IC 9426

UNITED STATES BUREAU OF MINES
INFORMATION CIRCULAR/1995

Analysis of Underground Coal Mine Fire Incidents in the United States From 1978 Through 1992

UNITED STATES DEPARTMENT OF THE INTERIOR

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By William H. Pomroy and Annie M. Carigiet

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

in	inch	pct	percent
min	minute		

Quantities in this report are expressed in U.S. customary units of measure rather than the standard USBM practice of expressing quantities in metric units. U.S. customary units are used because the Federal agencies that compile coal mine production data used in this report (Energy Information Administration, U.S. Department of Energy; and Mine Safety and Health Administration, U.S. Department of Labor) provide this data only in U.S. customary units, and because the previous USBM report summarizing coal mine fire incidents in the United States from 1950 to 1977 (Information Circular 8830) also uses U.S. customary units. Users of this report are expected to compare, analyze, and evaluate data from this report and the other sources. Use of metric units in this report would therefore have required such users to perform extensive unit conversions.

ANALYSIS OF UNDERGROUND COAL MINE FIRE INCIDENTS IN THE UNITED STATES FROM 1978 THROUGH 1992

By William H. Pomroy[1] and Annie M. Carigiet[2]

ABSTRACT

This U.S. Bureau of Mines publication is an analysis of underground coal mine fire incidents occurring in the United States during the 15 years from 1978 through 1992. The fire data used in this analysis were obtained from U.S. Mine Safety and Health Administration mine fire investigation reports. Fires were analyzed by year, State, coalbed thickness, mine size, mining method, ignition source, burning substance, location, equipment involved, detection method, time of day, time of year, number of injuries and fatalities, method of extinguishment, and evacuation measures taken. In all, 164 fires are included in this report, or an average of 10.8 fires per year. The most fires occurred in West Virginia, Kentucky, and Pennsylvania, respectively. However, the fire incidence rates for these States, expressed as the number of fires per million tons of coal mined, were the lowest, second lowest, and fourth lowest of all underground coal producing States. The most common ignition source was electricity; the most common burning substance was coal; the most frequent fire location was the belt entry; the most common equipment involved in fires was the conveyor belt; and the most common extinguishing agent was water.

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INTRODUCTION

Underground fires represent a serious and constant threat to the safety of mine workers. Miners in the immediate vicinity of a fire must contend with intense heat, blinding smoke, toxic fumes, roof falls, and the other direct effects of a fire. However, the vast majority of victims never actually see the fire, succumbing instead to deadly fume-laden air or asphyxiation. The mine's ventilation system, which normally supplies fresh air to the workings, can transport smoke and fire gasses with equal efficiency. Additionally, the heat produced by a fire can significantly alter normal airflows and directions. Miners remote from a fire may be forced to evacuate through smoke and fumes. Sometimes a fire may block the escape route. Miners can become confused by unfamiliar ventilation system behavior and usually do not have knowledge of the fire's location. No peril is more feared by miners than a raging fire in the mine.

Efforts to improve mine fire safety have been a priority for mine operators, regulatory authorities, equipment manufacturers, research organizations, and others for many years, and significant progress toward reducing fire hazards has been achieved. Underground fires are now rare events, and injuries and fatalities caused by mine fires are at an alltime low. However, the threat of fire has not been eliminated entirely, and as long as combustible materials and ignition sources are present underground, the potential for disastrous fires will remain. Despite the recognized seriousness of the mine fire hazard and the industry's best efforts toward fire prevention, it is somewhat alarming to note that the number of fires per million worker-hours is higher in underground mines than in above-ground industrial occupancies (*1*).[3]

The U.S. Bureau of Mines (USBM), mining and mining-affiliated companies, academic institutions, and others have directed considerable research attention to reducing fire hazards in mining. A critical prerequisite to the development of a sound research strategy is up-to-date and accurate data describing and quantifying the industry's mine fire experience. Such data would also be useful for regulatory decision making, fire safety product marketing, development of fire safety training programs, and similar purposes.

In support of the above objectives, the USBM and other agencies have completed various analyses of coal mine fires (*2-4*). A comprehensive and detailed statistical analysis covering the period from 1950 through 1977 was summarized in USBM Information Circular (IC) 8830, "A Statistical Analysis of Coal Mine Fire Incidents in the United States From 1950 to 1977," which was published in 1980 (*5*). The most recent data contained in that report are now over 15 years old, and significant changes have occurred in the U.S. underground coal mining industry since then. As a result, the data in IC 8830 are of limited usefulness for assessing current mine fire problems. This current report was prepared as an update of IC 8830 to cover the subsequent 15-year period from 1978 through 1992.

The fire data used in the preparation of this report were obtained from the files of U.S. Mine Safety and Health Administration (MSHA) mine fire Reports of Investigation maintained at MSHA's Pittsburgh Safety Technology Center. These Reports of Investigation are prepared by MSHA Coal Mine Safety and Health staff for every fire reported to MSHA authorities. Reporting of fires to MSHA is in accordance with mandatory Federal regulations requiring coal mine operators to immediately notify MSHA in the event of a fire causing an injury or any noninjury fire lasting longer than 30 min (*6*). For each such fire (defined as "reportable"), MSHA produces a Report of Investigation describing the mine, circumstances leading to the fire, cause and detection of the fire, mine emergency and fire-fighting operations, post-fire mine recovery, and conclusions and recommendations.

This report differs from IC 8830 (*5*) in several important respects. The scope of the earlier report included both surface and underground mine fires, whereas this report covers only underground fires. This report utilized only one source of fire data, the aforementioned MSHA Reports of Investigation on file at the Pittsburgh Safety Technology Center. In contrast, IC 8830 summarized data from three independent sources. In addition to MSHA Reports of Investigation, IC 8830 reported data on nonreportable fires and included a section analyzing the expert opinions of several mine safety directors. The data on nonreportable fires were obtained from cooperating mining companies in an effort to establish similarities and differences between the causes and characteristics of reportable and nonreportable fires and to estimate the percentage of fires that were extinguished before they became reportable.

Another difference between this report (*5*) and the earlier report is the source of the MSHA Reports of Investigation. For the earlier report, MSHA's Health and Safety Analysis Center and all MSHA Coal Mine Safety and Health district and subdistrict offices were visited. Project personnel personally searched the files at these offices for fire reports. It was noted at the time that the files at the district and subdistrict offices contained informal, internal memoranda concerning short-duration fires that were legally nonreportable, but were reported as a courtesy. All fire reports, whether reportable or not, were included in the analysis for IC 8830.

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

Most of the fire incidents included in this report meet MSHA's definition of a reportable fire, with only a very few being nonreportable. It is likely that more "courtesy reports" of short-duration, nonreportable fires would have been found had all MSHA district and subdistrict offices been visited for this report, as had been the case for the earlier report (*5*). As a result, the reader should be aware that when comparing the two reports, the data contained in the earlier report may be slightly skewed toward shorter duration fires.

The data tables included in this report present data in three 5-year subgroupings covering the 1978-82, 1983-87, and 1988-92 periods, as well as for the entire 15-year period from 1978 through 1992. Data are presented in this fashion to highlight the changes that occur slowly over time.

A small discrepancy in the dates of coverage for IC 8830 (*5*) and this report should be noted. Although the title of IC 8830 refers to the period from 1950 to 1977, its period of coverage did not actually extend to the end of calendar year 1977. Rather, it extended only to the end of September 1977. However, three additional fires occurred during the fourth quarter of 1977. In order for both IC 8830 and this report to provide continuous coverage of all reported underground coal mine fires from 1950 through 1992, the three late 1977 fires that are not contained in IC 8830 are included in this report. Where data are grouped by time period in this report, the late 1977 fires are included in the 1978-82 grouping.

Discussion of the data usually covers the entire 15-year period from 1978 through 1992. However, certain discussions focus on the most recent period, 1988-92, as these data are most relevant to current mining practices. To reveal changes that have occurred over a longer time period, data from this study are compared to data from IC 8830 (*5*). Normally, these discussions include the entire 1950 through 1977 period covered by IC 8830. However, certain discussions focus on other time periods, such as 1953 through 1977, corresponding to the beginning of Federal mine safety legislation standardizing fire reporting requirements, or 1970 through 1977, corresponding to the effective date of the 1969 Mine Safety and Health Act. Column summation totals may vary slightly because of rounding.

DATA ANALYSIS

Data were assembled in two forms: actual numbers of fires and fire incidence rates. Fire incidence rates, for purposes of this report, are defined as the number of fires per million tons[4] of coal mined. Fire incidence rates are included to enable the reader to more meaningfully compare data from industry sectors having differing levels of coal production and therefore differing exposure to fire risks. The coal production data required for calculating incidence rates was obtained from the U.S. Department of Energy (DOE), Energy Information Administration (*7*), and the U.S. Department of Labor, MSHA (*8-22*). Production data vary slightly because of differing reporting requirements from these sources.

Data are presented in two formats: tables and figures. Tables are provided that include the exact number of fires, mine production data, incidence rates, etc. Figures are included to enable the reader to better discern patterns in the data, such as trends over time. The data were not statistically analyzed because of the often small number of fires occurring in a given category and time period.

The mine fire Reports of Investigation obtained from the MSHA Pittsburgh Safety Technology Center and used in this report were entered into a computer database using Paradox database software for data reduction and analysis. Those wishing to obtain a copy of this database are invited to contact the authors.

STATE AND TIME TRENDS

A total of 164 fires were reported to MSHA from 1978 through 1992. Table 1 shows fires by State for each year from 1978 through 1992, fires by State for the three major time periods, and total number of fires by State. Overall, the average number of fires per year was 10.8, compared to 32.4 fires per year for the preceding 15-year period from 1963 through 1977 (*5*). The three States having the greatest number of fire incidents during the 15 years from 1963 through 1977 were West Virginia, Pennsylvania, and Kentucky (*23*). These same three States recorded the greatest number of fires during the 1978 through 1992 period as well (with Pennsylvania and Kentucky in reversed order).

Table 2 shows underground coal mine production for the 1978 through 1992 period. Table 3 shows fire incidence rates for the same time period. The fire incidence rate for all States over the entire 15-year period from 1978 through 1992 was 0.031. From IC 8830 (*5*), the fire incidence rate for the 1950 through 1977 period was 0.115, almost four times higher. Figure 1 shows underground coal mine fires, underground coal mine production, and fire incidence rates for the 1978 through 1992 period. An upward trend is evident in coal production, and an overall downward trend is evident in both fires and fire incidence rates.

[4] In this report, "tons" refer to "short tons."

Table 1.—Number of fires by State and year

State	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1978-82	1983-87	1988-92	Total
Alabama	1	0	0	2	1	1	0	2	3	0	0	0	0	0	1	4	6	1	11
Colorado	0	0	1	1	0	1	1	0	2	2	1	0	1	0	0	2	6	2	10
Illinois	4	4	0	2	0	3	2	1	1	0	1	0	0	1	0	12	7	2	21
Indiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iowa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kentucky	1	1	1	2	2	0	3	2	3	4	4	2	1	0	1	7	12	8	27
Maryland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New Mexico	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	1
Ohio	1	0	1	1	3	0	0	0	1	1	0	0	1	0	0	6	2	1	9
Pennsylvania	1	0	1	1	3	1	2	0	2	3	3	2	3	1	1	6	8	10	24
Tennessee	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Utah	0	0	1	1	1	1	1	0	1	1	1	1	0	0	0	3	4	2	9
Virginia	1	0	1	1	3	2	4	1	1	0	2	1	2	0	1	6	8	6	20
West Virginia	1	5	5	2	2	2	1	1	3	4	1	1	0	0	3	15	11	5	31
Wyoming	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1
Total	10	10	14	13	15	11	14	7	17	15	13	7	8	2	8	62	64	38	164

Table 2.—Underground coal mine production by State and year, 10^6 tons

State	1978[1]	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1978-82	1983-87	1988-92	Total
Alabama	7.8	8.4	9.5	8.6	11.3	10.9	13.2	14.4	13.2	14.3	14.8	16.3	17.5	17.1	15.9	45.6	66.0	81.6	193.2
Colorado	5.6	6.1	6.2	6.6	6.6	5.6	6.4	6.3	5.5	5.6	6.9	8.5	10.6	9.6	10.2	31.1	29.4	45.8	106.3
Illinois	32.2	32.7	35.0	29.2	34.7	31.8	38.5	37.3	39.7	37.5	38.5	39.3	41.7	43.1	47.0	163.8	184.8	209.6	558.2
Indiana	0.7	0.8	0.7	0.6	1.6	1.8	2.2	2.1	1.9	2.4	2.4	2.5	3.1	2.8	2.6	4.4	10.4	13.4	28.2
Iowa	0.2	0.1	0.2	0	0	0	0.2	0.2	0.1	0	0	0	0	0	0	0.5	0.5	0	1.0
Kentucky	74.9	73.4	75.0	77.2	74.8	64.8	78.2	80.3	87.2	92.1	94.1	98.6	105.3	97.3	95.7	375.3	402.6	491.0	1,268.9
Maryland	0.5	0.9	1.6	1.7	1.9	1.6	2.2	1.8	2.5	2.4	2.1	1.8	2.1	2.6	2.4	6.6	10.5	11.0	28.1
New Mexico	0.8	0.8	0.9	0.8	0.7	0.1	0.6	0.8	0.8	0.6	0.2	0	0	0	0.1	4.0	2.9	2.9	7.2
Ohio	15.5	14.5	12.9	10.7	12.2	10.8	14.1	13.6	14.4	12.6	11.3	10.8	12.9	12.2	12	65.8	65.5	59.2	190.5
Pennsylvania	42.5	43.3	41.5	34.2	35.5	34.5	36.9	35.5	36.8	37.8	38.8	39.1	40.1	40.6	44.7	197.0	181.5	203.3	581.8
Tennessee	5.2	4.3	4.7	5.1	4.5	4.4	5.2	5.1	5.2	4.8	4.6	4.6	4.5	3.1	2	23.8	24.7	18.8	67.3
Utah	11.3	12.0	13.3	13.8	17.0	11.8	12.3	12.8	14.3	16.5	18.2	20.1	22.1	21.9	21.3	67.4	67.7	103.6	238.7
Virginia	27.3	27.4	31.4	32.3	31.0	26.8	32.6	33.3	33.8	36.7	37.6	35.9	39.1	34.1	34.6	149.4	163.2	181.3	493.9
West Virginia	83.6	91.3	95.8	89.1	103.5	91.9	105.8	103.5	103.1	107.2	109.8	113.1	123.3	119.8	115.1	463.3	511.5	581.1	1,555.0
Wyoming	0.9	0.7	0.9	1.3	1.3	1.3	1.3	1.1	0.2	0.1	1.1	1.6	1.7	2.4	2.5	5.1	4.0	9.3	18.4
Total	309.0	316.7	329.6	311.2	336.6	298.1	349.7	348.1	358.7	370.6	380.4	392.2	424.0	406.6	406.1	1,603.1	1,725.2	2,009.3	5,337.6

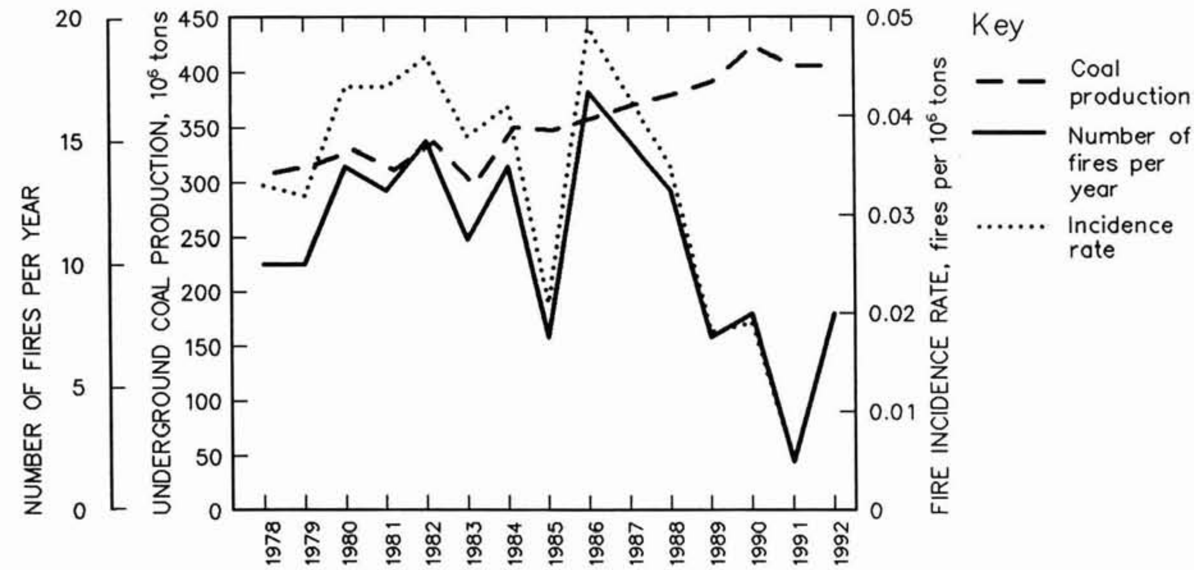
[1]Includes fourth quarter 1977.

Source: MSHA (*4*).

Table 3.—Fire incidence rate by State and year

State	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1978-82	1983-87	1988-92	Total
Alabama	0.128	0	0	0.233	0.088	0.092	0	0.139	0.227	0	0	0	0	0	0.063	0.088	0.091	0.012	0.057
Colorado	0	0	0.161	0.152	0	0.179	0.156	0	0.364	0.357	0.145	0	0.094	0	0	0.064	0.204	0.044	0.094
Illinois	0.124	0.122	0.057	0.068	0	0.094	0.052	0.027	0.025	0	0.026	0	0	0.023	0	0.073	0.038	0.010	0.038
Indiana	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Iowa	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kentucky	0.013	0.014	0.013	0.026	0.027	0	0.038	0.025	0.034	0.043	0.043	0.020	0.009	0	0.010	0.019	0.030	0.016	0.021
Maryland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
New Mexico	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10.000	0	0	3.300	0.139
Ohio	0.065	0	0.078	0.093	0.246	0	0	0	0.069	0.079	0	0	0.078	0	0	0.091	0.031	0.017	0.047
Pennsylvania	0.024	0	0.024	0.029	0.085	0.029	0.054	0	0.054	0.079	0.077	0.051	0.075	0.025	0.022	0.030	0.044	0.049	0.041
Tennessee	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Utah	0	0	0.075	0.072	0.059	0.085	0.081	0	0.070	0.061	0.055	0.050	0	0	0	0.045	0.059	0.019	0.038
Virginia	0.037	0	0.032	0.031	0.097	0.075	0.123	0.030	0.030	0	0.053	0.028	0.051	0	0.029	0.040	0.049	0.033	0.040
West Virginia	0.012	0.055	0.052	0.022	0.019	0.022	0.009	0.010	0.029	0.037	0.009	0.008	0	0	0.026	0.032	0.022	0.009	0.020
Wyoming	0	0	1.111	0	0	0	0	0	0	0	0	0	0	0	0	0.196	0	0	0.054
Total	0.033	0.032	0.043	0.043	0.046	0.038	0.041	0.021	0.049	0.042	0.035	0.018	0.019	0.005	0.020	0.040	0.038	0.019	0.031

Figure 1



Number of underground coal mine fires per year, underground coal mine production, and fire incidence rate, 1978-92.

COALBED THICKNESS

Table 4 shows the number of fires that occurred during the three major time periods and the total number of fires by various ranges of coalbed thickness. Table 5 shows underground coal mine production by year for the same coalbed thickness ranges. Table 6 shows the number of reported fires, number of fires per million tons of production, and expected number of fires if fires occurred in linear proportion to production. Over three-quarters of all fires for which coalbed thickness was reported occurred in mines having coalbed thicknesses from 49 to 96 in. The range from 73 to 96 in had the highest number of fires per million tons of production. Figure 2 shows reported fires, expected fires, fire incidence rates, and underground coal mine production by coalbed thickness. An upward trend is evident in the fire incidence rate from thinner to thicker coalbeds.

Table 4.—Number of fires by coalbed thickness and time period

Coalbed thickness, in	1978-82	1983-87	1988-92	Total
36 or less	3	2	4	9
37 to 48	5	2	4	11
49 to 60	14	20	8	42
61 to 72	7	11	8	26
73 to 96	18	15	8	41
More than 96	3	7	2	12
Not reported	12	7	4	23
Total	62	64	38	164

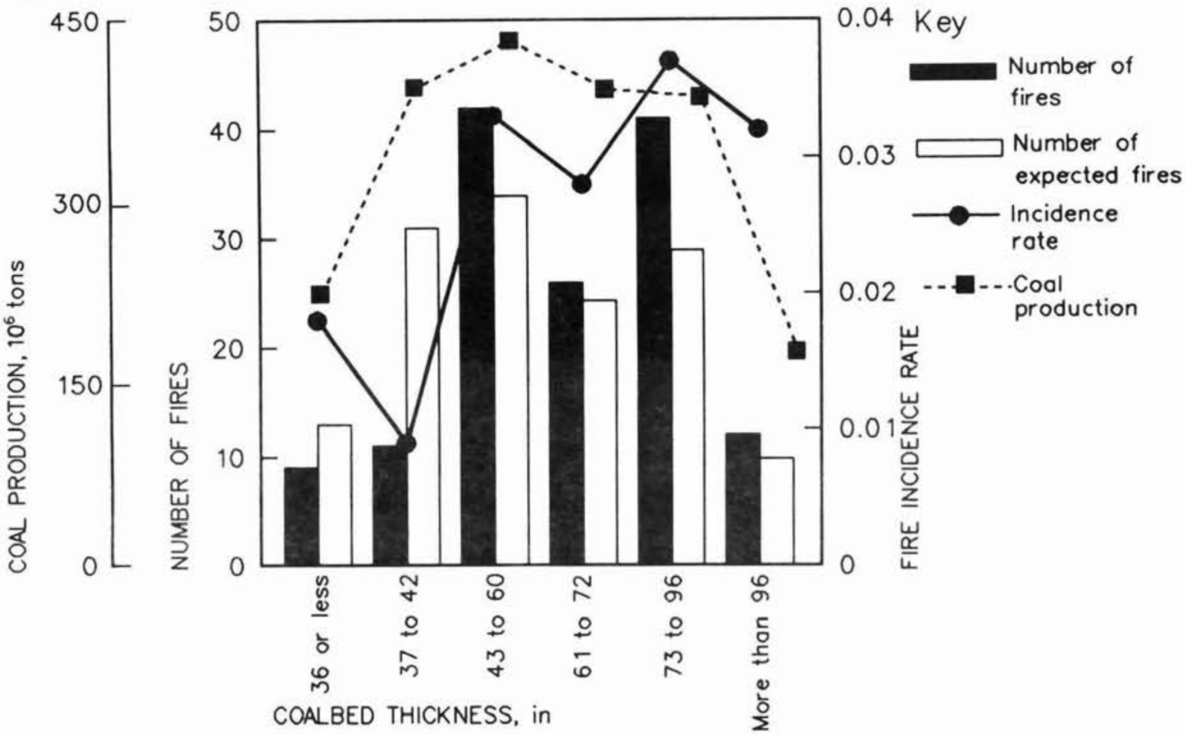
MINE SIZE

Fire data were analyzed with respect to mine size using two independent measures of mine size: mine production tonnage and number of underground employees. However, the reader is cautioned that previous research by the USBM and others has caused the reliability of self-reported accident data by small mines to be questioned (*24*). For a variety of reasons, small mines have been shown to underreport accidents that do not result in a serious injury or fatality. Since most fires do not cause an injury or fatality, it is probable that small mines are underrepresented in the fire data. The analysis in this section (and throughout the report) is based almost entirely on fires that were self-reported by mining companies without attempting to correct for the probable reporting bias.

Table 7 shows fires by mine size as defined by daily production tonnage. The most fires occurred at mines having production greater than 2,000 tons per day. However, as shown in table 8, mines producing more than 2,000 tons per day account for the greatest percentage of overall production. Therefore, it is logical that these mines should also account for the most fires.

A more meaningful representation of the data requires the number of fires within each mine size category to be compared to that category's proportion of total production. Table 9 shows the number of reported fires by daily production tonnage, incidence rates, and expected number of fires if fires were in linear proportion to production

Figure 2



Number of fires, number of expected fires, fire incidence rate, and underground coal mine production by coalbed thickness, 1978-92.

Table 5.—Underground coal mine production by coalbed thickness and year, 10^6 tons

Coalbed thickness, in	1978[1]	1979	1980	1981	1982	1983	1984	1985	1986	1987
36 or less	20.9	25.0	25.5	26.7	27.0	23.0	29.7	26.5	31.0	28.0
37 to 48	82.6	79.2	79.5	78.8	78.2	65.1	75.9	78.1	77.9	83.0
49 to 60	78.0	84.0	87.3	78.7	85.2	71.4	82.9	97.5	90.7	94.5
61 to 72	46.6	44.4	52.5	47.8	51.6	54.3	63.3	47.4	53.9	65.6
73 to 96	56.3	65.5	64.8	59.8	72.7	67.0	78.4	83.3	85.6	78.1
More than 96	19.8	18.3	19.7	19.4	21.9	17.6	19.8	16.1	19.4	22.0
Total	304.2	316.4	329.3	311.2	336.6	298.4	350.0	348.9	359.0	371.2

Coalbed thickness, in	1988	1989	1990	1991	1992	1978-82	1983-87	1988-92	Total
36 or less	33.2	31.1	57.9	48.2	54.2	125.1	138.2	224.6	487.9
37 to 48	80.5	87.8	77.6	77.2	71.9	398.3	380.0	395.0	1,173.0
49 to 60	93.2	93.7	85.8	81.5	78.8	413.2	437.0	433.0	1,283.0
61 to 72	68.5	72.4	81.0	85.0	86.3	242.9	284.5	393.2	920.6
73 to 96	76.0	72.8	83.6	78.4	75.9	319.1	392.4	386.7	1,098.0
More than 96	29.0	34.8	37.8	36.0	39.2	99.1	95.4	176.8	371.3
Total	380.4	392.6	423.7	406.3	406.3	1,597.0	1,727.0	2,009.3	5,333.3

[1]Includes fourth quarter 1977.

Source: MSHA (*4*).

Mines producing 401 to 800 tons per day experienced the fewest fires relative to production; mines producing greater than 2,000 tons per day experienced the greatest number of fires relative to production.

The other independent measure of mine size is the number of underground employees. Table 10 shows the number of reported fires by mine size as defined by number of underground employees. The greatest number of fires was reported at mines having more than 250 underground employees. However, as shown in table 11, mines employing more than 250 underground workers also account for the greatest percentage of overall production; therefore, the higher number of fires does not necessarily indicate a greater hazard. Just as was true in the earlier analysis, it is logical that these larger mines should also account for the most fires.

Table 6.—Number of fires, fire incidence rate, and number of expected fires by coalbed thickness

Coalbed thickness, in	Number of fires	Fire incidence rate	Number of expected fires
36 or less	9	0.018	12.9
37 to 42	11	0.009	31.0
43 to 60	42	0.033	33.9
61 to 72	26	0.028	24.3
73 to 96	41	0.037	29.0
More than 96 ..	12	0.032	9.8
Total known ...	141	NA	NA
Not reported ..	23	NA	141.0
Total	164	NA	NA

NA Not available.

Table 12 shows the number of reported fires by number of underground employees, incidence rates, and expected number of fires if fires were in linear proportion to production. Mines employing 35 to 99 underground workers experienced the fewest fires relative to production, whereas mines employing 250 or more underground workers experienced the greatest number of fires relative to production.

Figures 3 and 4 show reported fires, expected fires, fire incidence rates, and underground coal mine production by mine size, defined by daily production tonnage and number of underground employees, respectively. Increasing trends in both number of fires and fire incidence rates are evident for both measures of mine size. However, as noted above, these results are valid only if reporting of fires is consistent between all size groups.

MINING METHOD

Underground coal mines in the United States are categorized as either longwall or room and pillar, depending on the extraction system used. The layout of longwall mine workings is considerably different than the room-and-pillar arrangements employed in continuous and conventional mining. In turn, these differences profoundly affect ventilation, haulage, emergency escape routes, and other mine characteristics that impact fire safety. Therefore, an analysis of reported fires and fire incidence rates by mining method (longwall or room and pillar) is of considerable interest.

The MSHA Accident Investigation Reports used as the primary source of fire incident data for this report provided mining method information in about 50 pct of cases. For the cases where the mining method was omitted from these reports, information on the mining method was obtained from the "Longwall Census" reports

Table 7.—Number of fires by daily underground coal mine production tonnage range and year

Production, tons per day	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
0 to 200	0	0	0	1	1	0	0	0	0	0
201 to 400	0	1	1	0	1	0	1	1	1	0
401 to 800	0	0	0	1	1	1	0	0	0	4
801 to 2,000	0	0	1	1	2	6	3	0	0	2
More than 2,000 ...	8	5	6	8	8	0	10	6	13	6
Not reported	2	4	6	2	2	1	0	0	3	3
Not producing	0	0	0	0	0	3	0	0	0	0
Total	10	10	14	13	15	11	14	7	17	15

Production, tons per day	1988	1989	1990	1991	1992	1978-82	1983-87	1988-92	Total
0 to 200	2	0	1	0	0	2	0	3	5
201 to 400	0	2	0	0	0	3	3	2	8
401 to 800	0	0	0	0	0	2	5	0	7
801 to 2,000	2	0	0	0	2	4	11	4	19
More than 2,000 ...	8	5	6	2	4	35	35	25	95
Not reported	1	0	1	0	2	16	7	4	27
Not producing	0	0	0	0	0	0	3	0	3
Total	13	7	8	2	8	62	64	38	164

Table 8.—Underground coal mine production by daily production tonnage range and year

Production, tons per day	1978[1]	1979	1980	1981	1982	1983	1984	1985	1986	1987
0 to 200	38.6	22.6	20.5	22.8	23.5	19.0	18.0	16.7	17.4	15.7
201 to 400	31.8	29.5	32.0	34.3	33.2	27.9	29.3	28.0	25.3	24.5
401 to 800	39.9	35.7	39.2	40.9	41.1	36.0	43.0	38.7	37.6	36.8
801 to 2,000	69.5	62.8	70.4	71.0	65.0	48.6	59.0	61.5	62.9	61.2
More than 2,000 ..	128.9	165.7	167.3	142.4	174.2	166.9	200.7	203.8	215.7	232.9
Total	308.7	316.3	329.4	311.4	337.0	298.4	350.0	348.7	358.9	371.1
	1988	1989	1990	1991	1992	1978-82	1983-87	1988-92	Total	
0 to 200	14.0	12.2	11.8	9.6	8.1	128.0	86.8	55.7	270.5	
201 to 400	21.3	21.9	21.1	19.3	16.5	160.8	135.0	100.1	396.0	
401 to 800	39.8	38.4	40.0	32.1	30.3	196.8	192.1	180.6	569.5	
801 to 2,000	64.0	64.7	75.4	73.3	72.1	338.7	293.2	349.5	981.4	
More than 2,000 ..	241.5	255.4	275.3	272.1	279.3	778.5	1,020.0	1,323.0	3,122.0	
Total	380.6	392.6	423.6	406.4	406.3	1,602.0	1,727.1	2,009.0	5,338.1	

[1]Includes fourth quarter 1977.

Source: MSHA (*4*).

Table 9.—Number of fires, fire incidence rate, and number of expected fires by daily underground coal mine production tonnage range

Production, tons per day	Number of fires	Fire incidence rate	Number of expected fires
0 to 200	5	0.018	6.8
201 to 400	8	0.020	9.9
401 to 800	7	0.012	14.3
801 to 2,000	19	0.019	24.6
More than 2,000 ...	95	0.030	78.4
Total known	134	NAp	134.0
Unknown or not reported	30	NAp	NAp
Total	164	NAp	NAp

NAp Not applicable.

conducted by "Coal Mining & Processing" magazine (name changed to "Coal Mining" in 1984 and then changed to "Coal" in 1988) for the years 1982 and 1984 through 1992 (*25-35*). A summary of fire incidents in longwall and room-and-pillar mines from 1982 through 1992 is shown in table 13. The reader is cautioned that these data are classified by mine type and not by location within a mine. Fires in a longwall mine could have occurred at a longwall face or somewhere else in a longwall mining section. However, they might also have occurred in another part of the mine and involve equipment and procedures that are common to both longwall and room-and-pillar mines.

Table 10.—Number of fires by number of underground employees and year

Number of employees	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
1 to 34	0	0	1	2	3	1	1	1	1	2
35 to 99	0	1	0	1	0	0	3	0	1	2
100 to 249	0	0	2	2	1	3	6	1	5	4
250 or more	8	5	5	7	9	3	4	5	7	3
Not reported	2	4	6	1	2	[1]4	0	0	3	4
Total	10	10	14	13	15	11	14	7	17	15
	1988	1989	1990	1991	1992	1978-82	1983-87	1988-92	Total	
1 to 34	2	2	1	0	0	6	6	5	17	
35 to 99	2	0	1	0	1	2	6	4	12	
100 to 249	4	1	1	0	2	5	19	8	32	
250 or more	5	4	4	2	3	34	22	18	74	
Not reported	0	0	1	0	2	15	11	3	29	
Total	13	7	8	2	8	62	64	38	164	

[1]Includes three fires that ocurred in temporarily inactive mines.

Table 11.—Underground coal mine production by number of underground employees and year, 10^6 tons

Number of employees	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987
1 to 34	35.9	46.0	53.4	55.5	61.2	57.4	69.6	67.7	71.0	72.1
35 to 99	34.7	40.4	45.0	48.3	50.0	43.0	53.1	52.9	57.6	58.6
100 to 249	56.8	69.3	78.3	75.6	75.5	69.6	79.0	83.6	91.1	100.2
250 or more	101.3	144.2	143.8	120.0	141.6	121.7	140.3	137.8	132.6	133.1
Total	228.7	299.9	320.5	299.4	328.3	291.7	342.0	342.0	352.3	364.0
	1988	1989	1990	1991	1992	1978-82	1983-87	1988-92	Total	
1 to 34	75.1	77.7	83.4	74.0	78.6	252.0	337.8	388.8	978.6	
35 to 99	68.6	73.6	80.6	82.0	81.1	218.4	265.2	385.9	869.5	
100 to 249	90.1	95.3	102.4	101.2	99.9	355.5	423.5	488.9	1,267.9	
250 or more	142.7	139.9	152.7	146.3	143.8	650.9	665.5	725.4	2,041.8	
Total	376.5	386.5	419.1	403.5	403.4	1,476.8	1,692.0	1,989.0	5,157.8	

Source: MSHA (8-22).

Table 12.—Number of fires, fire incidence rate, and number of expected fires by number of underground employees

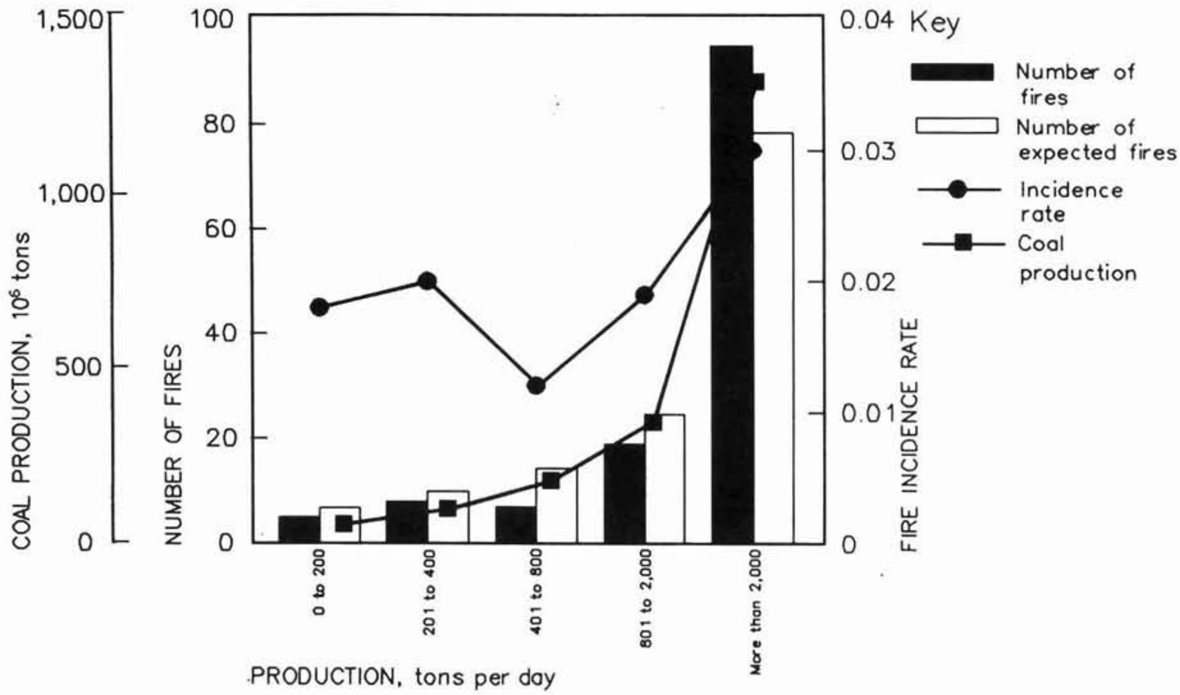
Number of employees	Number of fires	Fire incidence rate	Number of expected fires
1 to 34	17	0.017	25.6
35 to 99	12	0.014	22.8
100 to 249	32	0.025	33.2
250 or more	74	0.036	53.5
Total (known)	135	NAp	135.1
Unknown or not reported	29	NAp	NAp
Total	164	NAp	NAp

NAp Not applicable.

Table 13.—Number of fires by year and mining method

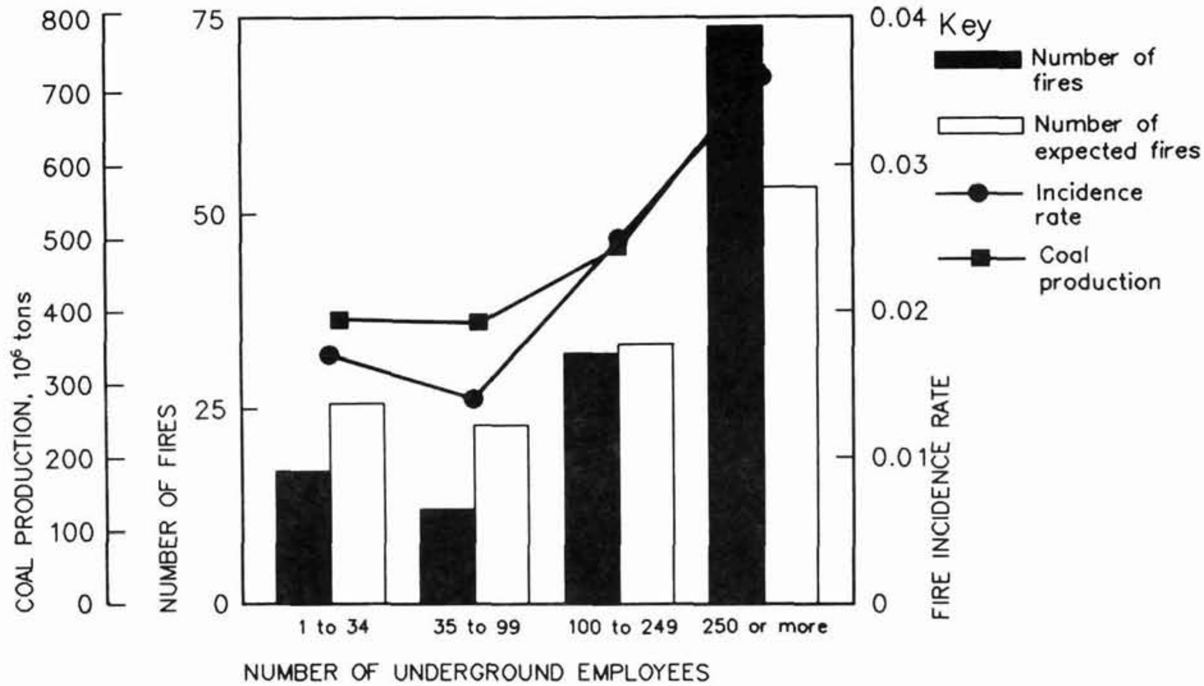
Year	Longwall	Room and pillar
1982	5	10
1983	4	7
1984	6	8
1985	2	5
1986	10	7
1987	7	8
1988	4	9
1989	3	4
1990	2	6
1991	1	1
1992	5	3
Total	49	68

Figure 3



Number of fires, number of expected fires, fire incidence rate, and underground coal mine production by daily tonnage range, 1978-92.

Figure 4



Number of fires, number of expected fires, fire incidence rate, and underground coal mine production by underground employees, 1978-92.

For fire incidence rate calculations, coal production data from longwall operations are required. However, until quite recently, such industry-wide data were not routinely collected and published. DOE's Energy Information Administration collects coal mine production data from mining companies on its EIA-7A form. This form was modified to include questions on production method (longwall or room and pillar) in 1989, and production method data were first published in 1990.

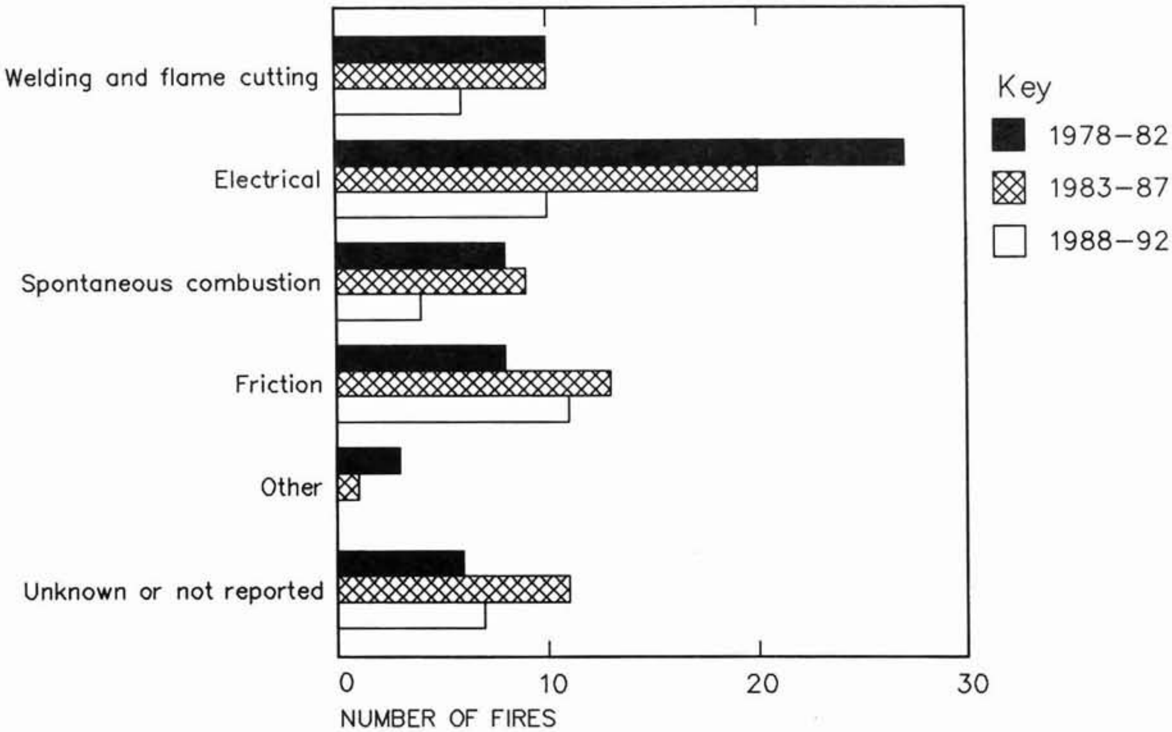
For the years 1990 through 1992, DOE reports that longwall mining accounted for 29, 29, and 31 pct, respectively, of total underground coal production. Even these figures are suspect, however. In 1991, mining equipment manufacturers and suppliers estimated longwall faces accounted for 37 pct of production from U.S. underground coal mines (*36*). Using the DOE longwall production data for the 1990-1992 period, the incidence rate for fires in longwall operations was 0.022. The incidence rate for fires in room-and-pillar operations during the same time period was 0.012. Based on the equipment manufacturers' and suppliers' estimate of longwall production, the incidence rates would be 0.017 and 0.013, respectively. These results suggest a somewhat higher hazard may exist in longwall mines.

IGNITION SOURCE

Reported fires by ignition source for the three major time periods are listed in table 14 and illustrated in figure 5. Of the 164 fires reported to MSHA, the ignition source was known and reported in 140 cases. The leading underground coal mine fire ignition source for the 1978 through 1992 period is electrical, accounting for over 41 pct of all fires for which the ignition source was known and 35 pct of all fires. Electrical fires include fires that resulted directly from an electrical fault or failure, such as a short circuit or insulation failure. Not all fires on electrically powered equipment were necessarily classified as electrical fires. Such fires were classified as electrical only if the fire originated from an electrical fault or failure.

The second leading cause of fires was friction, accounting for about one-quarter of all fires for which the ignition source was reported. Frictional fires include conveyor belts rubbing on pulleys or stationary objects, overheated brakes, overheated compressors, etc. The frequency of electrical fires declined over time, whereas fires caused by frictional sources increased. For the most recent time period, friction was the leading cause of fires.

Figure 5



Number of fires by ignition source, 1978-92.

Table 14.—Number of fires by ignition source and time period

Ignition source	1978-82	1983-87	1988-92	Total
Welding and flame cutting . . .	10	10	6	26
Electrical	27	20	10	57
Spontaneous combustion	8	9	4	21
Friction	8	13	11	32
Other	[1]3	[2]1	0	4
Unknown or not reported	6	11	7	24
Total	62	64	38	164

[1]Overheated brakes, two roof falls.
[2]Roof fall.

Referring to IC 8830 (*5*), the leading ignition sources during the 1970 through 1977 period were (in descending order) electrical, spontaneous combustion, welding and cutting, and friction. These same four ignition sources accounted for the greatest number of fires in the 1978 through 1992 period, however in different rank order.

BURNING SUBSTANCE

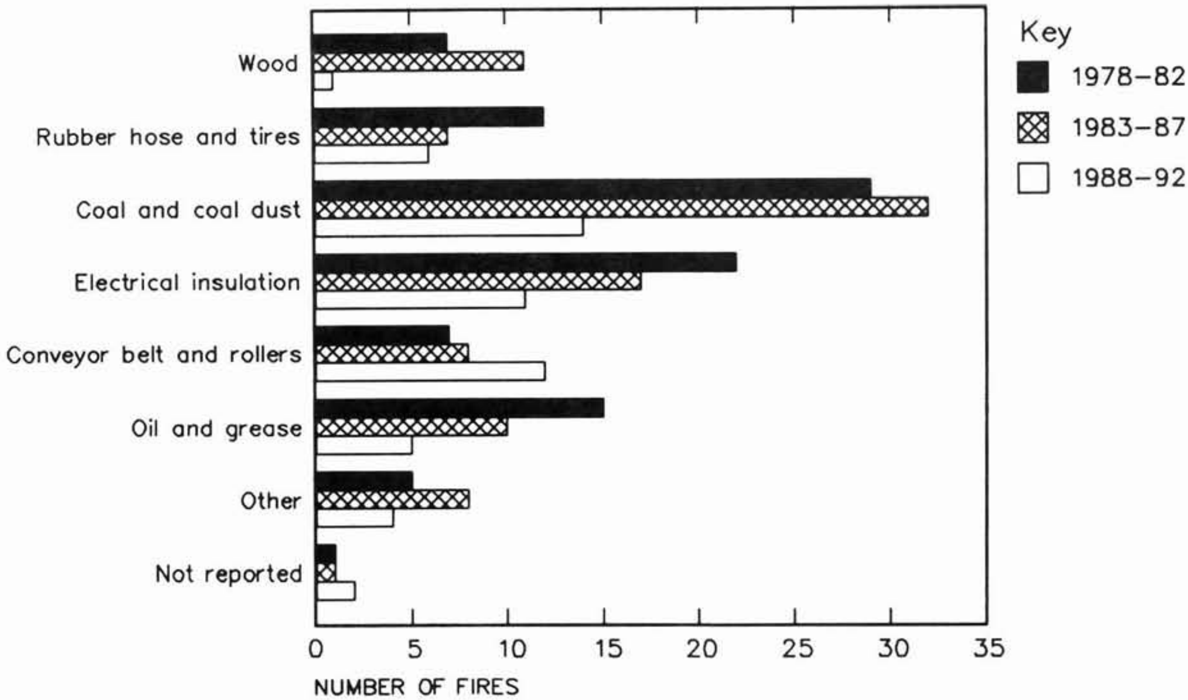
Table 15 identifies the substances that were involved in the fires. These data are illustrated in figure 6. More than one substance was involved in most fires, so the column totals add to considerably more than the total of 164 fires that occurred during the period. Coal-coal dust was the most common burning substance, followed by electrical insulation, oil-grease, conveyor belt-rollers, and rubber hose-tires. Data from IC 8830 (*5*) for the 1953-77 period show the same five leading burning substances. As shown in figure 6, all burning substances experienced a drop in the number of fires over time, except for conveyor belt and rollers, which showed an increase for each time period.

Table 15.—Number of fires by burning substance and time period

Substance	1978-82	1983-87	1988-92	Total
Wood	7	11	1	19
Rubber hose and tires	12	7	6	25
Coal and coal dust	29	32	14	75
Electrical insulation	22	17	11	50
Conveyor belt and rollers	7	8	12	27
Oil and grease	15	10	5	30
Other[1]	5	8	4	17
Not reported	1	1	2	4
Total (known)	92	85	49	226

[1]Acetylene, methane, brattice, clothing, polyurethane foam, and resin.

Figure 6



Number of fires by burning substance, 1978-92.

UNDERGROUND LOCATION

The underground locations where coal mine fires originated are listed in table 16 and illustrated in figure 7. In most cases, mine personnel were able to determine precisely where the fire originated. In a few cases, mine personnel inferred the point of origin from their knowledge of the location of specific fire hazards and the behavior of the fire.

Table 16.—Number of fires by underground location and time period

Location	1978-82	1983-87	1988-92	Total
Shaft, slope, bottom, or station	5	2	2	9
Track haulage	15	4	4	23
Belt entry	10	16	11	37
Working face	12	11	8	31
Intake entry	8	15	2	25
Power center or electrical equipment	2	5	4	11
Mined out, caved, or gob	7	7	2	16
Unknown or not reported	1	2	2	5
Other[1]	2	2	3	7
Total	62	64	38	164

[1]Return entry, shop, and stockpile recovery tunnel.

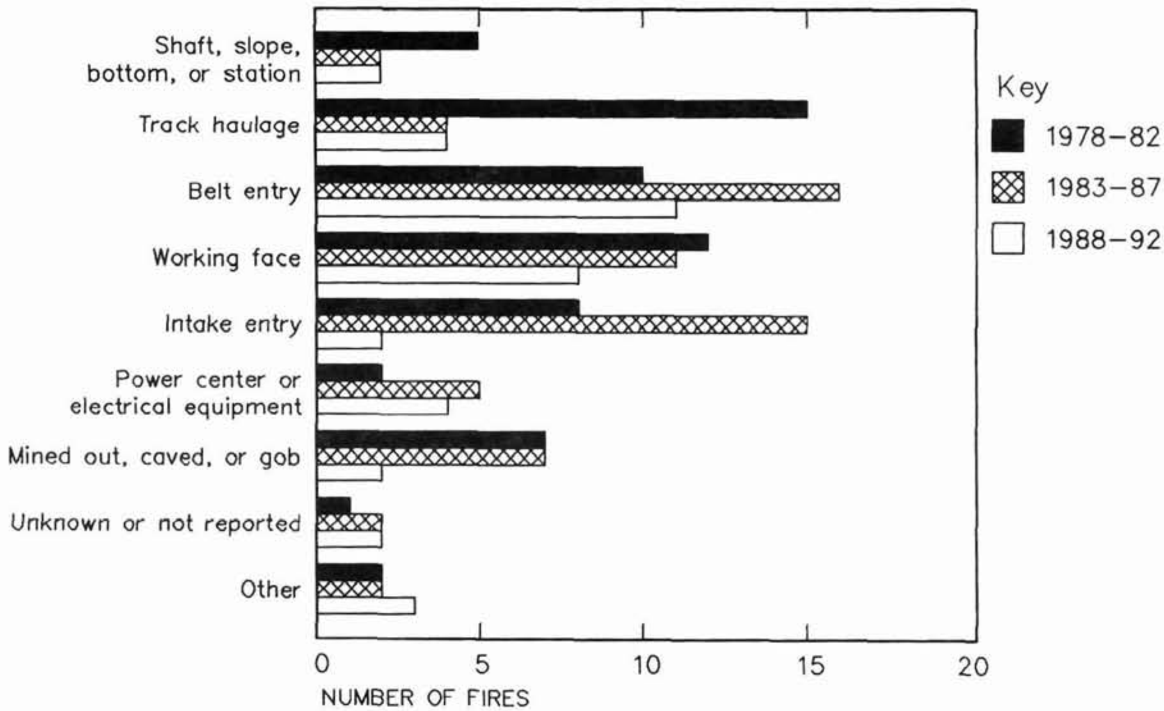
The most frequent fire locations before 1982 were the track-haulage entry and working face areas. This finding is consistent with the 1950-77 data from IC 8830 (*5*), but in reverse rank order. Beginning with the 1983-87 period and continuing through the 1988-92 period, the belt entry becomes the leading fire location, whereas fires occurring in the track-haulage entry drop dramatically. The increase in the number of fires in belt entries is probably related to the increased utilization of belt haulage over the past decade rather than an increased level of fire hazard in belt entries.

An increasing trend is also evident for power centers or electrical equipment. However, the actual number of fires in this category is relatively low for all three time periods (1978-82, 1983-87, and 1988-92).

EQUIPMENT INVOLVED

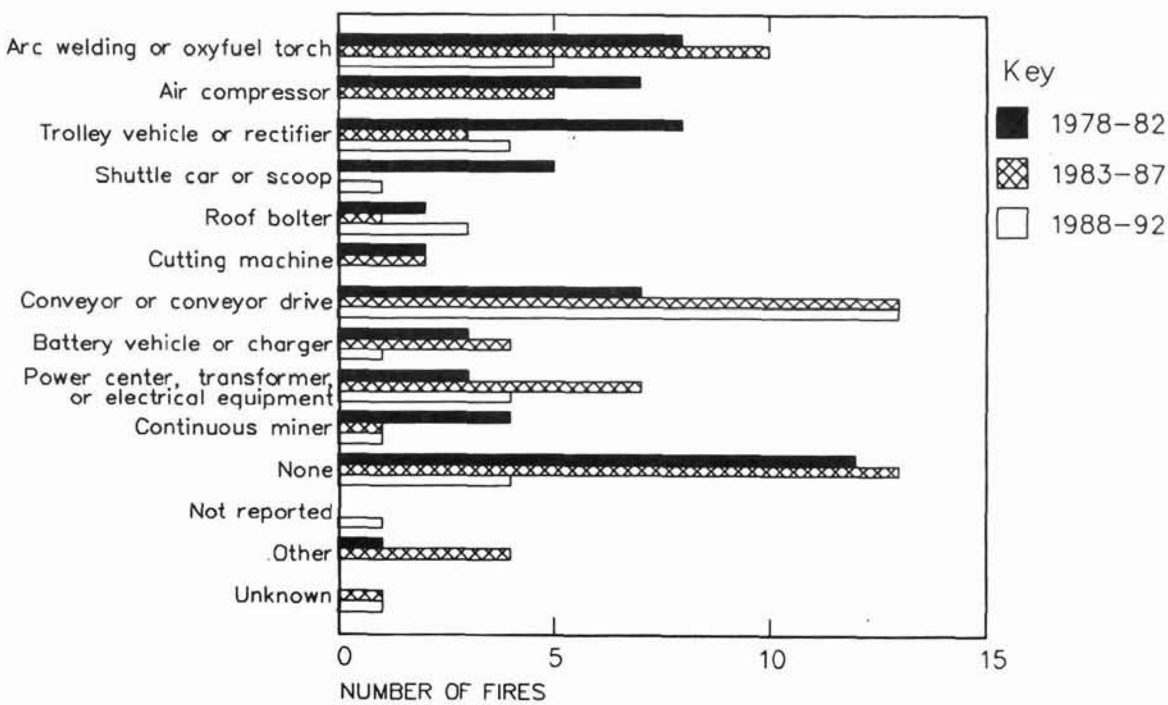
The equipment involved in underground coal mine fires is listed in table 17 and illustrated in figure 8. The equipment category accounting for the greatest number of fires during the 1978 through 1992 period was conveyor-conveyor drive, followed by arc welding-oxyfuel cutting equipment, trolley vehicle-rectifier, and power center-transformer-electrical equipment. Increasing trends are observed for roof bolters, power centers-transformers-electrical equipment, and conveyor-conveyor drives. However, the high number of fires associated with conveyors and conveyor drives makes that increasing trend the most important.

Figure 7



Number of fires by underground location, 1978-92.

Figure 8



Number of fires by equipment involved, 1978-92.

Table 17.—Number of fires by equipment involved and time period

Equipment	1968-72	1973-77	1978-82	1983-87	1988-92	1978-92
Arc welding or oxyfuel torch	4	2	8	10	5	23
Air compressor	3	4	7	5	0	12
Trolley vehicle or rectifier	11	6	8	3	4	15
Shuttle car or scoop	17	2	5	0	1	6
Roof bolter	6	4	2	1	3	6
Cutting machine	27	4	2	2	0	4
Conveyor or conveyor drive	24	9	7	13	13	33
Battery vehicle or charger	NA	NA	3	4	1	8
Power center, transformer or electrical equipment	4	9	3	7	4	14
Continuous miner	8	1	4	1	1	6
None	49	21	12	13	4	29
Not reported	0	0	0	0	1	1
Other	12	0	1	4	0	[1]5
Unknown	2	0	0	1	1	2
Total	167	62	62	64	38	164

NA Not available.
[1]Car spotter, two diesel trucks, and two water pumps.

Although all other equipment types show downward trends, two categories are particularly noteworthy. The number of fires on cutting machines showed a marked downward trend, especially for the 1968 to 1972 period versus the post-1972 period. This finding is consistent with the downward trend in conventional mining, which is the only mining method to utilize the cutting machine. The other noteworthy downward trend was in the "none" category, which also dropped dramatically, meaning that more and more fires in recent years have involved mining equipment.

One of the more significant trends in underground coal mining equipment utilization in recent years is the increasing application of diesel-powered mobile equipment. This trend has been accompanied by increasing safety concerns related to the storage, handling, and use of large quantities of diesel fuel underground, and the potential fire risks associated with the mobile equipment itself. However, these data do not indicate a serious problem. Only, two diesel equipment fires are included in table 17, and referring to table 15, reported fires involving rubber hose and tires and oil and grease are declining.

DETECTION METHOD

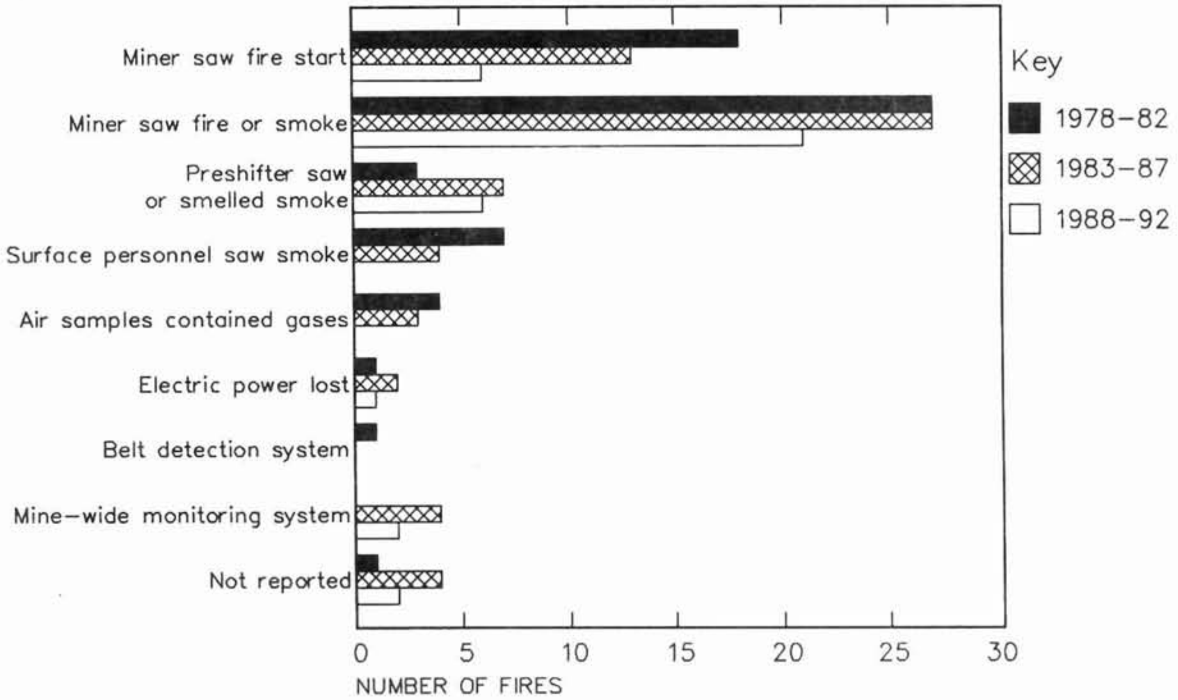
The methods by which underground coal mine fires were detected are listed in table 18 and illustrated in figure 9. The leading methods were miners who were present when the fire started, and miners who saw or smelled smoke at some time after the fire started. These two methods accounted for 112 of the 164 fires, or 68 pct during the 1978 through 1992 period. This compares to 693 out of 987 fires, or 70 pct for the 1953 through 1977 period. Two other findings from the detection data are noteworthy. Despite the high number of fires occurring on conveyors (the most frequent equipment involved in fires), and MSHA regulations which, until recently, required thermal detection systems on belt lines and at belt drives (carbon monoxide gas or smoke detection systems may now be used in place of thermal detection systems), only two fires, or 1.2 pct, were detected by belt fire detection systems. In several instances where belts were involved in fires, the belt fire detection system did alarm; however, it was after the fire had been detected by other means. This finding is consistent with a large body of conveyor belt entry fire detection research, which indicates the relative insensitivity of spot-thermal belt fire detection systems.

Table 18.—Number of fires by method of detection and time period

Method of detection	1978-82	1983-87	1988-92	1978-92
Miner saw fire start	18	13	6	37
Miner saw fire or smoke	27	27	21	75
Preshifter saw or smelled smoke	3	7	6	16
Surface personnel saw smoke	7	4	0	11
Air samples contained gases	4	3	0	7
Electric power lost	1	2	1	4
Belt detection system	1	0	0	1
Mine-wide monitoring system	0	4	2	6
Not reported	1	4	2	7
Total	62	64	38	164

Finally, it is noteworthy that mine atmosphere analysis accounted for 13 fires or 7.9 pct. Six of these fires were detected by a mine-wide monitoring system. With increased usage of mine-wide monitoring systems, mine atmosphere analysis can be expected to become a more common means of fire detection in the future. However, even more importantly, the reader is reminded that the source of data for this analysis consisted almost entirely of reportable fires, meaning that they caused an injury or

Figure 9



Number of fires by method of detection, 1978-92.

were noninjury fires lasting longer that 30 min. Since mine-wide monitoring systems are capable of detecting fires in their early stages, it is quite possible, and indeed probable, that a much larger number of fires were actually detected by mine-wide monitoring systems than the data in table 17 indicate. However, the fires would likely have been discovered while they were still very small and easily extinguished, hence not causing injury or lasting longer than 30 min and, therefore, not having to be reported to MSHA. Although the low number of fires detected by conveyor belt thermal fire detection systems might be attributed to this same reasoning, such an explanation is unlikely because of the well-documented slow response time of these systems.

TIME OF DAY

The time of day (expressed as an interval corresponding to day, evening, or night shift) when underground coal mine fires were first discovered is listed in table 19 and illustrated in figure 10. These times are not intended to represent the time when the fires actually started. However, in many cases, personnel were present at the time, or very close to the time when the fires started. In a few cases, particularly for spontaneous combustion fires, discovery lagged initiation by a considerable amount, and a definitive determination of the time when initiation occurred was impossible. For consistency in data reporting, the times indicated in table 19 are the time of day when the fires were first discovered and reported.

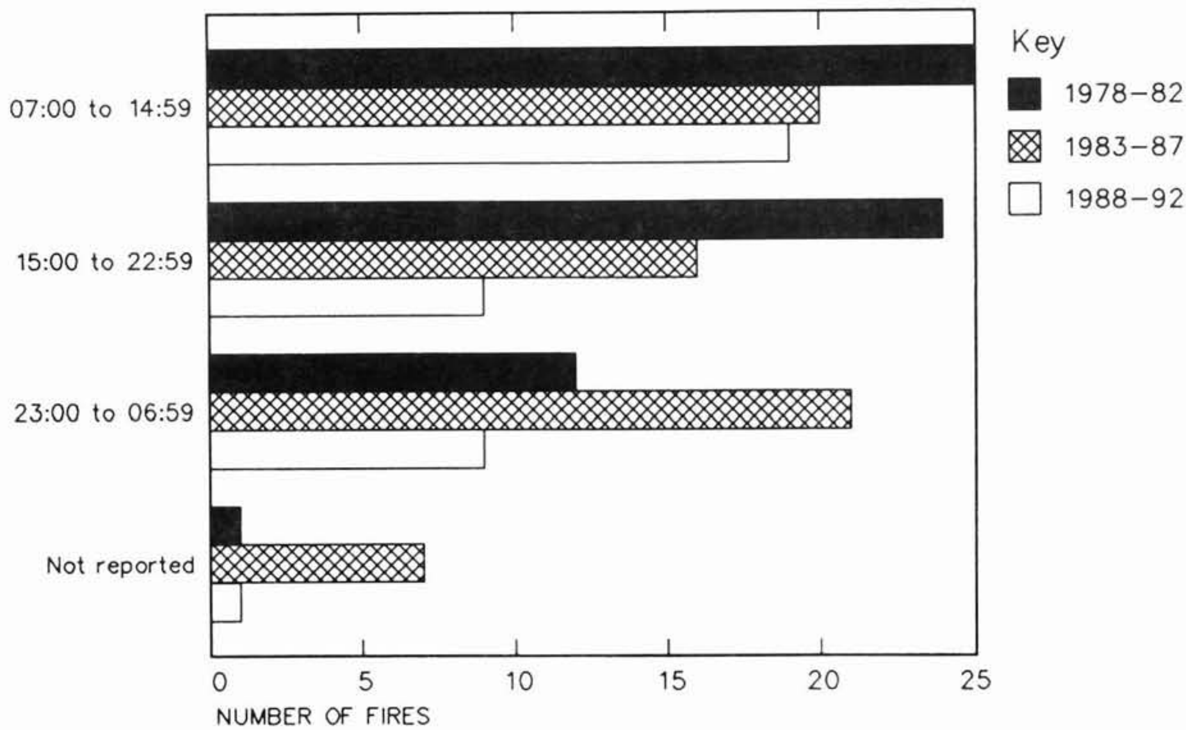
Table 19.—Number of fires by time of day and time period

Time of day	1978-82	1983-87	1988-92	1978-92
07:00 to 14:59	25	20	19	64
15:00 to 22:59	24	16	9	49
23:00 to 06:59	12	21	9	42
Not reported	1	7	1	9
Total	62	64	38	164

The greatest number of fires was discovered on the day shift, followed by the evening shift and night shift. However, these findings are not particularly useful. Since the mining activity that correlates with both the occurrence and discovery of fires is generally greater during the day shift, one would expect more fires to occur and be discovered during the day shift. A more meaningful and revealing insight would be provided by determining whether the discovery of fires during a particular shift was in proportion, or not in proportion to the level of mining activity occurring during that shift.

It was not possible to precisely determine whether the discovery of fires was in proportion to the level of mining activity on a given shift because data quantifying the level of underground coal mining activity occurring during each shift were not available. However, an indication of the

Figure 10



Number of fires by time of day, 1978-92.

level of mining activity was obtained from a U.S. Bureau of Labor Statistics (BLS) survey of shiftwork practices in various U.S. industries (*37*). These data show that about 81.7 pct of the mining work force is employed on the day shift, 7.5 pct on the evening shift, and 10.8 pct on the night shift.

These data are not necessarily representative of shiftwork practices specific to the underground coal mining industry ("mining" as defined in the BLS survey includes all sectors of the mining industry, including surface and underground metal, nonmetal, and coal mining, as well as oil and gas production). However, using the BLS factors to estimate the expected number of fires discovered on each shift, the discovery of fires on the day shift was considerably lower than expected, and the discovery of fires on the evening and night shifts was considerably higher than expected.

TIME OF YEAR

Reported fires by time of year are listed in table 20 and illustrated in figure 11. Data are shown grouped by season, with fall including September through November, winter including December through February, spring including March through May, and summer including June through August. No dramatic trends are evident in the data; however, a slight decrease was noted for the winter months during the most recent time period.

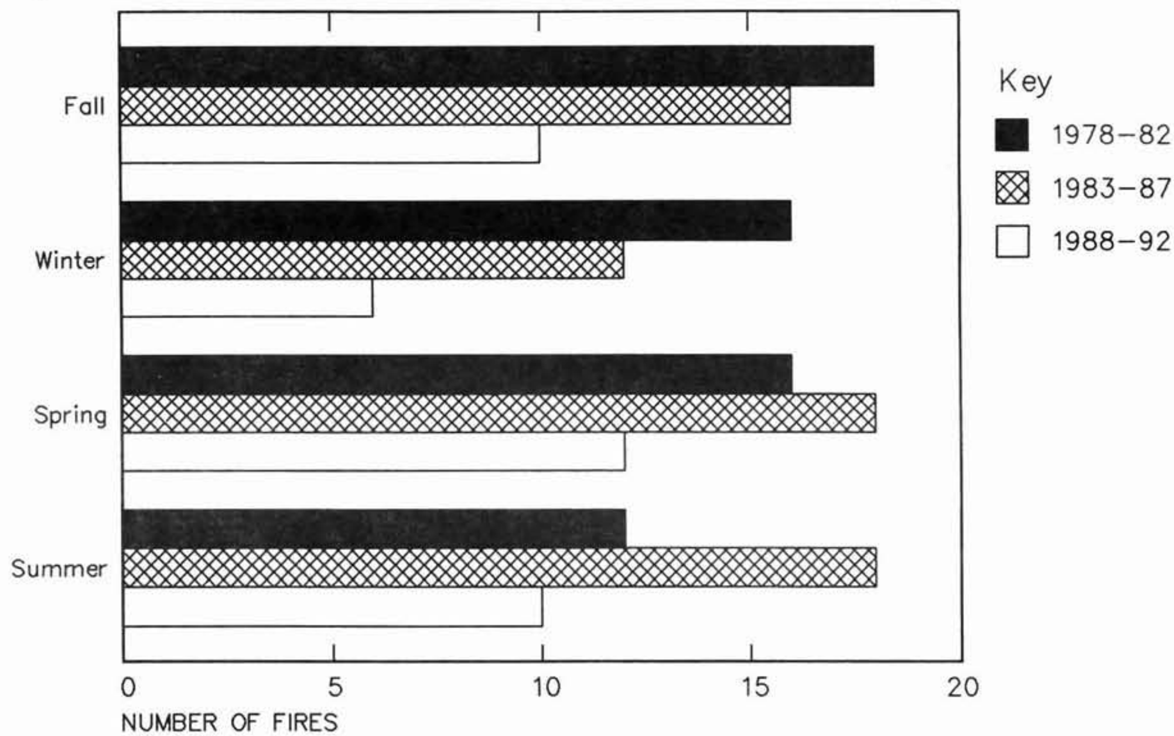
Table 20.—Number of fires by time of year and time period

Time of year	1978-82	1983-87	1988-92	1978-92
Fall	18	16	10	44
Winter	16	12	6	34
Spring	16	18	12	46
Summer	12	18	10	40
Total	62	64	38	164

INJURIES AND FATALITIES

Table 21 shows injuries and fatalities caused by underground coal mine fires from 1978 through 1992, and the location, equipment involved, and ignition source for each fire that caused an injury or fatality. Over this 15-year period, a total of 17 fires caused 43 injuries and 30 fatalities. The injury incidence rate (injuries per 100 million tons of coal mined) over this period was 0.82, and the fatality incidence rate (fatalities per 100 million tons of coal mined) was 0.57. The injury incidence rate during the 1950 through 1977 period was 2.35, or 2.86 times the 1978 through 1992 rate. The fatal incidence rate over the 1950 through 1977 period was 0.79, or 1.38 times the 1978 through 1992 rate.

Figure 11



Number of fires by time of year, 1978-92.

Table 21.—Injuries and fatal fires by year, number of injuries and/or fatalities, location, equipment involved, and ignition source

Year	Number of injuries	Number of fatalities	Location	Equipment involved	Ignition source
1978	0	1	Shaft bottom	Oxyacetylene torch	Flame cutting.
	6	0	Track entry	Trolley line	Electrical.
1979	1	0	..do.	..do.	Electrical.
1980	2	0	Working face	Shuttle car	Electrical.
1981	1	0	Track entry	Trolley line	Electrical.
1982	1	0	Not reported	Oxyacetylene torch	Flame cutting.
	2	0	Track entry	Air compressor	Friction.
1984	10	0	Longwall headgate	Power cable	Electrical.
	0	27	Main intake	Air compressor	Friction.
1986	3	0	Longwall face	Oxyacetylene torch	Flame cutting.
	2	1	Belt entry	Conveyor belt	Friction.
1987	0	1	Working face	Continuous miner	Friction.
	3	0	Longwall headgate	Air compressor	Friction.
	1	0	Belt entry	Conveyor belt	Unknown.
1988	5	0	..do.	..do.	Friction.
1992	1	0	Working face	Power center	Electrical.
	5	0	..do.	Not reported	Not reported.
Total	43	30	NAp	NAp	NAp.

NAp Not applicable.

The most frequent locations for injury fires were the track entry (4 fires, 10 injuries), working face (3 fires, 8 injuries), and belt entry (3 fires, 8 injuries). The four track entry fires all occurred before 1983, while the three belt entry fires all occurred after 1985. For fatal fires, no single location accounted for more than one fire, with fires occurring at the shaft bottom, main intake, belt entry, and working face. From IC 8830 (5), the most frequent location for injury fires during the 1970 through 1977 period was the working face (five fires) and haulageway (two fires). For fatal fires, two were located at the face and three were outby during the 1970-77 period.

The equipment most frequently involved in injury fires was the trolley line (three fires, eight injuries) and conveyor belt (three fires, eight injuries). Oxyacetylene cutting torches and air compressors were each involved in two injury fires. No single type of equipment was involved in more than one fatal fire, with fires involving an oxyacetylene torch, air compressor, conveyor belt, and continuous miner. From IC 8830 (*5*), the equipment most frequently involved in injury fires during the 1970 through 1977 period was oxyacetylene cutting torches, with three fires. For fatal fires, no type of equipment was involved in more than one fire during the 1970-77 period.

The most common ignition sources for injury fires were electrical (6 fires, 20 injuries), friction (4 fires, 10 injuries), and flame cutting (2 fires, 4 injuries). The ignition source for three of the four fatal fires was friction; however, the source of the friction was different in all three cases (overheated air compressor, stuck idlers on conveyor belt, frictional ignition of methane at a working face). From IC 8830 (*5*), the most common ignition source for injury fires during the 1970 through 1977 period was electrical (six fires), with no other ignition source accounting for more than one fire. During that time period, all five fatal fires were electrical in origin.

METHOD OF EXTINGUISHMENT

The attempted and successful extinguishing agents for underground coal mine fires from 1978 through 1992 are listed in table 22. Figure 12 shows successful extinguishing agents only. For all three time periods, water was the most common attempted and successful extinguishing agent, followed by dry chemicals. Use of rock dust was more common than sealing (including both sealing with and without carbon dioxide or nitrogen injection). However, sealing was successful in extinguishing more fires than rock dust. Fire-fighting usually involved the use of more than one extinguishing agent, and, often, more than one extinguishing agent was required for successful extinguishment. Thus, the totals in both attempted extinguishment and successful extinguishment add to more than the total number of fires that occurred during the period.

The success rate for the various extinguishing agents is also shown in table 22 for all time periods. The success rate is the ratio of the number of fires that were successfully extinguished with a given agent to the number of fires in which an attempt was made to extinguish the fire with that agent.

This analysis is not intended to suggest that one agent is inherently more effective in fighting coal mine fires than another agent based solely on the difference in the number of successful attempts or success rate. Other factors were often significant, such as the quantity of agent immediately available to fire fighters and the size of the fire.

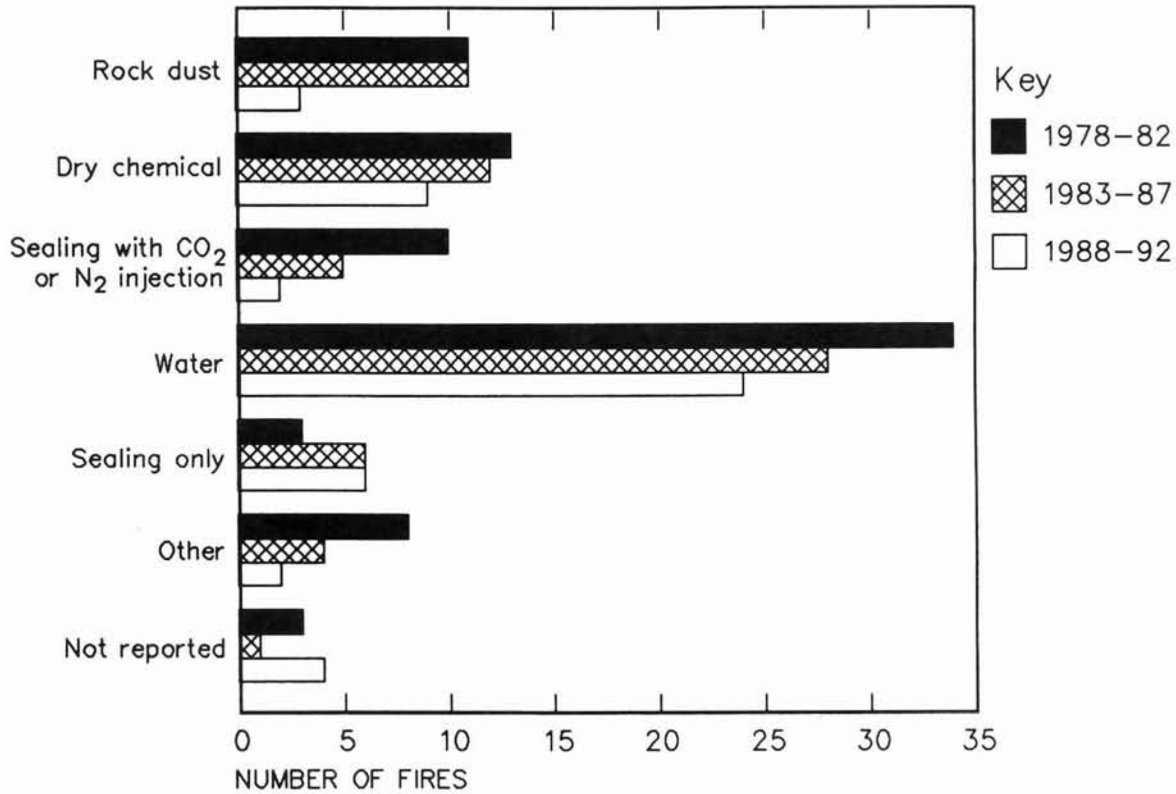
In the case of water versus rock dust or dry chemical extinguishers, for example, fire fighters might use rock dust or dry chemicals to suppress a fire while a hose line is connected and extended to the fire area. Total extinguishment could be achieved with water, and table 22 indicates water as the successful extinguishing agent. However, successful extinguishment might not have been possible without the temporary control of the fire using rock dust or dry chemical extinguishers.

Table 22.—Number of fires by method of extinguishment, time period, and number of attempts, number of successful attempts, and success rate of extinguishment

Method of extinguishment	1978-82			1983-87		
	Number of attempts	Number of successful attempts	Success rate	Number of attempts	Number of successful attempts	Success rate
Rock dust	21	11	0.52	13	11	0.85
Dry chemicals	32	13	0.41	17	12	0.71
Sealing with CO_2 or N_2 injection	10	10	1.00	7	5	0.71
Water	39	34	0.87	35	28	0.80
Sealing only	3	3	1.00	9	6	0.67
Other	6	8	NA	7	4	NA
Not reported	3	3	NA	1	1	NA
	1988-92			1978-92		
	Number of attempts	Number of successful attempts	Success rate	Number of attempts	Number of successful attempts	Success rate
Rock dust	10	3	0.30	44	25	0.57
Dry chemicals	25	9	0.36	74	34	0.46
Sealing with CO_2 or N_2 injection	2	2	1.00	19	17	0.89
Water	40	24	0.60	114	86	0.75
Sealing only	7	6	0.86	19	15	0.79
Other	9	2	NA	22	14	NA
Not reported	4	4	NA	8	8	NA

NA Not available.

Figure 12



Number of fires by successful method of extinguishment, 1978-92.

More importantly, it must be remembered that the data utilized in this analysis are limited, almost entirely, to reportable fires. However, it is believed that most fires are successfully extinguished before they become reportable (less than 30 min and without injury). For example, in IC 8830 (*5*), it is estimated that three times more fires are extinguished at the nonreportable stage than those that cause an injury or last longer than 30 min, thus becoming reportable. In order for a fire to be extinguished while still nonreportable, firefighting would almost certainly have to be initiated immediately, or within a very few minutes after those fires start. Dry chemicals, rock dust, and manually operated or automatic fire suppression systems would be the most likely methods to be used immediately on a fire, thereby achieving extinguishment while the fire is still nonreportable. The relatively small number of cases of successful extinguishment for dry chemical, rock dust, and manually operated or automatic fire suppression systems is believed to relate more to their effectiveness in extinguishing fires than to their lack of use or lack of effectiveness.

If it were possible to determine the success rate for extinguishing agents based on the total number of fires occurring rather than the number of reportable fires, the results would almost certainly be quite different than those shown in table 22. Again, referring to IC 8830 (*5*) where such data are included, the most common successful extinguishing agent for reportable fires from 1953 through 1977 was water, but the most common successful extinguishing agent for nonreportable fires during that period was dry chemicals.

Sealing a mine or portion of a mine is the fire extinguishing method of last resort and is implemented only when all other methods have been tried and failed, or eliminated from consideration. Sealing a mine or portion of a mine is laborious and dangerous work, extremely costly, risks the loss of considerable coal resources, and often prevents mine production activities for months or years. Carbon dioxide or nitrogen injection can add considerable expense to the already high costs of sealing a mine. Every attempt is made to extinguish a mine fire by means other than sealing. Thus, the number of fires where extinguishment was attempted by sealing is a measure of the failure of other fire-fighting methods. During the 1978 through 1992 period, 23 pct of mine fires required all or part of the mine to be sealed. The proportion of mine fires that were required to be sealed during the 1953 through 1977 period was exactly the same: 23 pct.

MINE EVACUATIONS

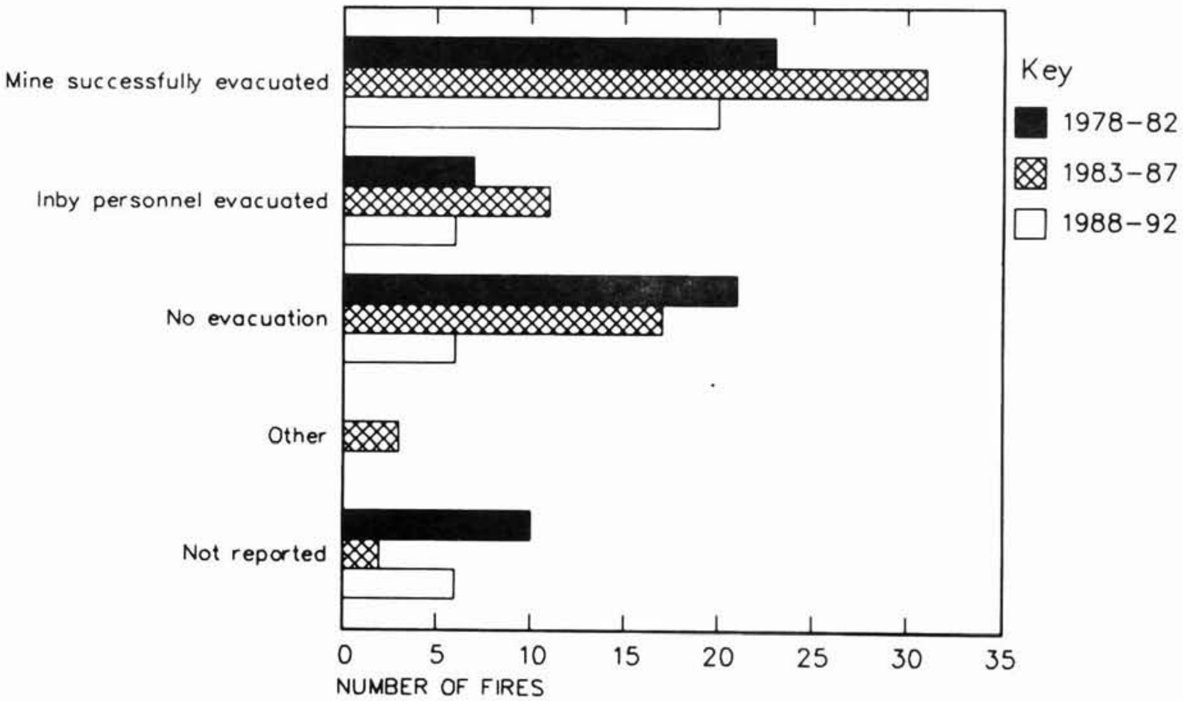
The number and extent of mine evacuations implemented at mines experiencing reportable fires during the 1978 through 1992 period are listed in table 23 and illustrated in figure 13. During this period, total mine evacuations were implemented in 74 out of 164 fires, or 45 pct. During the 1978 through 1982 period, total mine evacuations were implemented in 23 out of 62 fires, or 37 pct. During the 1988 through 1992 period, this proportion had increased to 20 out of 38 fires, or 53 pct. When considering both total evacuations and partial evacuations (evacuating inby personnel only), the proportion increased from 48 pct in the earlier time period to 68 pct in the later time period. The downward trend in the "no evacuation" category is clearly evident in figure 13.

The fire report data do not support a definitive explanation for this increase in the percentage of fires resulting in total or partial evacuations. It may result from a generally increased level of knowledge of, and caution by, management regarding the risks to underground personnel from fire.

Table 23.—Number of fires by degree of mine evacuation and time period

Degree of evacuation	1978-82	1983-87	1988-92	1978-92
Mine successfully evacuated	23	31	20	74
Inby personnel evacuated	7	11	6	24
No evacuation	21	17	6	44
Other	0	3	0	3
Not reported	11	2	6	19
Total	62	64	38	164

Figure 13



Number of fires by degree of mine evacuation, 1978-92.

CONCLUSIONS

The major findings of this statistical analysis of underground coal mine fires are shown in table 24. For comparison purposes, table 25 contains the major findings from IC 8830 (*5*).

During the 1978 through 1992 period, the overall fire incidence rate (fires per million tons of coal mined) was 0.031. The fire incidence rate for the 1950 through 1977 period was 0.115, over three times higher than the rate for the 1978 through 1992 period. The injury incidence rate (injuries caused by underground coal mine fires per 100 million tons of coal mined) for the 1978 through 1992 period was 0.82. The injury incidence rate for the 1950 through 1977 period was 2.35, over 2½ times higher than the rate for the 1978 through 1992 period. The fatality incidence rate (fatalities caused by underground coal mine fires per 100 million tons of coal mined) for the 1978 through 1992 period was 0.57. The fatality incidence rate for the 1950 through 1977 period was 0.79, about one-third higher than the rate for the 1978 through 1992 period.

In comparing the 1950 through 1977 period to the 1978 through 1992 period, significant reductions in the incidence rates for total fires, injuries, and fatalities are clearly evident. However, since 1968, no downward trend is evident in incidence rates for total fires, injuries, or fatalities.

Table 24.—Major findings of statistical analysis of underground coal mine fires, 1978-92

Category	All fires	Injury fires	Fatal fires
Ignition source	Electrical, friction, welding or cutting.	Electrical, friction, welding or cutting.	Friction, welding or cutting.
Detection	Miner saw or smelled smoke, miner saw fire start, examiner saw or smelled smoke.	Miner saw fire start, miner saw or smelled smoke.	Miner saw fire start, miner saw or smelled smoke.
Burning substance	Coal, electrical insulation, conveyor belt or rollers.	Coal, electrical insulation, conveyor belt or rollers.	Coal, conveyor belt or rollers, electrical insulation.
Equipment involved	Conveyor belt, welding or cutting, trolley line, electrical equipment.	Trolley line, conveyor belt, welding or cutting, air compressor.	Conveyor belt, air compressor, welding or cutting, continuous miner.
Location	Belt entry, working face, intake aircourse, track entry.	Track entry, working face, belt entry, longwall.	Shaft bottom, intake aircourse, belt entry, working face.
Successful extinguishing agent	Water, dry chemicals, rock dust	Water, dry chemicals, rock dust.	Water, dry chemicals.

Table 25.—Major findings of statistical analysis of underground coal mines fires, 1950-77

Category	All fires	Injury fires	Fatal fires
Ignition source	Electrical, spontaneous combustion, friction.	Electrical, welding or cutting	Electrical.
Detection	Miner saw fire start, miner saw or smelled smoke.	Miner saw fire start, miner saw or smelled smoke.	Miner saw fire start, miner saw or smelled smoke.
Burning substance	Electrical insulation, coal, conveyor belt or rollers.	Electrical insulation, coal, conveyor belt or rollers.	Electrical insulation, coal, conveyor belt or rollers.
Equipment involved	Conveyor belt, cutting machine, track locomotive.	Welding or cutting	Conveyor belt, cutting machine, track locomotive.
Location	Outby working face, working face, haulageway.	Outby face, haulageway	Outby face, working face.
Successful extinguishing agent	Water, dry chemicals, rock dust	Water, dry chemicals, rock dust.	Water, dry chemicals, rock dust.

Following the pattern established during the 1950 through 1977 period, electricity was the most frequent ignition source for underground coal mine fires during 1978 through 1992, followed by friction and welding-cutting. However, for the most recent time period, friction became the leading ignition source. The most frequent ignition sources for injury fires were also electricity, friction, and welding-cutting. For fatal fires, friction was the most frequent ignition source. The most notable differences between the 1950-77 and the 1978-92 ignition source data are the decline in the incidence of electrical fires and the emergence of friction as an ignition source of increasing significance. Electricity is still the most frequent source of fires, but during the 1950-77 period, 62 pct of all fires were electrical in origin, compared to 35 pct during the 1978-92 period. In contrast, friction was the ignition source in 21 pct of all fires during the 1978-92 period, but only 9.6 pct during the 1950-77 period. It is likely that the increased usage of conveyor belts for both section haulage and main haulage underground and the increased use of mobile equipment and air compressors have all contributed to the increase in fires caused by friction.

The most frequent method of fire detection during the 1978-92 period was nearby miners who saw or smelled smoke and investigated until they discovered a fire. The next most frequent fire detection methods were miners who were present when the fire actually started and pre-shift examiners or supervisors who saw or smelled smoke as they fire bossed the mine. For injury and fatal fires, the most frequent method of fire detection was miners who saw the fire start, followed by nearby miners who saw or smelled smoke. During the 1950-77 period, the most frequent method of fire detection for all fires, injury fires, and fatal fires were miners who saw the fire start, followed by nearby miners who saw or smelled smoke.

Coal, electrical insulation, and rubber were the most frequent burning substances involved in underground coal mine fires during both the 1950-77 and 1978-92 periods. These three materials were also the most frequent burning substances for injury fires and fatal fires during both time periods. Coal was involved in about 45 pct of all fires. Electrical insulation was involved in 43 pct of fires prior to 1978, but only 30 pct after 1978. Rubber was involved in about 30 pct of fires during both time periods. During the 1978 through 1992 period, fires involving rubber were equally divided between rubber hoses-tires and conveyor belts.

During the 1978-92 period, conveyor belts, welding and cutting equipment, and trolley lines were the equipment most frequently involved in underground coal mine fires. The equipment most frequently involved in injury fires during that period was the trolley line, followed by conveyor belts, welding and cutting equipment, and air compressors. Only four fatal fires occurred during the period, with one each involving a conveyor belt, air compressor, welding and cutting equipment, and continuous miner. During the 1950-77 period, conveyor belts were the equipment most frequently involved in fires, followed by cutting machines and trolley locomotives. During that time period, the equipment most frequently involved in injury fires was welding and cutting equipment. For fatal fires, it was conveyor belts, cutting machines, and trolley locomotives. Conveyor belts, trolley-powered equipment, and welding and cutting equipment have been the leading equipment involved in underground coal mine fires for over 40 years, from 1950 through 1992. The only new equipment type to become an important factor in recent years is the air compressor.

During the 1978-92 period, the most fires occurred in the belt entry, followed by the working face area, the intake entry, and the track entry. The most injury fires occurred in the track entry, followed by the working face area and the belt entry. Fatal fires occurred in the shaft bottom area, belt entry, intake entry, and working face area. During the 1950-77 period, most fires occurred immediately outby the working face. This area was also the frequent location for injury fires and fatal fires during that time period. Other frequent fire locations included the working face and haulageway (both track and belt).

The agent that was most frequently successful in extinguishing underground coal mine fires was water, followed by dry chemicals and rock dust. This was true for all fires from 1950 through 1992, as well as for injury fires over that period and for fatal fires during the 1950-77 period.

Two significant conclusions can be drawn from this analysis. First and most important, the fire incidence rate, injury incidence rate, and fatality incidence rate have all declined between the 1950 through 1977 period and the 1978 through 1992 period. Likely causes of this decline are safer mining equipment and practices and stricter enforcement of mine fire safety regulations.

The other significant conclusion is the similarity between the 1950 through 1977 and the 1978 through 1992 data sets regarding ignition sources, fire detection, burning substances, equipment involved, location, and successful extinguishing agent. These sets were almost identical for both time periods (though sometimes in differing rank order), which together span over 40 years. This observation is in apparent conflict with the obvious and fundamental changes in mining technology, methods, and equipment that have occurred over the past four decades.

One possible explanation for the decline in fire incidence rates but lack of change in fire characteristics is that the newer technology and equipment may, in relative terms, present less fire risk, while the older technology and methods may present an inherently greater fire risk, even when improved fire protection technology and stricter regulations are applied. As older, more fire-prone equipment is mothballed or scrapped, or "old technology" mines are shut down, the fire risks they represent are mothballed, scrapped, and shut down along with them, resulting in a lower overall fire incidence rate. For example, in the earlier time periods, a large number of fires were reported on trolley equipment and cutting machines. These represent older mining technologies. However, for the most recent time period, very few fires were reported on longwall faces, which represent a newer technology. As new and safer materials, fire protection technologies, electrical systems, hydraulic systems, etc. are developed and made available, they may be more readily incorporated into new equipment designs and newer mines than retrofitted to older equipment or installed in older mines. Fires involving the newer generation of equipment may be occurring, but might be of shorter duration and therefore not reportable.

Future implications of these findings are not obvious. Although a continuation of the decline in the number or fires and fire incidence rates might be expected, such a decline would not be automatic. The observed decline in reported fires and incidence rates is probably the result of a combination of many factors, though improvements in mining and safety technology coupled with stricter regulations and enforcement activities must certainly be the predominate factors responsible. It must therefore be concluded that further reductions in the number of fires and the fire incidence rate will be possible only through continued efforts in all of these areas.

It must also be recognized that although newer mining technology may be inherently less fire prone than older technology, it is not without risk. Conveyor belt haulage, for example, may be an improvement over track haulage in terms of fire risk, but conveyors are, nonetheless, a significant source of fires in underground coal mines. As new technologies are introduced, their effect on mine fire protection must continually be assessed and deficiencies corrected on an ongoing basis.

Clearly, improvements in mine fire protection technology are necessary and achievable, and use of data such as that contained in this report can assist in these efforts.

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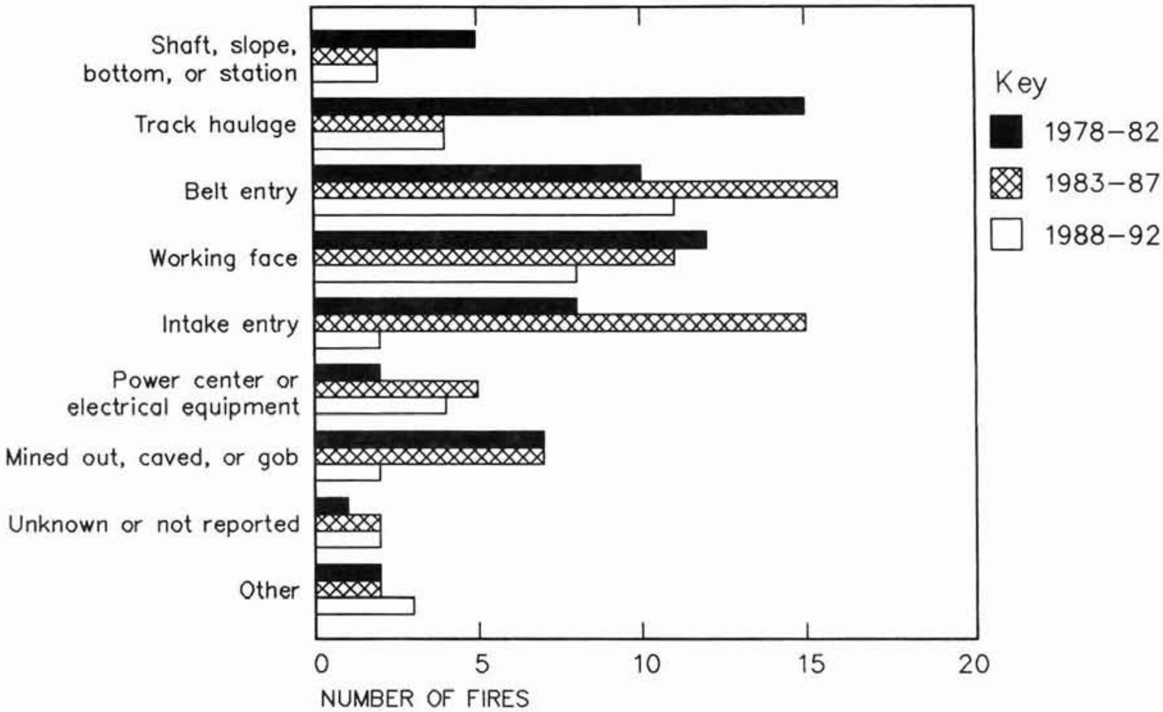
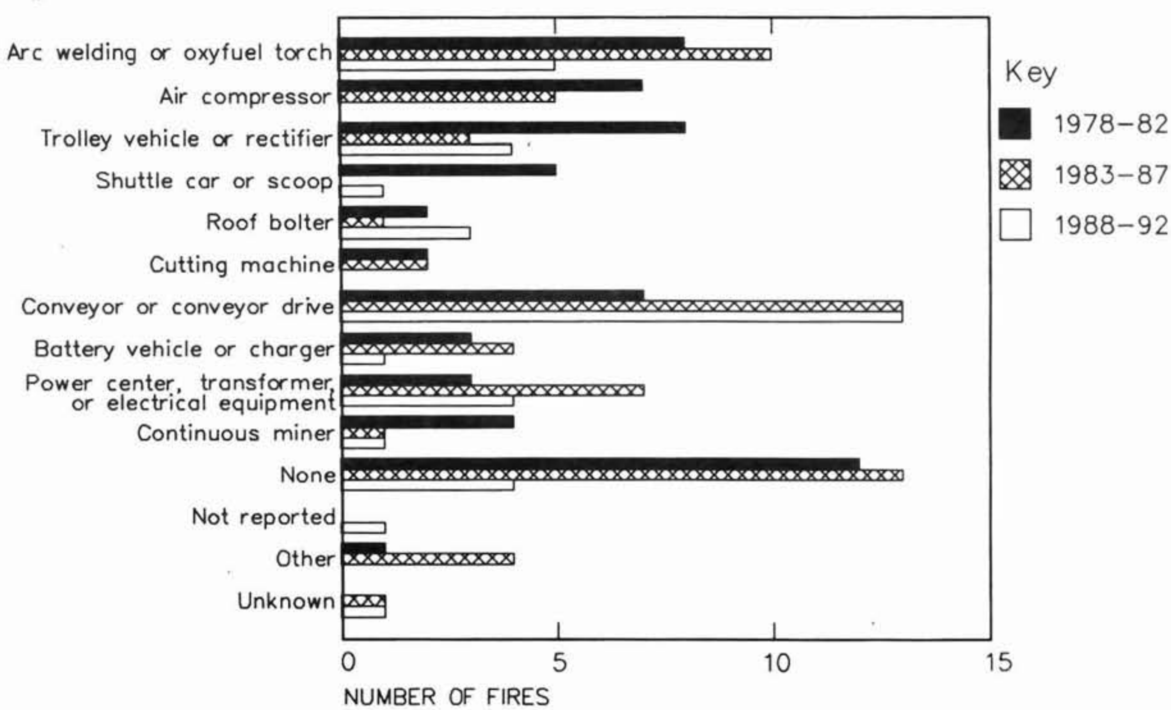
Figure 7



Number of fires by underground location, 1978-92.

Figure 8



Number of fires by equipment involved, 1978-92.