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Review of Fire Test Methods and Incident Data for Portable Electric Cables in Underground Coal Mines

Emil Braun

Center for Fire Research
National Engineering Laboratory
U.S. Department of Commerce
National Bureau of Standards
Washington, DC 20234

June 1981

Final Report

Sponsored by
U.S. Bureau of Mines
Pittsburgh, Pennsylvania 15213

ıe Safety and Health Administration
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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

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REVIEW OF FIRE TEST METHODS AND INCIDENT DATA FOR PORTABLE ELECTRIC CABLES IN UNDERGROUND COAL MINES

Emil Braun

Abstract

Electrically powered underground coal mining machinery is connected to a load center or distribution box by electric cables. The connecting cables used on mobile machines are required to meet fire performance requirements defined in the Code of Federal Regulations. This report reviews Mine Safety and Health Administration's (MSHA) current test method and compares it to British practices. Incident data for fires caused by trailing cable failures and splice failures were also reviewed. It was found that the MSHA test method is more severe than the British but that neither evaluated grouped cable fire performance. The incident data indicated that the grouped configuration of cables on a reel accounted for a majority of the fires since 1970.

Key words: Coal mines; electrical cables; fire incidents; fire tests; test methods; trailing cables.

1. INTRODUCTION

At the request of the Mine Safety and Health Administration (MSHA) and the Bureau of Mines (BOM), the Center for Fire Research at the National Bureau of Standards initiated a review of current practices for the certification and approval of portable electric (trailing) cables for use in underground coal mines.

Underground coal mining machinery is generally electrically driven. Mobile machines, not battery powered, are connected to a load center or distribution box by portable electric (trailing) cables. These cables are stored on cable reels mounted on the mobile machinery. The cable reels are designed to maintain positive tension on the trailing cable during reeling and unreeling operations as well as to form an interface between the cable and the machine. According to the Code of Federal Regulations [1][1], trailing cables must (1) have current carrying capacities consistent with the Insulated Power Cable Engineers Association standards and (2) exhibit flame-resistant properties. Cable lengths are limited to a maximum of 500 feet. Longer cable lengths are permitted, but under reduced maximum current loads.

MSHA permits the use of temporary splices in trailing cables provided that they are made in a "workmanlike manner" and are mechanically strong and electrically insulated. Splice kits are provided by manufacturers for this purpose. The materials used in these kits must also meet the same fire test requirements imposed on trailing cables. The maximum number of temporary splices permitted in a single length of trailing cable is not made clear by the regulation. There are two references in Title 30 of the Code of Federal Regulations regarding the number of permitted splices in a portable (trailing) cable. The Code of Federal Regulations state in section 18.35 paragraph 8 that a single length of portable cable may not have "more than five well made splices." Section 75.603, however, states that any trailing cable may not have more than one temporary splice.

This report reviews MSHA's current test method and compares it to British practices. Incident data for fires caused by trailing cable and splice failures are also reviewed.

2. TEST METHODS

Many countries require fire testing of electrical cables as part of their qualification for use in underground mining. However, since some incident data are readily available for British underground coal mining operations, their test method was selected for comparison to MSHA test procedures. Both the United States and the United Kingdom perform fire tests on the original cable, but, because MSHA allows a trailing cable to have not more than five temporary splices, splicing materials are also tested for fire resistance. The British do not permit mine operators to use temporary splices in trailing cables.

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[1] Numbers in brackets refer to the references at the end of this report.

2.1 MSHA Test Method

The test for the flame resistance of cables is described in section 18.64 of the Code of Federal Regulations, Title 30. In performing the test, a 914 mm (3 ft) length of cable is horizontally mounted in a rectangular enclosure 432 x 368 x 991 mm (17 x 14-1/2 x 39 in) and, after preheating the conductors to 204°C (400°F) with an electric current, the cable is exposed to a premixed methane flame from a Tirrell burner for 1 minute.

The test requires that two out of three specimens either self-extinguish within 4 minutes or that the burn length be less than 6 inches.

The test procedure is divided into three parts: (1) Test specimen preparation and mounting; (2) Preheating of the specimen; and (3) Flame exposure.

2.1.1 Specimen Preparation

A single cable specimen 914 mm (3 ft) long is placed on a supporting rack composed of three asbestos-covered metal rods. The rods are spaced such that 406 mm (16 in) are between the left and center rods and 203 mm (8 in) are between the right and center rods. For a single conductor cable, the free conductor ends are connected to a source of electric current. Multiconductor cables are wired so that all conductors are in series. The free ends are then connected to a low voltage, high current power supply.

Conductor temperature is monitored by placing a thermocouple in contact with one of the conductors in a cable. The thermocouple is located 660 mm (26 in) from the left end of the specimen. This is accomplished by slitting the insulation down to a conductor and forcing the thermocouple into it. The insulation is then replaced and bound over the thermocouple.

Splice kits are tested by assembling a suitable approved cable with the splice kit and testing the assembly according to the flame-resistance test for cables.

2.1.2 Preheating

This test method uses an electric current five times the conductor rating to preheat the test specimen. The current is applied to the cable specimen until the instrumentated conductor has reached 204°C (400°F) at which time the external flame source is applied. Since the applied voltage is not defined, low voltage high current sources have been employed. Initially, MSHA used an autotransformer to apply A.C. current to the cable specimen. Currently, MSHA uses a constant current low voltage D.C. source. Full power is applied to the cable specimen at the start of the test. The rate of heating is controlled, primarily, by the cable's thermal inertia.

2.1.3 Flame Exposure

The test method employs a Tirrell gas burner as an external ignition source. The burner is adjusted to produce an overall flame height of 127 mm (5 in) with an inner cone height of 76 mm (3 in). The distance between the top of the burner and the bottom of the cable specimen is 76 mm (3 in). The type of gas is not defined, but MSHA currently uses a fuel source that contains 93 percent methane.

After the cable has been preheated to 204°C (400°F), the flame is applied to the lower surface of the cable 356 mm (14 in) from the left end for 1 minute. At the end of this exposure period, the burner is withdrawn and the current is disconnected.

2.2 British Test Method

The British test for resistance to flame of trailing cables for mining purposes is described in BS 708 [2], with reference to BS 738 [3]. As in the MSHA test, BS 708 tests a horizontally-mounted cable specimen exposed to a laboratory burner. The exposure time is 5 minutes. A sample is considered self-extinguishing if flaming ceases within 30 seconds of removal of the exposure source and the total length of damaged cable does not exceed 152 mm (6 in).

2.2.1 Specimen Preparation

A 305 mm (12 in) long specimen of finished cable is held horizontally (the method of mounting is not described) in a metal enclosure--914 mm (36 in) high, 457 mm (18 in) wide, and 305 mm (12 in) deep. No additional preconditioning or preheating of the cable specimen is required.

2.2.2 Flame Exposure

The Barthel burner described in BS 738 is used as the ignition source in this test method. This is a spirit burner using industrial methylated spirit (alcohol) as the fuel. The flame height is correctly set when a bare copper wire 0.71 mm (0.028 in) in diameter inserted into the flame 51 mm (2 in) above the top of the burner melts within 6 seconds.

For the actual test, the burner is positioned at an angle of 45° to the horizontal with the top of the burner 51 mm (2 in) from the bottom of the specimen. The flame is applied normal to the longitudinal axis of the specimen for 5 minutes.

3. INCIDENT DATA

A comprehensive collection of fire incident data for underground coal mines was obtained from the Allen Corporation [4]. This report contained an annotated bibliography of U.S. coal mine fire reports from 1950 to 1977, including MSHA incident reports. This study did not include explosions or fires that resulted from explosions. However, it did include fires that later caused an explosion. Since 1967, MSHA has defined a reportable fire incident as one in which (1) an individual is injured or killed or (2) the fire persists for at least 30 minutes from the time of discovery.

Several summary reports received from England were reviewed [5,6]. While not providing specific information on trailing cable incidents, gross comparisons were made between British experience and United States experience with electrical fires.

3.1 U.S. Coal Mines

Allen Corporation compiled records of a total of 1,019 underground coal mine fires that occurred between 1950 and 1977. Table 1 lists the sources of ignition of these fires and the frequency of occurrence. Electrical failures caused the largest number of fires, 63.3 percent, followed by frictional heating, 9.8 percent, and spontaneous combustion, 7.3 percent. On an annual basis electrical failures have accounted for a large fraction of the total number of underground coal mine fires. Table 2 shows that from 1950 to 1977 the fraction of electrical failures compared to all fires ranged between 43 and 73 percent. After 1970 improvements in fire safety performance have appeared across all aspects of mining, but the significance is unclear due to changes in the reporting requirements. These requirements were defined in the Federal Coal Mine Health and Safety Act of 1969. After 1969, reportable fire incidents were limited to those that either persisted for more than 30 minutes after discovery or an injury occurred. The total number of fire incidents caused by

Table 1. Ignition sources of underground coal mine fires in the U.S. -- 1950 to 1977

Ignition Source		Number of Incidents	Percentage
Electrical		645	63.3
Friction		100	9.8
Spontaneous		74	7.3
Welding/cutting		34	3.3
Explosives		17	1.7
Vandalism		12	1.2
Engine or clutch overheat		12	1.2
Open flame		10	1.0
Adjacent or surface fire		9	0.9
Other		6	0.6
Unknown		100	9.8
	Total	1,019	100

Table 2. Number of electrically caused fires in U.S. coal mines -- 1950 to 1977

Time Period	Electrical Failures	All Fires	Percentage for Electrical Failures
'50-'52	12	28	43
'53-'55	62	110	56
'56-'58	111	168	66
'59-'61	114	184	62
'62-'64	101	150	67
'65-'67	105	149	70
'68-'69	74	101	73
'70-'71	23	46	50
'72-'73	21	38	55
'74-'75	10	20	50
'76-'77	12	25	48

electrical failures has been consistently decreasing since 1967, along with the total number of all fire occurrences.

There were a total of 243 reported fire incidents in coal mines attributable to trailing cable failures (table 3) in the United States from 1950 to 1977. This represents 24 percent of all fire incidents and 38 percent of the fire incidents caused by electrical failures. Trailing cable incidents have been as few as one in the 1950 to 1952 period and as high as 51 during the 1956 to 1958 period. Since 1972, there has been an average of one trailing cable failure reported per year. Figure 1 compares the number of incidents of trailing cable fires and electrical fires to the total fire incident data from 1950 to 1977. While the total coal production in the U.S. during this period has remained constant, at approximately 300 million short tons per year [4], the total number of reported fire incidents has been declining since 1961.

Table 3 is a tabulation of the causes of trailing cable fires in U.S. coal mines from 1950 to 1977. Thirty-three percent of the failures were caused by defective temporary splices. Between 1970 and 1977, defective temporary splices accounted for 24 percent of the failures. In 29 incidents the splice failure occurred with the spliced section of cable wound on the cable reel. Electrical short circuits accounted for 26 percent of the total number of trailing cable failures. These were equally divided between the cable failing on the reel and cable failures on extended portions of the cable. Mobile machinery driving over trailing cables is also a frequent cause of cable failures--19 percent. However, since 1972, cases of fire resulting from machinery crushing a cable have not been reported. On the other hand, temporary splice failures resulting in fire have continued to occur.

Table 4 is a description of the amount of cable destroyed per incident. In 56 percent of the cases this has not been specified. The loss of an entire cable reel occurred in 15 percent of the cases. Of the remaining 29 percent of the fire incidents, 63 damaged cable lengths between 0.6 M and 120 M, while in five cases more than 120 M were lost. In only three cases was there less than 0.6 M lost. The data were divided into two categories--pre 1967 and post 1967. The data indicate that all fires involving very long cable lengths have been greatly reduced. From 1968 to 1977, only two cable fires destroyed 30 M to 120 M of cable and no cable fires have been reported to have destroyed more than 120 M of cable. A comparable reduction in the number of incidents involving very short lengths of cable was also noted. This reduction, however, may be due to the previously mentioned changes in reporting requirements.

Table 3. Causes of trailing cable fires in U.S. coal mines -- 1950 to 1977

	1950-61	1962-69	1970-77	Total
Defective temporary splice				
-- extended	35	16	1	52
-- reeled	5	21	3	29
Electrical short on cable				
-- extended	19	11	1	31
-- reeled	11	17	3	31
Machine crushed cable				
-- other	14	13	2	29
-- own	8	8	-	16
Overheated cable				
-- reeled	7	2	3	12
-- extended	5	1	1	7
Junction box short	4	2	1	7
Insulation failure (abrasion)	5	1	-	6
Roof fault	5	1	-	6
Defective permanent splice	-	1	1	2
Miscellaneous	2	3	-	5
Unknown	7	2	1	10
Total	127	99	17	243

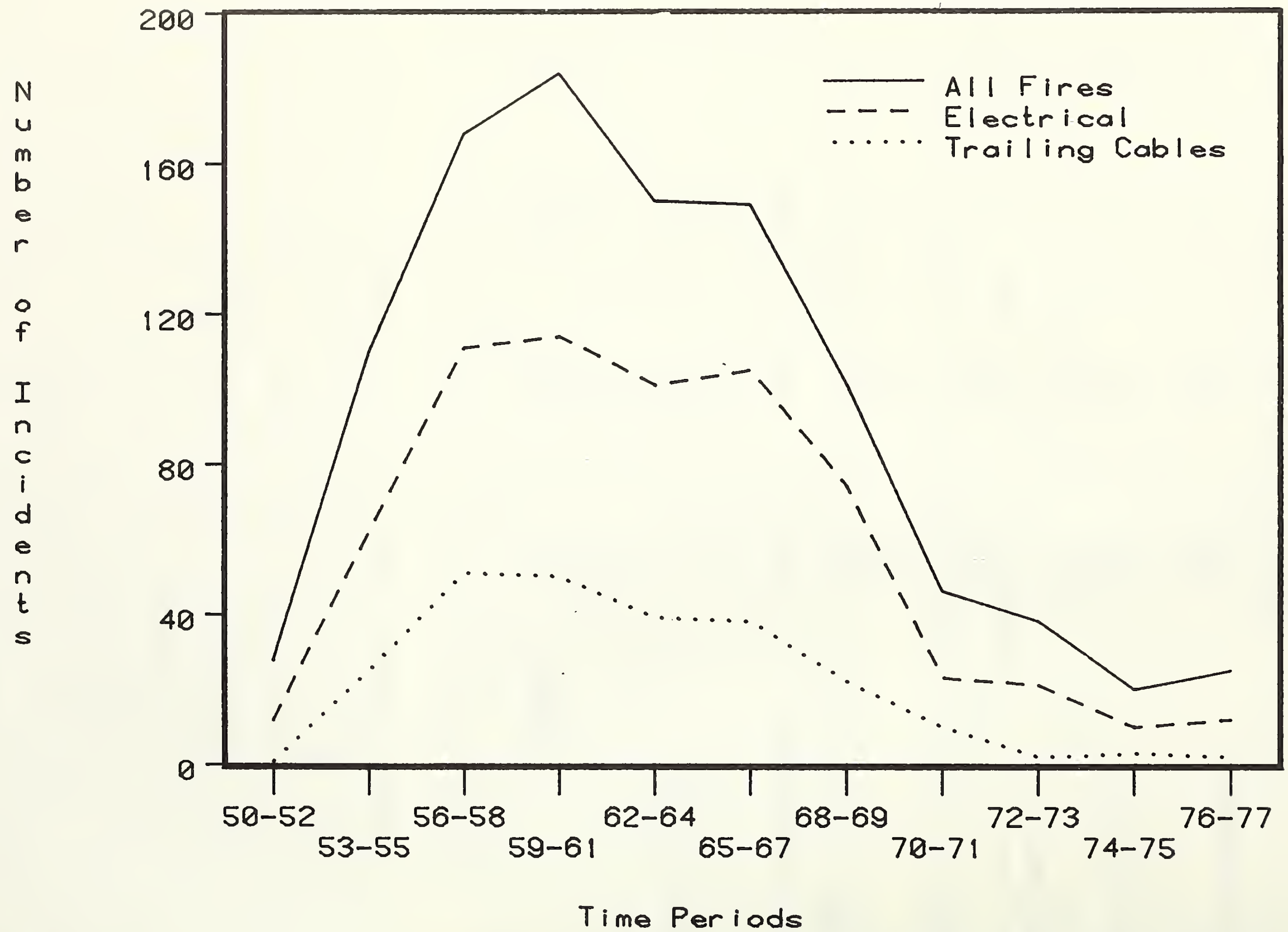

Figure 1. Comparison of trends for trailing cable fires, electrical fires, and all fires occurring in U.S. underground coal mines

Table 4. Length of trailing cable damaged by fire in U.S. coal mines -- 1950 to 1977

Length	1950-67	1968-77	Total
Less than 0.6M	3	-	3
0.6M - ≤3M	19	1	20
3M - ≤30M	13	5	18
30M - ≤120M	23	2	25
Greater than 120M	5	-	5
Cable reel	24	13	37
Not specified	117	18	135
Total	204	39	243

3.2 British Coal Mines

Several summary fire incident reports were obtained from Her Majesty's Chief Inspector of Mines and Quarries, London, England. The British reporting system appears to be more comprehensive, in that any fire incident is reportable. The summary reports all fire incidents from 1968 to 1975. These data are summarized in table 5. The number one cause of underground coal mine fires in England is the conveyor belt system. This is followed by electrical failures--21 percent. During the same period, the U.S. experience showed that 62 percent of all fires were electrical in origin while only 18 percent could be attributed to the conveyor system.

The British data indicate that they have large fluctuations in the number of fire incidents per year. Figure 2 compares these annual variations in the number of all fire incidents to the number of fire incidents per year caused by electrical sources. While electrically caused fires have varied from year to year, the variations have not been as great as seen in the total fire incident count. The British, unfortunately, do not classify trailing cable fires separately from other electrical fires. However, their description of several electrically caused fires do not appear to contain any involving trailing cables. Qualitatively, many of the British incidents appear to be due to arcing or overheating of the cable following the breakdown of insulation on electrical equipment.

4. DISCUSSION

The United States and British fire test methods for the evaluation and qualification of trailing cables expose a single length of cable to a small ignition source. The cable, held in a horizontal position, is exposed to an external open flame source. The U.S. test method appears to have a more severe exposure, even though the flame exposure in the British test method is five times longer. This is true because the U.S. test method has a preheating procedure that elevates the cable core to a steady-state temperature of 204°C (400°F). Heat losses from the cable's insulating jacket to its core are minimized. However, in the British test, the flame exposure begins with the cable at ambient conditions. This maximizes the heat losses to the cable core, increasing the time to bring the insulation to its combustion temperature. Because of this energy imbalance between the two test methods, it is difficult to assess the importance of the differences between their acceptance criteria. The United States permits after-flame times of up to 4 minutes, while the British limit after-flame times to less than 30 seconds.

Table 5. Ignition sources of underground coal mine fires in England -- 1968 to 1975

	Number of Incidents	Percentage
Conveyor belts	181	45.3
Electricity	84	21.0
Mechanical friction	38	9.5
Locomotives	33	8.3
Spontaneous	31	7.8
Explosives	7	1.8
Cutting/welding	6	1.5
Miscellaneous	6	1.5
Unknown	14	3.5
Total	400	100

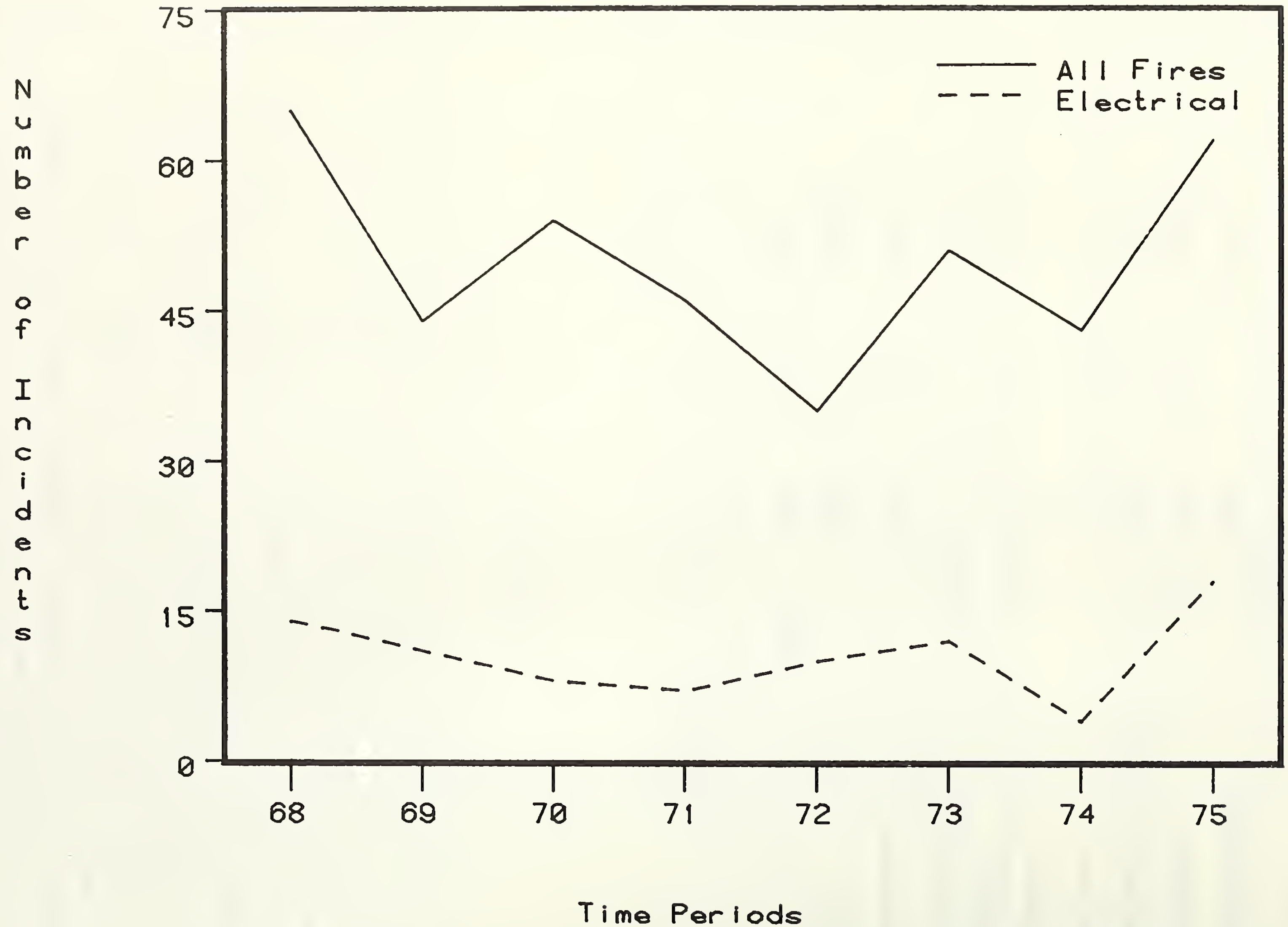

Figure 2. British coal mine fire experience, comparison of trends for all fires and electrically caused fires -- 1968 to 1975

Since the British do not allow cables to be temporarily spliced, they have experienced no fires caused by splice failures. In the United States, temporary splices are permitted and account for 34 percent of all the trailing cable failures prior to 1967 and 24 percent since that time. In a survey conducted in 1962, Williams and Devett [7] found that of 232 splices studied in the field only 3 percent had all the characteristics desirable in splicing techniques (i.e., mechanically strong, electrically insulated, flexible, and sealed against moisture). King, et al. [8], found that flexure testing of unspliced and spliced cables yielded a significantly lower life cycle to failure for spliced cables. For one cable type and splicing technique, their data also appear to indicate approximately a 50 percent reduction in life cycle to failure for field spliced cables as compared to laboratory spliced cables.

Early work by Ilsley and Hooker [9] involved the study of the heating of trailing cables. They recommended the derating of cable current-carrying capacity. In part, current MSHA ampacity tables are based on the work of Ilsley and Hooker. Hanslovan [10] recently investigated the causes of damage to trailing cables. He studied seven stresses that are placed on a trailing cable under field conditions. Among these stresses was temperature fluctuations. Hanslovan measured cable temperatures on reeled cables. He found that maximum reeled cable jacket temperatures measured underground could be in excess of 120°C (250°F). He did not measure the jacket temperatures in the vicinity of a cable splice. With the increased potential for high resistance shorts, larger temperature extremes should be expected. Lupton, et al. [11], demonstrated that flame propagation and char zone as well as after-flame time increase with increasing cable temperatures. Yuwata and Nakada [12] showed that grouped cables produced higher temperatures than single cables and ignited more readily. Cables on a cable reel should perform in a similar manner.

5. CONCLUSIONS

(1) In a comparison of United States and British test methods, the U.S. test procedure appears to be more sensitive because of preheating requirements.

(2) The incident data indicates that:

- The number of electrical fire incidents involving portable cables as well as all fires in U.S. coal mines have been declining since 1967, and

- Since 1970, the majority of trailing cable fires have been caused by cable failures with the cable wound on a reel.

- The existing U.S. test is reducing the fire problem.

(3) The current test procedure does not appear to be able to predict grouped cable performance as found with a reeled cable. The presently utilized ampacity tables are based on individual cable performance in air. Conductor temperatures will exceed the rated value in a reeled configuration and insulation temperatures will be higher.

(4) The U.S. regulations are ambiguous with regard to the number of permitted splices in a trailing cable.

6. RECOMMENDATIONS

(1) Clarify current regulations regarding the number of permitted splices in a trailing cable.

(2) Develop ampacity tables for reeled cables.

(3) Develop a fire test for cable performance that evaluates cable performance while on the reel.

7. REFERENCES

[1] Code of Federal Regulations, Title 30, Section 18.64.

[2] British Standard 708, Trailing cables for mining purposes, British Standard Institution.

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[12] Yuwata, Z. and Nakada, T., Ignition properties of cables owing to overload current, Furukawa Denko Jiho, Vol. 62, pp. 79-91 (Japanese, English summary) (1977).

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

Electrically powered underground coal mining machinery is connected to a load center or distribution box by electric cables. The connecting cables used on mobile machines are required to meet fire performance requirements defined in the Code of Federal Regulations. This report reviews Mine Safety and Health Administration's (MSHA) current test method and compares it to British practices. Incident data for fires caused by trailing cable failures and splice failures were also reviewed. It was found that the MSHA test method is more severe than the British but that neither evaluated grouped cable fire performance. The incident data indicated that the grouped configuration of cables on a reel accounted for a majority of the fires since 1970.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Coal mines; electrical cables; fire incidents; fire tests; test methods; trailing cables

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