolute temperature in °K

A, B are constants.

Mine communication cables are likely to fall into classes 0, A and B, with Class A (105°C) probably being the most representative. Saums and Pendleton (Ref. 10) indicate that the average life of a Class A insulating material, with a 20,000 hour lifetime at 105°C, will decrease to about 100 hours at 200°C and 10 hours at 250°C. The figure shows that the life of even the highest rated Class C materials (> 250°C) plummet to about 10 hours at temperatures around 350°C.

This brief discussion on the thermal response of cable insulation has been included to indicate an approach and resources for defining criteria for cable functional failure that can be applied in the methodology described in Section A of this Appendix.

TABLE IV-2

IEEE THERMAL CLASSIFICATION SYSTEM

Class	Temperature °C	Applicable Materials
Class 0	90	Unimpregnated cellulose
Class A	105	Polyvinyl acetal, polyurethane, impregnated cellulose, polyamide
Class B	130	Epoxy, polyester glass (styrene type) phenolic glass
Class F	155	Terephthalate polyester, modified silicone
Class H	180	Silicone, silicone glass, silicone rubber, ester-imide, cyanurated terephthalate polyester
Class 200*	200	Amide-imide overcoated ester-imide, amide-imide overcoated polyester
Class 200**	220	Amide-imide, polyimide, high-temperature polyamide fibers †
Class C	250+	Polytetrafluoroethylene, glass, ceramics

Source: Saums, H. L. and Pendleton, W.W., "Materials for Electrical Insulating and Dielectric Functions, Hayden Book Co., N.J., 1973.

*U.S. Navy-designated as Class K.

**Industry-designated as Class M.

† DuPont's Nomex

D. OPERATIONAL CONSIDERATIONS

Our interviews with several government and industry mining personnel revealed some practical operational considerations that are briefly summarized below. The objective is a survivable communication link for emergency communications with endangered and/or trapped miners and with mine rescue/recovery teams, in post disaster environments. An important parallel objective, of course, is its availability and practicality for daily operational communications.

In practice, it was felt that two to three hour cable survival times for communicating with endangered/trapped miners in fire and explosion environments would meet most needs. This is not inconsistent with most of the preliminary estimates of miner survival time tabulated in Appendix II. As suggested in Appendix II and the body of this report, additional protection is not generally needed, and burial may not be the most practical way to obtain whatever short-term protection may be needed. For extended duration communications among the rescue/recovery team members and between these and the surface, a system that is not totally dependent on the mine pager phone system appears to be the most realistic. Recent Bureau of Mines sponsored developments in portable medium frequency radio communications may provide the best equipment for meeting the needs of mine rescue/recovery teams. This possibility should be investigated.

To satisfy daily operational needs, the pager phone communication link must have a high availability, practical maintainability, and reasonable installation and operating life time costs. Communication cable burial will cause some increases in installation costs, depending on burial depth, quality of cable needed, and floor material, and some changes in maintenance costs. Since 60-70% of the mining operations in Appalachia are smaller than 70,000 tons per year, any cable protection guidelines dramatically different from current mine practice should be checked for their economic impact on such mines.

The following paragraphs present some summary considerations of the effects of cable burial on both the cable and the mine tunnel. The MSHA Roof Control and Geotechnical Services groups provided us with information on mine roof movement and mine opening stability of interest to cable burial.

They are not sure if a trench in the middle of an entry would adversely effect roof control stability. They tend to think that a shallow trench on the order of 18 to 20 inches would probably have no major effect. It could, however, initiate bottom movement by relieving certain counter-balancing lateral forces which surround the mine opening. There would be three types of movement which would effect the cable: offsets, vertical thrust vaulting, and squeezing. They feel that the actual degree of movement would be very unpredictable and that there is a strong need for additional study before any buried mine communication systems are considered feasible. Apparently, 10% of the coal mines in the United States have minimal bottom movement, 10% have excessive bottom movement, and 80% have bottom movement present, but its magnitude is undefined and needs to be further studied.

MSHA staff also provided information that shows roof movement is very active ten to fifteen days after the opening is made. There is an exponential time/movement relationship within the first week of mining. These movements are very localized and suggests that cable stretchability will not be an important design factor. In their opinion, the further the communication system lags behind at the initial development, the more stable the environment will be and the less likely that the cable will be severed or pinched. Using the typical figure of 100 feet of face advancement per week, this could prevent cable burial within up to about 4-6 crosscuts. This creates some serious problems with regard to the objective of communicating with miners trapped in face areas, and raises questions such as: Would a buried mine communication cable be of any use to workers operating in a face area 100 to 250 feet from the last cable terminal post? Would a communication line from the last permanent terminal post to the working area be any more reliable than a simple two-wire phone system typically in existence in most mines? Even if the cable is buried, will the unburied phone survive? There is also the problem of keeping the cable at the face. How will the cable be extended to the working area during advance mining without using numerous splices? The complexity of the splices and the need for secure watertight connections could have a severe impact on the reliability of the system.

The importance of keeping the cable back from the face area was illustrated by analytical data shown by the roof control people. One question arises as to whether the roof's movement is a rough approximation to movements in the floor. At the present time, no one has taken the time to drill bore holes into the floor to study its movement, to see if there is a correlation between floor and roof movement. Based on the distribution of forces, one might roughly assume that the same time/movement relationships exist in the floor. If so, this suggests a need to lag cable burial by ten to fifteen days (200 to 300 ft) behind the active face area.

We also obtained comments on a number of issues concerning potential movements in the roof and floor as a result of the trenching activity. One could expect minimal impact with regard to mine opening stability if the trench is less than 24 inches deep, but crushing of the cables should be expected to occur during the life of the phone system. The possibility was also pointed out that existing fracture fault systems might be activated locally by trenching, and that additional research is needed to evaluate this possibility. Thus additional work should focus on the time distance relationship between the face, time of mining, and the resulting adjustments in the roof, the rib and the floor.

In summary, there may be major problems associated with advancing buried cable to the face area where the men will probably be when an explosion occurs. If roof movement is a close approximation to what can be expected for the floor, movements can be expected for ten to fifteen days after a face is mined. Using an average face advance of 100 feet per week, there is a major question as to whether the phone system will be available at the face where it might be needed in an emergency. Splicing, to keep the system moving with the mine advance, will almost certainly result in decreased system reliability. The potential problem of reactivating local and regional fault systems which cross through the mine opening needs additional research to evaluate this possibility.

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