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Department of Health and Human Services
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

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By Maria I. De Rosa

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

hr	hour(s)	st	short ton
min	minute(s)		

ANALYSIS OF MINE FIRES FOR ALL U.S. UNDERGROUND AND SURFACE COAL MINING CATEGORIES: 1990–1999

By Maria I. De Rosa[1]

ABSTRACT

This report analyzes mine fires for all U.S. underground and surface coal mining categories by state and 2-year time periods during 1990–1999. Risk rate values are derived, and ignition source, methods of fire detection and suppression, and other variables are examined. The data were derived from Mine Safety and Health Administration (MSHA) mine fire accident publications and verbal communications with mine personnel. The analysis will provide the National Institute for Occupational Safety and Health, MSHA, and the mining industry with a better understanding of the causes and hazards associated with mine fires and will form a basis for future fire research programs.

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INTRODUCTION

Coal mine fires pose a constant danger to the safety of miners and to their livelihood. Underground mine fires pose an added hazard because of the confined environment with remote exits. Enactment of safety regulations [30 CFR[2] 75 and 77] for underground coal mines and surface coal operations has greatly improved the safety of miners. However, mine fires and fire injuries remain serious hazards for all coal mining operations.

This report analyzes mine fires and fire injuries for all U.S. coal mining categories (underground coal mines, surface of underground coal mines, surface coal mines, and coal preparation plants) during 1990–1999. Fires involving contractors are also included in the analysis. Similar analyses (for underground coal mines only) by the former U.S. Bureau of Mines (USBM) were reported by McDonald and Pomroy [1980] and Pomroy and Carigiet [1995] for 1950–1977 and 1978–1992, respectively. For comparison purposes, data for 1978–1992 are mentioned in the "Underground Coal Mine Fires" section of this report. Detailed analyses of mobile equipment fires for all underground and surface coal and metal/nonmetal mining categories during 1990–1999 have recently been reported by NIOSH [De Rosa 2004].

Risk rate values (fire and injury risk rates) for the 10-year period (1990–1999) and for five successive 2-year periods within the 10-year period are derived. Risk rate values for individual states for the 10-year period are also derived. Other variables by state and time period include employees' working hours, lost workdays, and coal production (underground and surface coal mines only). The number of fire fatalities is reported by time period. Variables such as ignition source, method of detection and suppression, equipment involved, location, and burning material are reported by five 2-year periods only. Furthermore, the number of fire injuries per number of fires causing injuries and total fires has been analyzed by year, ignition source, equipment involved, and location. For comparison purposes, the major fire and fire injury findings for all coal mining categories have been reported.

The data in this report were derived from "Injury Experience in Coal Mining" [MSHA 1991a, 1992, 1993, 1994a, 1995a, 1996, 1997, 1998b, 1999c, 2000], "Fire Accident Reports" [MSHA 1991b,c; 1994b; 1995b,c; 1998a,c,d,e,f; 1999a,b,d,e], MSHA "Fire Accident Abstracts" internal publications, and verbal communications with mine personnel. Mining companies are required by 30 CFR 50 to report to MSHA all fires that result in injuries and fires that are not extinguished within 30 min of discovery. A small number of fires lasting <30 min without injuries reported in the "Fire Accident Abstracts" have been included in this report.

The analysis in this report will provide the National Institute for Occupational Safety and Health (NIOSH), the Mine Safety and Health Administration (MSHA), and the mining industry with a better understanding of the causes and hazards of mine fires and fire injuries. It will also form a basis for developing future fire research programs.

METHODOLOGIES

For all coal mining categories, data on coal mine fires during 1990–1999 have been reported as actual numbers and calculated values.

1. For each mining category, actual numbers include the total number of fires, fire injuries, employees' working hours, lost workdays, and coal production (for underground and surface mines only) for a 10-year period (1990–1999) and for five successive 2-year periods within the 10-year period. These numbers have also been reported by state (10-year period). The actual number of fire fatalities has been reported by time period. Furthermore, actual numbers of fires for the five 2-year periods have been reported by ignition source, method of detection and suppression, equipment involved, location, and burning material. Actual numbers of fire injuries per number of fires causing injuries and total fires have been reported by year, ignition source, equipment involved, and location.

2. For each mining category, the calculated values include the fire and injury risk rates during the 10-year period and the five 2-year periods. The fire risk rate (Frr) values were calculated according to the USBM formula [Pomroy and Carigiet 1995]. The injury risk rate (Irr) values were calculated according to the MSHA formula [MSHA 1991a, 1992, 1993, 1994a, 1995a, 1996, 1997, 1998b, 1999c, 2000]. Also, risk rate values for individual states (10-year period) were calculated according to the above-mentioned formulas.

Of note is that only the risk rate values for the 10-year and five 2-year periods and risk rate values for individual states with the highest number of fires and fire injuries were considered for comparison purposes. The fatality risk rate values were not calculated because of the extremely small number of fire fatalities during the 10-year period.

3. Calculations of risk rate values are as follows:

a. Fire risk rate (Frr) value: Number of fires per million tons of coal produced [Pomroy and Carigiet 1995].
b. Injury risk rate (Irr) value: Number of fire injuries multiplied by 200,000 working hours per total employees' working hours [MSHA 1991a, 1992, 1993, 1994a, 1995a, 1996, 1997, 1998b, 1999c, 2000]. The Irr value is the average risk rate value for the number of fire injuries per 200,000 working hours for a given time period.

[2]*Code of Federal Regulations.* See CFR in references.

c. Total employees' working hours (Ewhr) value during 1990–1999: Sum of 10 yearly Ewhr values for all of the states involved in fires. This value also includes the Ewhr value reported for all other states not involved in fires. The Ewhr value for each state (10-year time period) is the sum of 10 yearly Ewhr values for that state.
d. Total employees' working hours (Ewhr) value for five 2-year time periods: Sum of two yearly Ewhr values for all of the states, involved and not involved in fires, within the 2-year period.
e. The coal production (CP) values in short tons were calculated similarly.
f. The lost workday (LWD) values were reported by state and time period.
g. An LWD value of 6,000, assigned by MSHA to each fatality, was reported.

FIRE DATA ANALYSIS FOR ALL COAL MINING CATEGORIES

UNDERGROUND COAL MINE FIRES

Table 1 and figure 1 show the number of fires and fire injuries that occurred in underground coal mines by state during 1990–1999. Table 1 also shows by state the risk rates, employees' working hours, lost workdays, and coal production. Overall, 87 fires occurred in 12 states. Twenty-seven of those fires caused 34 injuries (the yearly average was 8.7 fires and 3.4 injuries). One fire and one injury involved a contractor. The underground mine fires required 25 mine rescue team interventions and 30 mine/section evacuations followed by 13 mine/section sealing/flooding/CO_2/N_2 gas injections. The Ewhr value was $1,003 \times 10^6$ hr (Irr = 0.007), the CP value was $4,008 \times 10^6$ st (Frr = 0.022), and the LWD value was 208.

Virginia had the most fires (15 fires and 7 injuries). Pennsylvania had the most fire injuries (12 fires and 9 injuries), followed by Kentucky (12 fires and 6 injuries), and Alabama (12 fires and 4 injuries). Among these states, Alabama had the highest fire risk rate value (Frr = 0.073), whereas Pennsylvania had the highest injury risk rate value (Irr = 0.016).

Table 2, partly illustrated in figure 2, shows by time period the number of fires, fire injuries, risk rates, employees' working hours, lost workdays, and coal production. The number of fires and fire injuries show a decrease followed by an increase during the five time periods (see table 2 and figure 2). This was accompanied by a decline in employees' working hours throughout the periods and an overall small decrease in coal production. The Irr and Frr values follow patterns similar to those shown by the fire and injury values.

By comparison, data from Pomroy and Carigiet [1995] show that during 1978–1992 a total of 11 states were involved in 164 underground coal mine fires (yearly average, 10.8) with 43 injuries (yearly average, 2.9) and 27 fatalities (yearly average, 2; however, the 27 deaths occurred during a single fire caused by an overheated air compressor [MSHA 1984]). The CP value was $5,340 \times 10^6$ st (yearly average, 356×10^6 st) (Frr = 0.031). Data on employees' working hours and injury risk rates were not available.

Tables 3–8 show the number of fires by ignition source, method of detection and suppression, equipment involved, location, and burning material by time period. Figure 3 shows the major variables during 1990–1999. Table 9 shows the number of fire injuries per number of fires causing injuries and total fires by year, ignition source, equipment involved, and location.

Table 1.—Number of fires, fire injuries, and risk rates for underground coal mines by state, employees' working hours, lost workdays, and coal production, 1990–1999

State[1]	No. fires[1]	No. injuries[1]	LWD[2]	Ewhr,[2] 10^6 hr	CP,[2] 10^6 st	Frr[3]	Irr[3]
Alabama	12	4	6	67	165	0.073	0.012
Colorado	7	1	4	20	148	0.047	0.01
Illinois	12	1	6	96	403	0.03	0.002
Indiana	1	1	—	5	24	0.042	0.04
Kentucky	12	6	1	245	948	0.013	0.005
Ohio	1	—	—	32	133	0.0075	—
Pennsylvania	12	9	14	116	456	0.026	0.016
Tennessee	2	—	—	9	21	0.095	—
Utah	1	—	—	34	252	0.004	—
Virginia	15	7	140	96	291	0.052	0.015
West Virginia	9	5	37	271	1,131	0.008	0.004
Wyoming	3	—	—	3	23	0.13	—
All other states	—	—	—	9	13	—	—
Total	87	34	208	1,003	4,008	[3]0.022	[3]0.007

[1]Derived from MSHA "Fire Accident Abstract" and "Fire Accident Report" publications.
[2]Derived from MSHA "Injury Experience in Coal Mining" publications.
[3]Calculated according to USBM and MSHA formulas reported in the "Methodologies" section.

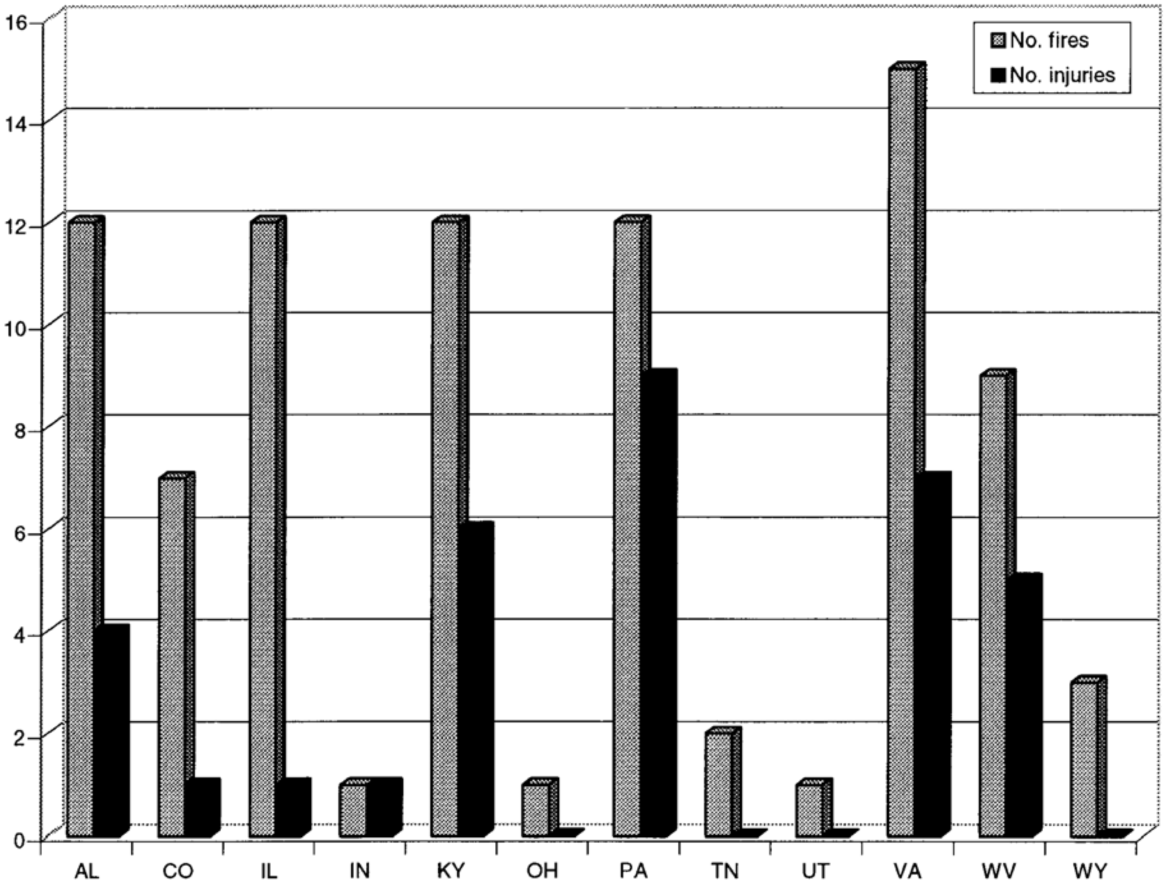

Figure 1.—Number of fires and fire injuries for underground coal mines by state, 1990–1999.

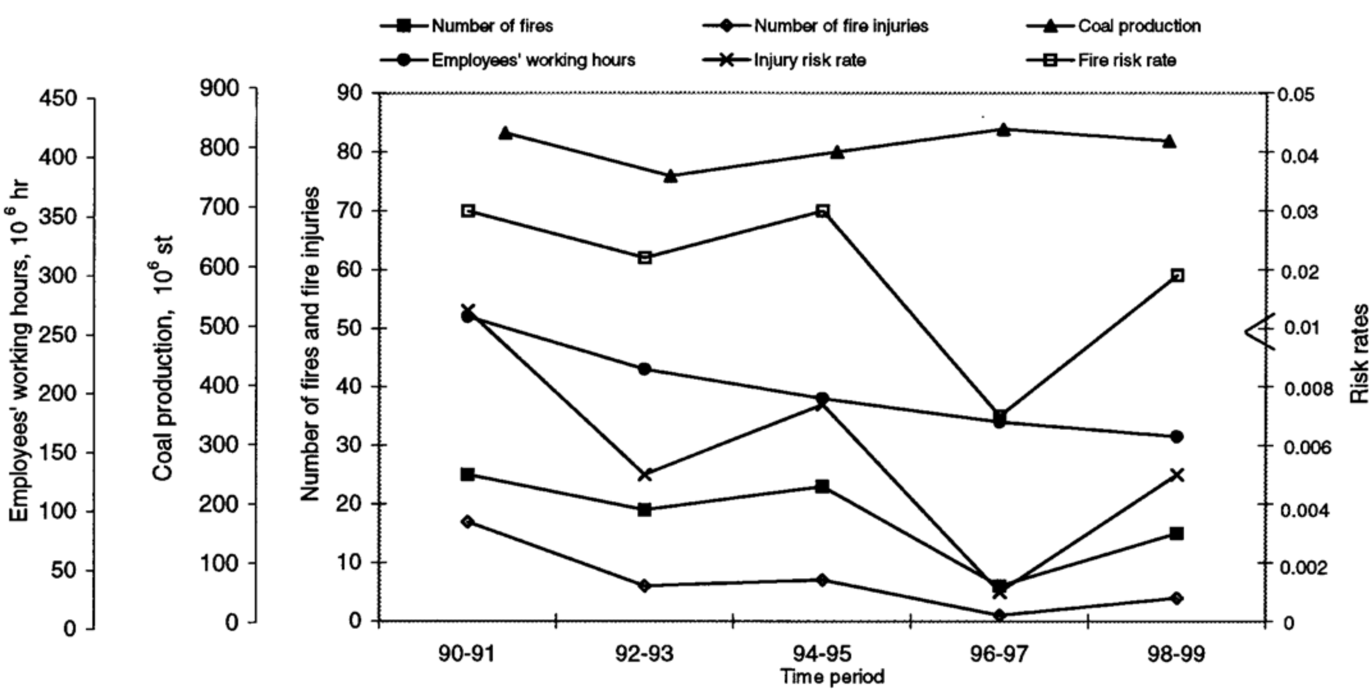

Figure 2.—Number of fires, fire injuries, risk rates, and coal production for underground coal mines by time period and employees' working hours, 1990–1999.

Table 2.—Number of fires, fire injuries, and risk rates for underground coal mines by time period, employees' working hours, lost workdays, and coal production. 1990–1999

	Time period					
	90-91	92-93	94-95	96-97	98-99	90-99
Number of fires[1]	25	18	23	6	15	87
Number of fire injuries[1]	17	5	7	1	4	34
LWD[2]	121	45	12	8	22	208
Ewhr,[2] 10^6 hr	257	209	196	179	162	1,003
CP,[2] 10^6 st	824	752	792	830	810	4,008
Frr[3]	0.03	0.024	0.03	0.007	0.019	[3]0.022
Irr[3]	0.013	0.005	0.007	0.001	0.005	[3]0.007

[1]Derived from MSHA "Fire Accident Abstract" and "Fire Accident Report" publications.
[2]Derived from MSHA "Injury Experience in Coal Mining" publications.
[3]Calculated according to USBM and MSHA formulas reported in the "Methodologies" section.

Table 3.—Number of fires for underground coal mines by ignition source and time period, 1990–1999

Ignition source	Time period					
	90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Flame cutting/welding spark/slag/flame[1]	8	2	3	2	2	17
Spontaneous combustion[2]	4	2	4	3	2	15
Electrical short/arcing/explosion[3]	5	7	9	1	6	28
Conveyor belt friction	1	5	5	—	4	15
Heat source	—	—	1	—	—	1
Overheated oil/grease	2	—	—	—	—	2
Mechanical malfunction/friction	3	1	1	—	—	5
Flammable liquid/refueling fuel on hot surfaces	1	—	—	—	—	1
Hydraulic fluid/fuel on equipment hot surfaces	—	1	—	—	—	1
Other	1	—	—	—	1	2
Total	25	18	23	6	15	87

[1]This source usually caused fires involving welders' clothing or oxyfuel/grease. However, in one instance sparks/hot slag/flames caused a methane ignition followed by a large fire requiring firefighting intervention and mine/section evacuation and sealing. In another instance, undetected hot slag caused a large fire requiring firefighting intervention and mine evacuation and sealing, followed by a methane explosion.
[2]This source at least twice was accompanied by methane explosions.
[3]This source caused 12 mobile equipment fires.

Table 4.—Number of fires for underground coal mines by method of detection and time period, 1990–1999

Method of detection	Time period					
	90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Visual method:						
Flames/flash fires	2	1	3	—	—	6
Sparks	7	2	3	1	2	15
Smoke	3	4	2	—	1	10
Late smoke detection	7	9	12	2	6	36
CO/H_2 gas sampling	1	1	2	2	1	7
Touched hot spots	1	—	—	—	1	2
CO/smoke belt detection system	—	—	1	—	—	1
Mine-wide monitoring system	—	—	—	—	1	1
Undetected	1	—	—	—	1	2
Explosion[1]	3	1	—	1	1	6
Power loss	—	—	—	—	1	1
Total	25	18	23	6	15	87

[1]Includes methane ignition, electrical cable, and starter box explosions.

Table 5.—Number of fires for underground coal mines by suppression method and time period, 1990–1999

Suppression method	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Mine/section sealing/flooding/CO_2/N_2 gas injections	3	2	3	2	3	13
Portable fire extinguisher	4	6	5	1	1	17
Water	6	2	8	1	3	20
Manual/FE[1]	7	1	1	—	2	11
FE-dry chemical powder/rock dust/water[2]	2	6	5	1	3	17
Machine water spray	2	—	—	—	—	2
FSS-dry chemical powder-water	—	1	1	—	1	3
Destroyed/heavily damaged[3]	1	—	—	1	2	4
Total	25	18	23	6	15	87

FE Portable fire extinguisher.
FSS Machine fire suppression system.
[1]Methods used by welders to extinguish clothing or oxyfuel/grease fires.
[2]In two instances, foam was also used.
[3]Due to failure of other firefighting methods, late fire detection, or undetected fires.

Table 6.—Number of fires for underground coal mines by equipment involved and time period, 1990–1999

Equipment	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Oxyfuel torch	8	2	4	2	2	18
Beltline/drive/pulley/feeder	3	4	5	—	4	16
Electrical system/cable/starter/breaker/ transformer/rectifier/voltage box	4	4	2	—	3	13
Generator/pump/fan	1	1	1	—	—	3
Mobile equipment[1]	4	5	7	1	4	21
Other[2]	5	2	4	3	2	16
Total	25	18	23	6	15	87

[1]Includes scoops, bolters, continuous miners, shearers, ore cart, shuttle cars, 3-wheelers, jeeps, railrunners, trolleys, locomotives, and power scalers.
[2]Includes nonequipment (mostly coal piles).

Table 7.—Number of fires for underground coal mines by location and time period, 1990–1999

Location	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Flame cutting/welding areas[1]	6	2	3	2	2	15
Gobline/sealed/abandoned/coal pit areas	3	2	3	1	1	10
Belt entry/feeder/slope/portal branch areas	6	5	7	—	6	24
Longwall panel/headgate/main return	2	—	1	3	1	7
Haulage/track rails	2	1	—	—	—	3
Power station/rectifier areas	—	1	—	—	1	2
Generator/transformer/fan/breaker/pump areas	1	2	2	—	1	6
Charging station	—	—	3	—	—	3
Mining face/intersection/crosscut areas	4	—	3	—	—	7
Maintenance areas	1	1	1	—	—	3
Mobile equipment working areas[2]	—	4	—	—	3	7
Total	25	18	23	6	15	87

[1]Includes belt entry, feeder, drive and pulley areas, shops, elevator shafts, overcasts, longwall face/headgate, and mobile equipment maintenance areas.
[2]Includes haulage, bolting, and transportation areas.

Table 8.—Number of fires for underground coal mines by burning material and time period, 1990–1999

Burning material	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Coal/coal dust	4	2	6	3	1	16
Electrical cables/wires/starter/voltage box/rectifier/ electrical insulation/breaker/transformer/batteries	5	7	7	1	6	26
Belt/feeder/drive/pulley	3	2	4	—	4	13
Oxyfuel/grease/clothing	7	2	2	1	1	13
Elevator shaft/motor	1	3	2	—	—	6
Flammable liquids/refueling fuel/methane	1	1	1	1	2	6
Hydraulic fluid	—	1	1	—	—	2
Gearbox	1	—	—	—	1	2
Oil/resin	3	—	—	—	—	3
Total	25	18	23	6	15	87

Table 9.—Number of fire injuries per number of fires causing injuries and total fires in underground coal mines by year, ignition source, equipment involved, and location, 1990–1999

Year	No. fires causing injuries	No. total fires	No. fire injuries	Ignition source	Equipment	Location
1990	2	16	8	Electrical short/arcing/battery explosion	Electrical cables/starter/ voltage box/battery.	Loading track/charging station.
	2	—	2	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
1991	1	9	1	Refueling fuel on hot surfaces	Mobile equipment[2]	Maintenance areas.
	4	—	4	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	1	—	1	Electrical short/arcing	Pump unit	Pump station.
	1	—	1	Conveyor belt friction	Beltline/pulley	Belt entry.
1992	2	14	3	Electrical short/arcing	Power cables/mobile equipment[2]	Trolley track rails/ transportation areas.
1993	2	4	2	Electrical short/arcing	Power breaker/mobile equipment[2]	Pump station/bolting areas.
1994	1	11	1	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	2	—	2	Electrical short/arcing	Power cable/mobile equipment[2]	Charging station/ mining areas.
	1	—	1	Conveyor belt friction	Beltline/drive/pulley	Belt entry.
1995	1	12	1	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	1	—	1	Heat source	Heater	Mining intersection.
	1	—	1	Conveyor belt friction	Coal feeder/motor	Belt entry.
1996	—	3	—	—	—	—
1997	1	3	1	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
1998	—	5	—			—
1999	1	10	1	Conveyor belt friction	Beltline/drive pulley	Belt entry.
	1	—	1	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	1	—	1	Hot surface	Mobile equipment[2]	Maintenance areas.
	1	—	1	Electrical short/arcing	Electrical power cables	Power station.
Total	27	87	34			

[1]Includes beltlines, longwall mining face, and mobile equipment maintenance areas.
[2]Includes bolters, scoops, jeeps, trolley, railrunners, and shuttle cars.

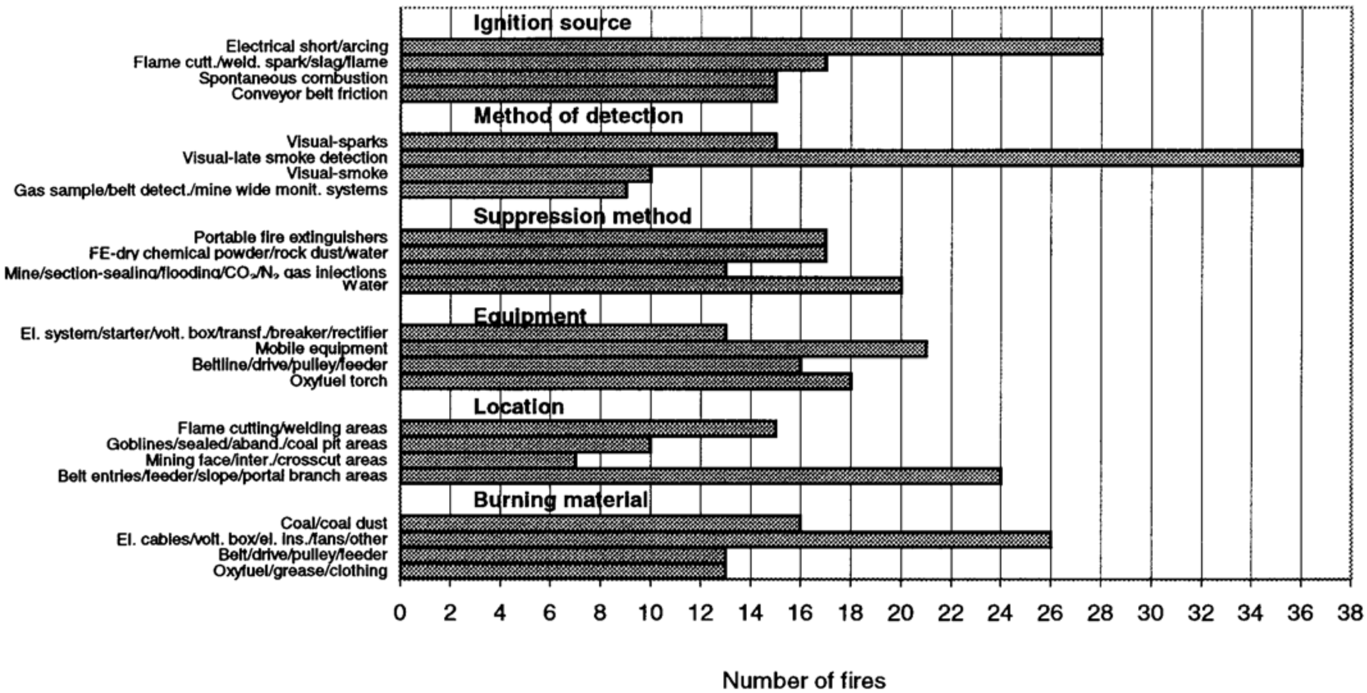

Figure 3.—Major variables for underground coal mine fires, 1990–1999. (FE = portable fire extinguisher)

Ignition Source

The number of fires and fire injuries by ignition source and time period is shown in tables 3 and 9. Electrical short/arcing caused the most fires (28 fires or 32% with 17 injuries). These occurred in electrical power and cable systems, power circuits and breakers, belt transformers, grounded cables and wires, batteries, high-voltage boxes, power generators, and rectifiers. The fires involved beltlines, drives, and pulleys; power centers and power units; and mobile equipment. Twelve mobile equipment electrical fires became large fires (at times involving the hydraulic lines) that required firefighting interventions and mine/section evacuations.

Another ignition source was flame cutting/welding spark/slag/flames (18 fires or 21% with 10 injuries). This source caused fires usually involving welders' clothing or oxyfuel/grease (grease embedded in the equipment's mechanical components). However, in at least one instance sparks/hot slag/flames caused a methane ignition followed by a large fire, which required firefighting intervention and mine/section evacuation and sealing. In another instance, undetected hot slag caused a large fire, which required firefighting intervention and mine evacuation and sealing followed by a methane explosion.

Friction of conveyor belts against pulleys, drives, rollers, idlers, and bearings resulted in 16 fires (18%) with 4 injuries. This source, usually detected long after the fire had started, caused extensive damage to beltlines, drives, and pulleys and disruption of mining operations.

Spontaneous combustion of coal resulted in 15 fires (17%). This source, usually detected long after the fire had started, caused fires involving goblines and sealed and abandoned areas, which severely disrupted mining operations. In at least two instances the spontaneous combustion fires were accompanied by methane explosions and required mine rescue team interventions and mine/section evacuations.

Other ignition sources were flammable liquid/refueling fuel on hot surfaces (four fires), mechanical malfunction/friction (two fires), overheated oil/grease (two fires), heat source (one fire), and hydraulic fluid sprayed onto mobile equipment hot surfaces (one fire). The latter fire grew out of control and required mine rescue team intervention.

During the first period (1990–1991), the largest number of fires were caused by the flame cutting welding spark/slag/flame source. During the second, third, and fifth periods, the largest number of fires were caused by the electrical short/arcing/explosion source. During the fourth period, the largest number of fires were caused by spontaneous combustion (see table 3). By comparison, data from Pomroy and Carigiet [1995] for 1978–1992 show that the leading ignition sources in underground coal mine fires were electrical short/arcing, belt friction, flame cutting/welding spark/slag, and spontaneous combustion.

Method of Detection

Table 4 shows the number of fires by method of detection and time period. The most frequent methods were miners who saw smoke long after the fire had started, followed by welders who saw sparks and miners who saw smoke shortly after the fires had started. Other methods of detection were operators who saw the fires when they started as flames/flash fires, miners who heard an explosion or touched hot spots, and operators who experienced power loss. Nine fires were detected by CO/H_2 gas sampling, CO/smoke belt fire detection systems, or mine-wide monitoring systems. Two fires were undetected.

During the first period, the largest number of fires were detected by sparks and detected late by smoke. During the second, third, and fifth periods, the largest number of fires were detected late by smoke. During the fourth period, the largest number of fires were detected late by smoke and by CO/H_2 gas sampling (see table 4). By comparison, data from Pomroy and Carigiet [1995] for 1978–1992 show that the most frequent methods of detection for underground coal mine fires were miners who saw the fires when they started or saw smoke shortly after they had started.

Suppression Method

Table 5 shows the number of fires by suppression method and time period. Usually more than one agent was used to fight a fire. The most common methods were water or portable fire extinguishers alone and portable fire extinguishers with dry chemical powder, rock dust, and water. In two instances, foam was also used. In 13 instances, mine/section sealing/flooding/CO_2/N_2 gas injections were required. Other methods included manual techniques with or without portable fire extinguishers (welders' methods to extinguish clothing or oxyfuel/grease fires) and machine water sprays.

Of note is that portable fire extinguishers alone, although used upon discovery of the fires, were successful in extinguishing only small fires involving grease, flammable liquids, power units, engine/mechanical malfunctions, oxyfuel/grease, and overheated oil. Three pieces of mobile equipment involved in fires had machine fire suppression systems. Dual activation (two activations) of machine fire suppression and motor deenergization systems was successful in temporarily abating the fires. However, the flames reignited, fueled by the flow of pressurized fluids entrapped in the lines (not affected by the motor deenergization operation).

Twelve of the mobile equipment electrical fires (which in at least one instance affected the hydraulic lines) and one hydraulic fluid fire became large fires because of unavailability of effective machine fire suppression systems, lack of an emergency line drainage system, or lack of effective and rapid local firefighting response capabilities. Mine rescue teams (required for 25 of the fires), upon mine/section evacuation (required 30 times), fought the mobile equipment fires (5 times) and other large fires with dry chemical powder, rock dust, and water. In all, five fires destroyed or heavily damaged equipment (including two pieces of mobile equipment) because of failure of other firefighting methods, late fire detection, undetected fires, or fire size.

Other factors that determined the success of fire-suppressing agents were the time that elapsed between detection and application of agents and effective and rapid local firefighting response capabilities.

During the first period, the largest number of fires were suppressed manually with or without portable fire extinguishers or by water alone. During the second period, the largest number of fires were suppressed with portable fire extinguishers, dry chemical powder, rock dust and water or with portable fire extinguishers alone. During the third period, the largest number of fires were suppressed with water alone. During the fourth period, the largest number of fires were extinguished by mine/section sealing/flooding/CO_2/N_2 gas injections. During the fifth period, the largest number of fires were extinguished by mine/section sealing/flooding/CO_2/N_2 gas injections; by dry chemical, rock dust, and water; or by water alone (see table 5). By comparison, data from Pomroy and Carigiet [1995] for 1978–1992 show that the most common suppression methods used in underground coal mine fires were water, dry chemical powder, rock dust, and sealing with CO_2/N_2 gas injections.

Equipment Involved

Table 6 shows the number of fires by equipment involved and time period. The equipment most often involved was mobile equipment (e.g., scoops, shuttle cars, bolters, railrunners, continuous miners, trolleys, ore carts, jeeps, locomotives, shearers, three-wheelers, and power scalers). This was followed by oxyfuel torches; beltlines, pulleys, drives, and feeders; and electrical systems, cables, breakers, starters, rectifiers, voltage boxes, and transformers. Other equipment included pumps, generators, and ventilation fans. Sixteen fires did not involve equipment (mostly coal piles).

During the first and fourth periods, the largest number of fires involved oxyfuel torches. During the second and third periods, the largest number of fires involved mobile equipment. During the fifth period, the largest number of fires involved mobile equipment and beltlines, drives, pulleys, and feeders (see table 6). By comparison, data from Pomroy and Carigiet [1995] for 1978–1992 show that the equipment most often involved in underground coal mine fires were beltlines and drives, followed by flame cutting/welding equipment.

Location

Table 7 shows the number of fires by location and time period. Figure 3 shows the major fire locations during 1990–1999. The most common locations were belt entry, feeder, slope and portal branch areas, flame cutting/welding areas (at the longwall face and headgate, belt entries, feeders, shops, elevator shafts, overcasts, and mobile equipment maintenance areas), and goblines, sealed, abandoned, and coal pit areas. Other fire locations were the mining face, intersection, and crosscut areas; the longwall panel/headgate and main return areas; and mobile equipment working areas (haulage, bolting, and transportation areas). Generator and pump housing, belt transformer, fan and breaker areas, haulage and track rail areas, rectifier, charging and power stations, and maintenance areas were other locations affected by fires.

During the first period, the largest number of fires occurred at flame cutting/welding areas and at belt entry, feeder, portal branch, and slope areas. During the second, third, and fifth periods, the largest number of fires occurred at belt entry, slope, feeder, and portal branch areas. During the fourth period, the largest number of fires occurred at longwall panel, headgate, and main return areas (see table 7). By comparison, data from Pomroy and Carigiet [1995] for 1978–1992 show that the most common fire locations in underground coal mines were belt entry, working face, intake entry, and track haulage areas.

Burning Materials

Table 8 shows the number of fires by burning material and time period. The materials most often involved were electrical cables, starters, voltage boxes, rectifiers, electrical insulation, breakers, transformers, and batteries. These were followed by coal and coal dust; belts, feeders, drives, and pulleys; and oxyfuel, grease, and clothing. Other burning materials were flammable liquids, methane, elevator shafts and motors, oil and resin, hydraulic fluids, and gearboxes.

During the first period, the largest number of fires involved oxyfuel, grease, and clothing materials. During the second, third, and fifth periods, the largest number of fires involved electrical cables, wires, starters, voltage boxes, transformers, starters, and batteries. During the fourth period, the largest number of fires involved coal and coal dust (see table 8). By comparison, data from Pomroy and Carigiet [1995] for 1978–1992 show that the most frequent burning materials in underground coal mines were coal and coal dust, electrical insulation, oil and grease, conveyor belts and rollers, wood, rubber hoses, and tires.

Fire Injuries

Table 9 shows the number of fire injuries per number of fires causing injuries and total fires by year, ignition source, equipment involved, and location during 1990–1999. Overall, there were 34 injuries caused by 27 fires. The greatest number of fire injuries occurred in 1990 (10 injuries caused by 4 fires) and 1991 (7 injuries caused by 7 fires). The ignition sources that caused most of the fire injuries were electrical short/arcing, battery explosion, and flame cutting/welding spark/slag/flames. Other ignition sources were conveyor belt friction, heat source, and refueling fuel on hot surfaces. The equipment most often involved in fire injuries were electrical power cables, voltage boxes, oxyfuel torches, beltlines, drives, pulleys and feeders, and mobile equipment. The most common locations for fire injuries were pump, power and charging stations, mobile equipment working areas, flame cutting/welding areas, trolley track rails and transportation areas, and belt entries.

By comparison, data from Pomroy and Carigiet [1995] for 1978–1992 show that the ignition sources causing the most of the fire injuries were electrical short/arcing, belt friction, and flame cutting/welding sources. The equipment most often involved in fire injuries and fire fatalities included air compressors (which caused 27 fatalities during one fire), trolley power cables, and oxyfuel torches. The most common locations for fire injuries were main intakes, belt entries, longwall headgate, working faces, and track entries.

SURFACE OF UNDERGROUND COAL MINE FIRES

Table 10 and figure 4 show the number of fires and fire injuries occurring at the surface of underground coal mines by state during 1990–1999. Table 10 also shows by state the risk rate, employees' working hours, and lost workdays.

A total of 65 fires occurred in 10 states. Thirteen of those fires caused 12 injuries and 1 fatality (the yearly average was 6.5 fires and 1.2 injuries). Four fires and one fire injury involved contractors. The Ewhr value was 97×10^6 hr (Irr = 0.025); the LWD value was 6,206. Pennsylvania had the most fires (20 fires and 5 injuries), followed by West Virginia (16 fires and 1 fatality) and Kentucky (15 fires and 3 injuries). Among these states, Pennsylvania had the highest injury risk rate value (Irr = 0.095).

Table 11, partly illustrated in figure 5, shows by time period the number of fires, fire injuries, and fire fatalities; risk rates; employees' working hours; and lost workdays. The number of fires and fire injuries show a decrease followed by an increase during the five time periods, accompanied by a decline in employees' working hours throughout the periods (see table 11 and figure 5). The Irr values follow patterns similar to those shown by the injury values.

Tables 12–17 show the number of fires by ignition source, method of detection and suppression, equipment involved, location, and burning material by time period. Figure 6 shows the major variables during 1990–1999. Table 18 shows the number of fire injuries per number of fires causing injuries and total fires by year, ignition source, equipment involved, and location.

Ignition Source

The number of fires and fire injuries by ignition source and time period is shown in tables 12 and 18. The leading sources were hydraulic fluid/fuel sprayed onto equipment hot surfaces (11 fires or 17% with 1 injury), spontaneous combustion/hot coal (11 fires or 17%), and flame cutting/welding spark/slag/flames (11 fires or 17% with 7 injuries). Three of the mobile equipment hydraulic fluid/fuel fires became large fires, which at times required fire department interventions. In at least two instances flames erupted in the cab, probably because of the ignition of flammable vapors and mists that penetrated the cab. Of note is that most of the hydraulic fluid/fuel fires were caused when hydraulic fluids sprayed onto equipment hot surfaces; subsequently, these fires involved the fuel lines. The flame cutting/welding spark/slag/flame source caused fires usually involving welders' clothing or oxyfuel/grease (grease embedded in the equipment's mechanical components). However, in one instance sparks/hot slag/flames caused a methane ignition followed by a large fire, and twice undetected hot slag caused coal belt fires. Other ignition sources were heat source (four fires), electrical short/arcing (four fires), conveyor belt friction (three fires), and overheated oil (one fire). Twenty ignition sources (mostly affecting facilities) were unknown.

During the first period, the largest number of fires were caused by hydraulic fluid/fuel sprayed onto equipment hot surfaces. During the second period, the largest number of fires were caused by spontaneous combustion/hot coal. During the third and fourth periods, the largest number of fires were caused by the flame cutting/welding spark/slag/flame source. During the fifth period, the largest number of fires were caused by flame cutting/welding spark/slag/flames, spontaneous combustion/hot coal, and hydraulic fluid/fuel sprayed onto equipment hot surfaces (see table 12).

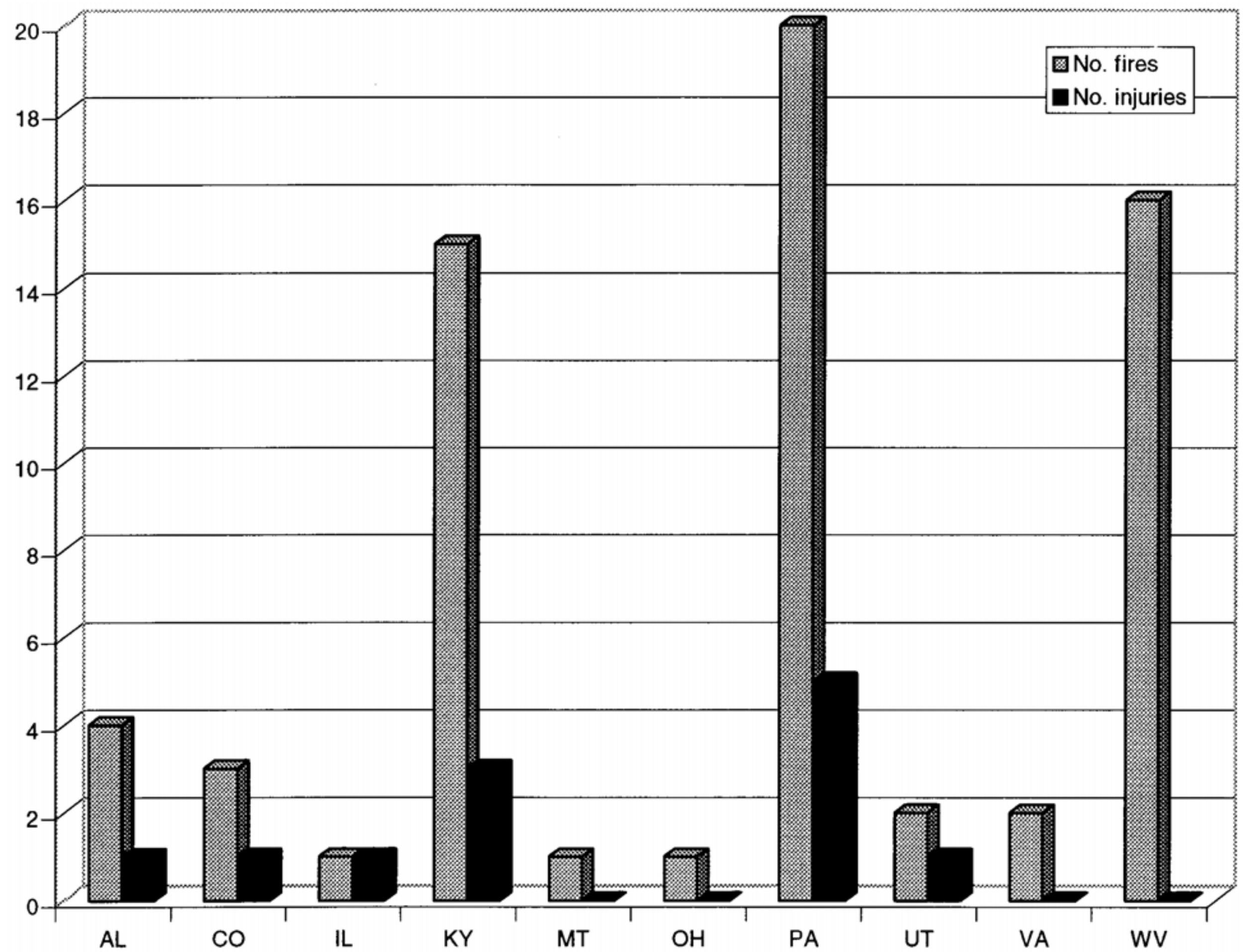

Figure 4.—Number of fires and fire injuries for surface of underground coal mines by state, 1990–1999.

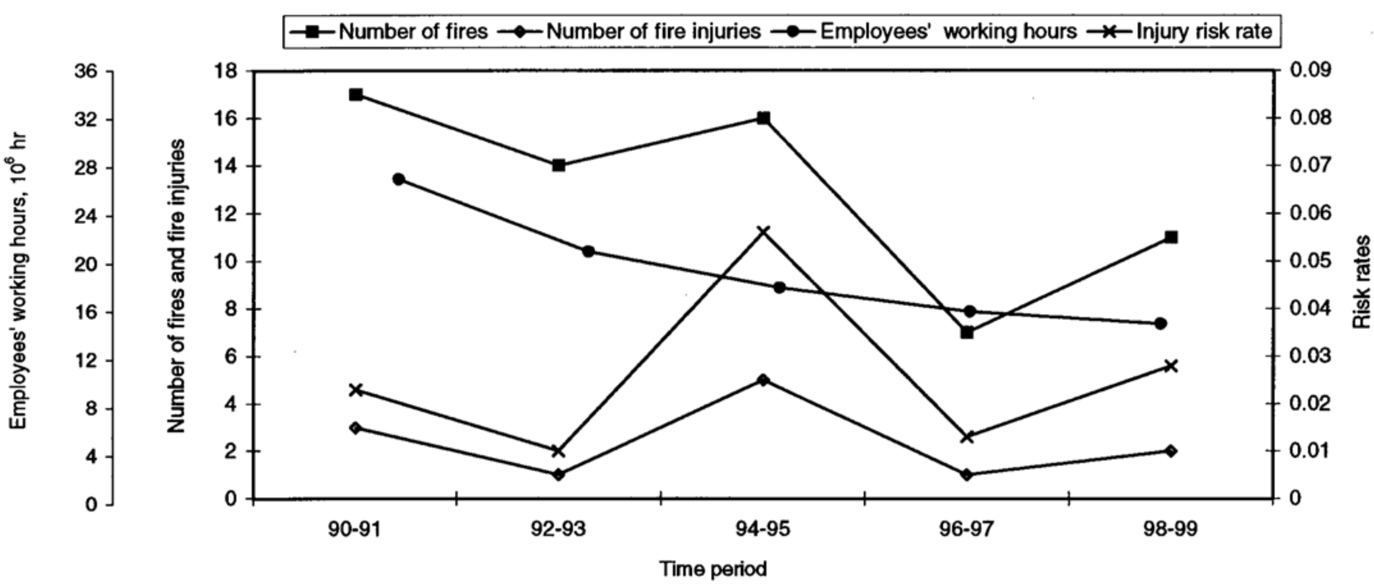

Figure 5.—Number of fires, fire injuries, and risk rates for surface of underground coal mines by time period and employee' working hours, 1990–1999.

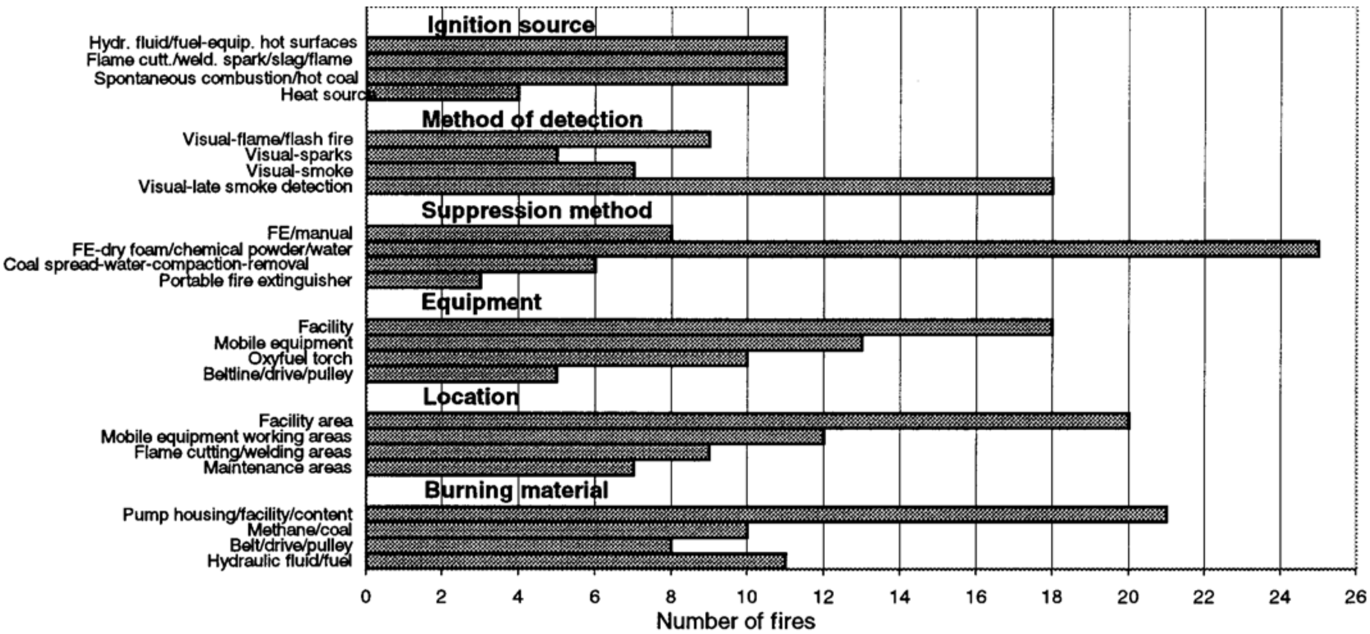

Figure 6.—Major variables for surface of underground coal mine fires, 1990–1999. (FE = portable fire extinguisher)

Table 10.—Number of fires, fire injuries, and risk rates for surface of underground coal mines by state, employees' working hours, and lost workdays, 1990–1999

State[1]	No. fires[1]	No. injuries[1]	LWD[2]	Ewhr,[2] 10^6 hr	Irr[3]
Alabama	4	1	4	5.8	0.035
Colorado	3	1	—	3.6	0.056
Illinois	1	1	42	6	0.033
Kentucky	15	3	88	23	0.026
Montana	1	—	—	0.12	—
Ohio	1	—	—	3.7	—
Pennsylvania	20	5	24	10.5	0.095
Utah	2	1	6	4	0.05
Virginia	2	—	42	11	—
West Virginia[4]	16	—	6000	20.4	—
Other states	—	—	—	8.8	—
Total	65	12	6206	97	30.025

[1]Derived from MSHA "Fire Accident Abstract" and "Fire Accident Report" publications.
[2]Derived from MSHA "Injury Experience in Coal Mining" publications.
[3]Calculated according to MSHA formula reported in the "Methodologies" section.
[4]West Virginia had 1 fire fatality.

Table 11.—Number of fires, fire injuries, fire fatalities, and risk rates for surface of underground coal mines by time period, employees' working hours, and lost workdays, 1990–1999

	Time period					
	90-91	92-93	94-95	96-97	98-99	90-99
Number of fires[1]	17	14	16	7	11	65
Number of fire injuries[1]	3	1	5	1	2	12
Number of fire fatalities	1	—	—	—	—	1
LWD[2]	6000	24	88	10	84	6206
Ewhr,[2] 10^6 hr	27	21	18	16	15	97
Irr[3]	0.023	0.01	0.056	0.0125	0.028	30.025

[1]Derived from MSHA "Fire Accident Abstract" and "Fire Accident Report" publications.
[2]Derived from MSHA "Injury Experience in Coal Mining" publications.
[3]Calculated according to MSHA formula reported in the "Methodologies" section.

Table 12.—Number of fires for surface of underground coal mines by ignition source and time period, 1990–1999

Ignition source	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Heat source	1	1	2	—	—	4
Flame cutting/welding spark/slag/flame[1]	2	1	4	2	2	11
Electrical short/arcing	3	—	—	—	1	4
Spontaneous combustion/hot coal	2	3	3	1	2	11
Conveyor belt friction	1	1	—	1	—	3
Hydraulic fluid/fuel on equipment hot surfaces	4	2	3	—	2	11
Overheated oil	1	—	—	—	—	1
Unknown/other	3	6	4	3	4	20
Total	17	14	16	7	11	65

[1]This source caused fires usually involving welders' clothing or oxyfuel/grease. However, in one instance undetected hot slag caused a methane ignition followed by a large fire, and twice undetected hot slag caused coal belt fires.

Table 13.—Number of fires for surface of underground coal mines by method of detection and time period, 1990–1999

Method of detection	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Visual method:						
Flames/flash fires	2	2	3	—	2	9
Sparks	2	—	—	1	2	5
Late smoke detection	6	3	4	2	3	18
Smoke	2	1	3	1	—	7
Smoldering	1	1	—	—	—	2
Smelled smoke	—	1	—	—	—	1
Explosion	1	—	2	—	—	3
Undetected	3	6	4	3	4	20
Total	17	14	16	7	11	65

Table 14.—Number of fires for surface of underground coal mines by suppression method and time period, 1990–1999

Suppression method	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Manual/FE[1]	3	—	3	—	2	8
FE-foam/dry chemical powder/water	6	6	7	3	3	25
Coal spread-water-compaction-removal[2]	2	—	1	1	2	6
Destroyed/heavily damaged[3]	3	6	4	3	4	20
Portable fire extinguisher	3	—	—	—	—	3
FE-FSS-dry chemical powder	—	1	1	—	—	2
Other	—	1	—	—	—	1
Total	17	14	16	7	11	65

FE Portable fire extinguisher.
FSS Machine fire suppression system.
[1]Methods used by welders to extinguish clothing or oxyfuel/grease fires.
[2]Methods used to extinguish spontaneous combustion/hot coal fires.
[3]Due to failure of other firefighting methods, late fire detection, or undetected fires.

Table 15.—Number of fires for surface of underground coal mines by equipment involved and time period, 1990–1999

Equipment	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Oxyfuel torch	2	1	3	2	2	10
Beltline/drive/pulley	2	1	1	1	—	5
Heater/maintenance equipment	2	1	2	—	—	5
Electrical power unit/system	1	—	—	—	1	2
Pump	1	—	—	—	—	1
Facilities	2	5	4	3	4	18
Mobile equipment[1]	6	2	3	—	2	13
Other[2]	1	4	3	1	2	11
Total	17	14	16	7	11	65

[1]Includes hoists, loaders, dozers, scrapers, trucks, highlifts, excavators, and tractors.
[2]Includes nonequipment (mostly coal piles).

Table 16.—Number of fires for surface of underground coal mines by location and time period, 1990–1999

Location	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Flame cutting/welding areas[1]	2	—	4	1	2	9
Coal silo/stock/refuse pile	1	2	1	—	2	6
Beltline/drawoff tunnel areas	1	2	2	1	—	6
Power station	2	—	—	—	1	3
Maintenance areas	3	1	3	—	—	7
Facility areas	2	6	4	4	4	20
Mobile equipment working areas[2]	5	3	2	—	2	12
Charging station	1	—	—	1	—	2
Total	17	14	16	7	11	65

[1]Includes beltline areas, storage silos, and mobile equipment maintenance areas.
[2]Includes loading, hoisting, and haulage areas.

Table 17.—Number of fires for surface of underground coal mines by burning material and time period, 1990–1999

Burning material	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Flammable liquids	1	1	2	—	2	6
Electrical wires/systems/batteries	2	—	—	—	1	3
Facility/content/pump housing	4	6	4	3	4	21
Belt/drive/pulley	3	2	2	1	—	8
Coal/methane	1	3	3	1	2	10
Wood ties/refuse pile/electrical insulation	1	—	1	1	—	3
Oxyfuel/grease/clothing	1	—	1	1	—	3
Hydraulic fluid/fuel	4	2	3	—	2	11
Total	17	14	16	7	11	65

Table 18.—Number of fire injuries per number of fires causing injuries and total fires at surface of underground coal mines by year, ignition source, equipment involved, and location, 1990–1999

Year	No. fires causing injuries	No. total fires	No. fire injuries	Ignition source	Equipment	Location
1990	1	7	1	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	1	—	1	Battery explosion	Mobile equipment[2]	Charging station.
1991[3]	2	10	1	Hydraulic fluid/fuel on equipment hot surfaces	Mobile equipment[2]	Loadout area.
1992	—	6	—	—	—	—
1993	1	8	1	Training fire	Turnout gear	Fire training area.
1994	2	6	2	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
1995	2	10	2	Heat source	Heater	Refuse/maintenance areas.
	1	—	1	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
1996	—	2	—	—	—	—
1997	1	5	1	Flame cutting/welding spark/slag/flame	Oxyfuel torch/mobile equipment.[2]	Maintenance areas.
1998	2	5	2	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
1999	—	6	—	—	—	—
Total	13	65	12			

[1]Includes beltline, drive, and pulley areas; storage silos; shops; and mobile equipment maintenance areas.
[2]Includes highlifts, loaders, and trucks.
[3]During 1991, there was 1 fire fatality.

Method of Detection

Table 13 shows the number of fires by method of detection and time period. The most frequent method of detection was miners who saw smoke long after the fires had started, followed by operators who saw the fires when they had started as flames/flash fires. Other methods of detection were miners who saw smoke shortly after the fires had started; welders who saw sparks; and miners who heard an explosion, saw smoldering of coal, or smelled smoke. Twenty fires were undetected. The largest number of fires were detected late by smoke throughout the periods (table 13).

Suppression Method

Table 14 shows the number of fires by suppression method and time period. The most common methods were dry chemical powder and water, followed by manual techniques with or without portable fire extinguishers (welders' methods to extinguish clothing or oxyfuel/grease fires) and coal spread, water, compaction, and removal (method used to extinguish spontaneous combustion/hot coal fires). Other fire suppression methods were portable fire extinguishers alone and foam and water.

Two pieces of mobile equipment involved in fires had machine fire suppression systems. Dual activation (one activation) of machine fire suppression and engine shutoff systems failed to temporarily abate the flames because of the flow of pressurized fluids entrapped in the lines (not affected by the engine shutoff operation). Most of the hydraulic fluid/fuel fires became large fires. In at least three instances these fires required fire department interventions because of the continuous flow of fluid/fuel from the pumps due to engine shutoff failure, lack of an emergency hydraulic line drainage system, difficulty in activating available emergency systems at ground level, or lack of effective and rapid local firefighting response capabilities. (Fire-resistant hydraulic fluid is not required for equipment use at surface coal operations.)

Fire brigades and fire departments (required in six instances) fought three mobile equipment fires and other large fires with foam, dry chemical powder, and water. However, 20 fires destroyed or heavily damaged equipment (including two pieces of mobile equipment) because of failure of other firefighting methods, late fire detection, undetected fires, or fire size.

The largest number of fires were suppressed with portable fire extinguishers, foam, dry chemical powder, and water throughout the periods (table 14).

Equipment Involved

Table 15 shows the number of fires by equipment involved and time period. The equipment most often involved included mobile equipment (hoists, dozers, loaders, scrapers, trucks, highlifts, excavators, and tractors) and oxyfuel torches. Other equipment included heaters and maintenance equipment, beltlines, drives and pulleys, maintenance equipment, electrical systems, power units, and pumps.

During the first period, the largest number of fires involved mobile equipment. During subsequent periods, the largest number of fires involved facilities (see table 15).

Location

Table 16 shows the number of fires by location and time period. The most common locations were facilities and mobile equipment working areas (e.g., loading, hoisting, and haulage areas). These were followed by flame cutting/welding areas (at beltline areas, storage silos, and mobile equipment maintenance areas) and maintenance areas. Other fire locations were coal silos, stock and refuse pile areas, beltline and drawoff tunnel areas, and power and charging stations.

During the first period, the largest number of fires occurred at mobile equipment working areas. During subsequent periods, the largest number of fires occurred at facility areas (see table 16).

Burning Materials

Table 17 shows the number of fires by burning material and time period. The materials most often involved were pump housing and facilities/content, followed by hydraulic fluid/fuel, coal and methane, and belts, drives, and pulleys. Other burning materials were flammable liquids, electrical systems, wires and batteries, wood ties, refuse piles, electrical insulation, and oxyfuel/grease/clothing. During the first period, the largest number of fires involved hydraulic fluid/fuel and facility/content materials. During subsequent periods, the largest number of fires involved facility/content materials (see table 17).

Fire Injuries

Table 18 shows the number of fire injuries per number of fires causing injuries and total fires by year, ignition source, equipment involved, and location during 1990–1999. Overall, 13 fires caused 12 injuries and 1 fatality.

The greatest number of fire injuries occurred in 1995 (three injuries caused by three fires). The sources that caused most of the fire injuries were flame cutting/welding spark/slag/flames, heat sources and pressurized can explosions, and hydraulic fluid/fuel sprayed onto equipment hot surfaces. Other ignition sources were an electrical short/arcing/battery explosion and a source used to light a training fire. The equipment most often involved included oxyfuel torches, heaters, mobile equipment, batteries, and turnout gear. The locations where most of the fire injuries occurred were flame cutting/welding, maintenance, and mobile equipment working areas. Other fire locations were charging stations and fire training areas.

The fire fatality in West Virginia in 1991 may actually have been caused by cardiac failure, although the victim's body was found among the burnt office rubble [MSHA 1991c].

SURFACE COAL MINE FIRES

Table 19 and figure 7 show the number of fires and fire injuries for surface coal mines by state during 1990–1999. Table 19 also shows by state the risk rates, employees' working hours, lost workdays, and coal production.

For surface coal mines, 215 fires occurred in 21 states during 1990–1999. Ninety-four of those fires caused 93 injuries and 1 fatality (the yearly average was 21.5 fires and 9.3 fire injuries). Fourteen fires and seven injuries involved contractors. The Ewhr value was 729×10^6 hr (Irr = 0.026), the CP value was $6{,}355 \times 10^6$ st (Frr = 0.034), and the LWD value was 8,141.

Kentucky had the most fires and fire injuries (45 fires and 23 injuries), followed by Pennsylvania (33 fires and 14 injuries), West Virginia (25 fires and 14 injuries), and Indiana (20 fires and 8 injuries). Among these states, Pennsylvania had the highest fire risk rate value (Frr = 0.145), while Kentucky had the highest injury risk rate value (Irr = 0.041).

Table 20, partly illustrated in figure 8, shows by time period the number of fires, fire injuries, fire fatalities, risk rates, employees' working hours, lost workdays, and coal production. There was a decrease in fires and fire injuries during most of the periods (an increase is seen only during 1994–1995), accompanied by a decline in employees' working hours throughout the periods and an increase in coal production during most of the periods. The Irr and Frr values follow patterns similar to those shown by the injury and fire values (see table 20 and figure 8).

Tables 21–26 show the number of fires by ignition source, method of detection and suppression, equipment involved, location, and burning material by time period. Figure 9 shows the major variables during 1990–1999. Table 27 shows the number of fire injuries per number of fires causing injuries and total fires by year, ignition source, equipment involved, and location.

Table 19.—Number of fires, fire injuries, and risk rates for surface coal mines by state, employees' working hours, lost workdays, and coal production, 1990–1999

State[1]	No. fires[1]	No. injuries[1]	LWD[2]	Ewhr,[2] 10^6 hr	CP,[2] 10^6 st	Frr[3]	Irr[3]
Alabama	5	4	176	24.8	80	0.063	0.032
Arizona	3	1	17	16.1	120.7	0.025	0.012
Colorado	2	—	—	11.6	91	0.022	—
Illinois	6	4	44	24.2	94	0.064	0.033
Indiana	20	8	430	53.7	280	0.071	0.03
Kansas	1	—	—	1.3	3.5	0.286	—
Kentucky	45	23	527	112.1	602.5	0.075	0.041
Louisiana	3	2	—	2.5	31.8	0.094	0.16
Missouri	3	2	41	4.8	11.4	0.263	0.083
Montana[4]	4	—	6,000	16	392.8	0.01	—
New Mexico	6	1	37	30	246.5	0.034	0.007
Ohio	11	6	8	40.3	168.1	0.065	0.03
Oklahoma	1	1	11	6.2	15.6	0.064	0.032
Pennsylvania	33	14	501	72.5	228.3	0.145	0.039
Tennessee	1	1	17	4.6	15	0.067	0.044
Texas	13	6	17	60.1	529.6	0.025	0.02
Utah	1	—	—	0.2	2.6	0.39	—
Virginia	6	3	79	22.7	88.4	0.068	0.026
Washington	1	—	—	10.4	47	0.021	—
West Virginia	25	14	182	92.7	536.6	0.047	0.03
Wyoming	25	3	54	62.7	2,454.1	0.01	0.01
Other states	—	—	—	60	394.5	—	—
Total	215	93	8,141	729	6,355	[3]0.034	[3]0.026

[1]Derived from MSHA "Fire Accident Abstract" and "Fire Accident Report" publications.
[2]Derived from MSHA "Injury Experience in Coal Mining" publications.
[3]Calculated according to USBM and MSHA formulas reported in the "Methodologies" section.
[4]Montana had one fire fatality.

Table 20.—Number of fires, fire injuries, fire fatalities, and risk rates for surface coal mines by time period, employees' working hours, lost workdays, and coal production, 1990–1999

	Time period					
	90-91	92-93	94-95	96-97	98-99	90-99
Number of fires[1]	67	37	47	40	24	215
Number of fire injuries[1]	32	17	19	16	9	93
Number of fire fatalities	1	—	—	—	—	1
LWD[2]	6,610	646	284	327	274	8,141
Ewhr,[2] 10^6 hr	177	154	143	131	124	729
CP,[2] 10^6 st	1,180	1,176	1,267	1,325	1,408	6,355
Frr[3]	0.057	0.032	0.037	0.03	0.017	[3]0.034
Irr[3]	0.036	0.022	0.026	0.024	0.015	[3]0.026

[1]Derived from MSHA "Fire Accident Abstract" and "Fire Accident Report" publications.
[2]Derived from MSHA "Injury Experience in Coal Mining" publications.
[3]Calculated according to USBM and MSHA formulas reported in the "Methodologies" section.

Table 21.—Number of fires for surface coal mines by ignition source and time period, 1990–1999

Ignition source	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Heat source	5	—	2	1	2	10
Flammable liquid/refueling fuel on hot surfaces	5	3	2	6	2	18
Flame cutting/welding spark/slag/flame[1]	20	12	14	7	6	59
Spontaneous combustion/hot coal	4	1	7	6	3	21
Conveyor belt friction	—	—	2	1	—	3
Hydraulic fluid/fuel on equipment hot surfaces	24	15	18	13	6	76
Engine/mechanical malfunction/friction/explosion	5	4	—	1	1	11
Overheated oil	1	—	1	1	1	4
Electrical short/arcing	1	2	—	3	2	8
Natural gas explosion	1	—	—	—	1	2
Unknown	1	—	1	1	—	3
Total	67	37	47	40	24	215

[1]This source caused fires usually involving welders' clothing or oxyfuel/grease. However, on four occasions undetected hot slag caused coal and belt fires. In another instance, undetected hot slag caused a coal chute smoldering fire, which, upon water application, produced a flashback accompanied by a gas explosion, resulting in one fatality.

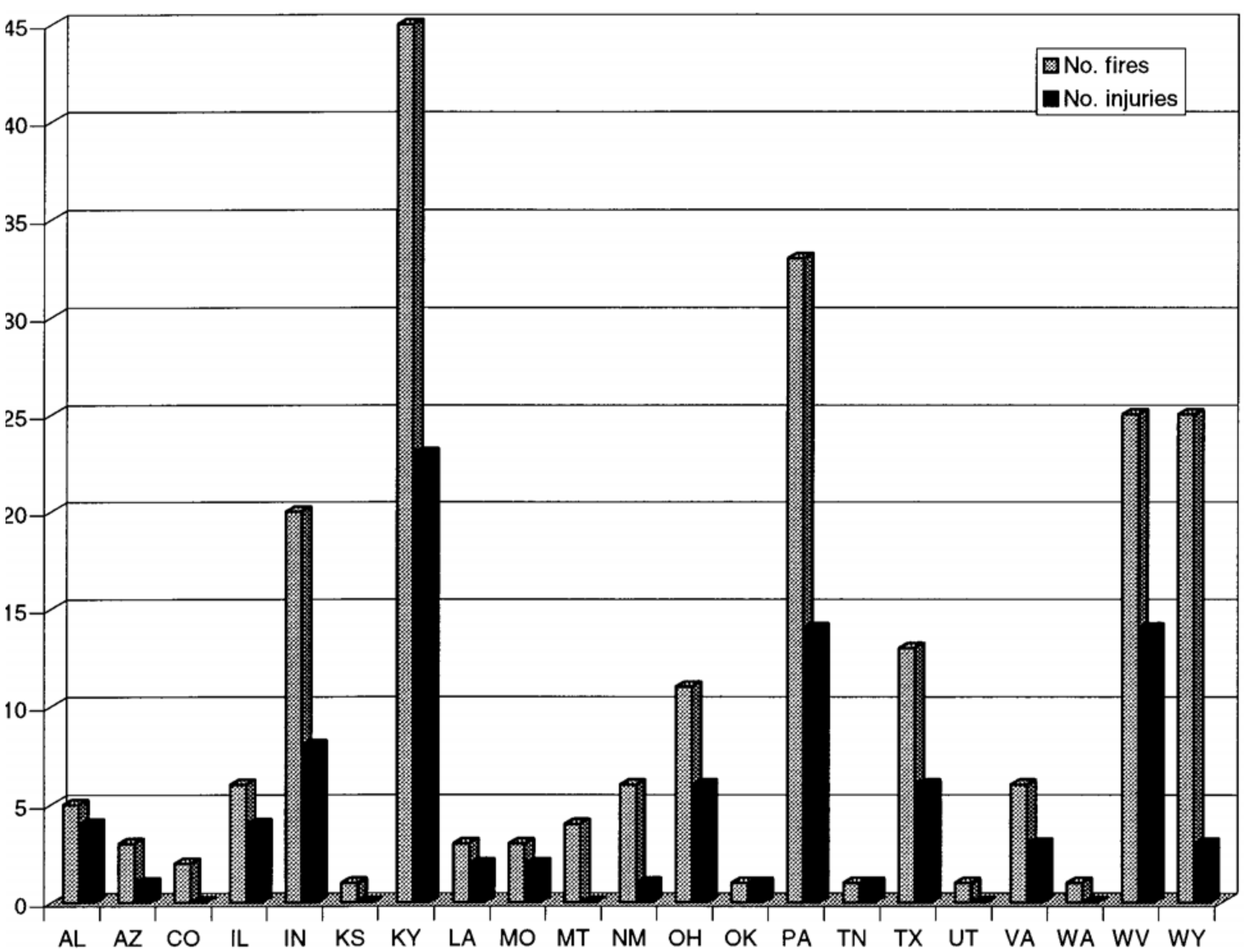

Figure 7.—Number of fires and fire injuries for surface coal mines by state, 1990–1999.

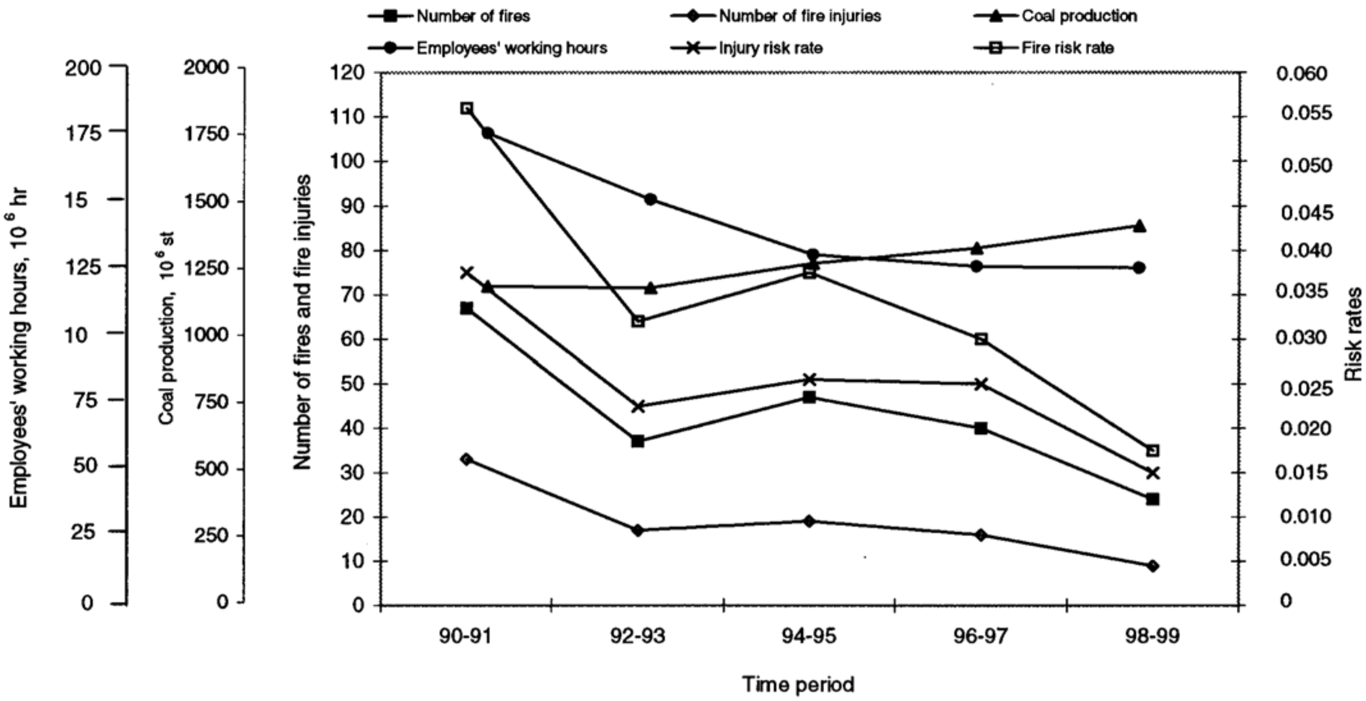

Figure 8.—Number of fires, fire injuries, risk rates, and coal production for surface coal mines by time period and employees' working hours, 1990–1999.

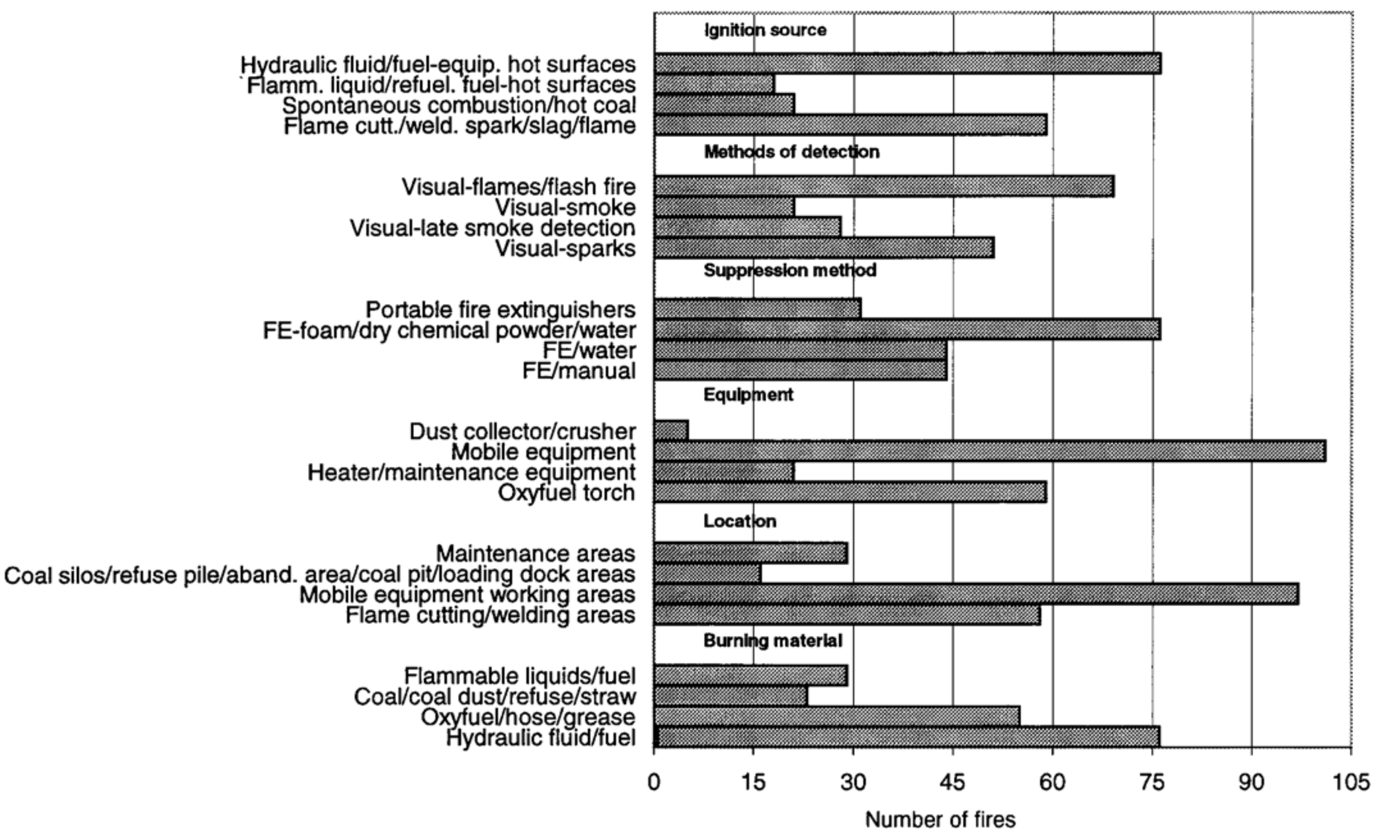

Figure 9.—Major variables for surface coal mine fires, 1990–1999. (FE = portable fire extinguisher)

Table 22.—Number of fires for surface coal mines by method of detection and time period, 1990–1999

Method of detection	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Visual method:						
Flames/flash fires	22	9	17	14	7	69
Smoke	4	8	—	5	4	21
Smoldering	1	—	—	—	—	1
Late smoke detection	6	2	7	9	4	28
Glow	—	—	1	—	—	1
Sparks	20	8	11	7	5	51
Electrical/mechanical sparks	1	5	—	—	1	7
Radiator smoke/oil mist spray	1	—	—	1	—	2
Undetected	4	2	4	2	1	13
Fire alarm/electrical trip warning	1	—	—	1	—	2
Smelled smoke	—	1	2	—	—	3
Explosion	5	—	2	—	1	8
Power loss	—	1	—	—	1	2
Popping sound	2	1	3	1	—	7
Total	67	37	47	40	24	215

Table 23.—Number of fires for surface coal mines by suppression method and time period, 1990–1999

Suppression method	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Manual/FE[1]	16	7	10	7	4	44
Portable fire extinguisher	8	8	1	10	4	31
FE-water	15	3	15	5	6	44
FE-water/foam/dry chemical power	23	15	18	15	5	76
Coal spread-water-compaction-removal[2]	—	—	—	2	—	2
FSS-dry chemical powder-water	2	—	—	1	2	5
Destroyed/heavily damaged[3]	3	4	3	—	3	13
Total	67	37	47	40	24	215

FE Portable fire extinguisher
FSS Machine fire suppression system
[1]Methods used by welders to extinguish clothing or oxyfuel/grease fires.
[2]Methods used to extinguish spontaneous combustion/hot coal fires.
[3]Due to failure of other firefighting methods, late fire detection, or undetected fires.

Table 24.—Number of fires for surface coal mines by equipment involved and time period, 1990–1999

Equipment	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Air compressor	2	—	—	—	—	2
Oxyfuel torch	20	12	14	7	6	59
Heater/maintenance equipment	8	1	5	3	4	21
Beltline/drive/pulley	—	—	2	1	—	3
Crusher/dust collector	1	—	2	2	—	5
Facility	1	—	1	1	—	3
Other/unknown	4	2	5	6	4	21
Mobile equipment[1]	31	22	18	20	10	101
Total	67	37	47	40	24	215

[1]Includes haulage/utility trucks, loaders, dozers, drills, shovels, backhoes, buckets, excavators, scrapers, auger/miners, and excavators.

Table 25.—Number of fires for surface coal mines by location and time period, 1990–1999

Location	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Flame cutting/welding areas[1]	21	12	13	7	5	58
Coal silos/loading dock/refuse pile/abandoned coal pit areas	1	2	6	4	3	16
Beltline area	1	—	2	2	—	5
Dust collector/baghouse/crusher areas	2	—	2	2	—	6
Facility	1	—	1	1	1	4
Maintenance areas	11	3	5	6	4	29
Mobile equipment working areas[2]	30	20	18	18	11	97
Total	67	37	47	40	24	215

[1]Includes coal chute, beltline, bucket/transfer house, shaft, dust collector and coal chute areas, and mobile equipment maintenance areas.
[2]Includes mining, haulage, loading, and drilling areas.

Table 26.—Number of fires for surface coal mines by burning material and time period, 1990–1999

Burning material	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Oxyfuel/hose/grease/clothing	20	9	13	8	5	55
Coal/coal dust/straw/refuse	5	2	7	4	5	23
Crusher/dust collector/furnace/baghouse	3	—	1	2	—	6
Belt/idler/pulleys	1	—	2	2	—	5
Facility/content	1	—	1	1	—	3
Flammable liquid/refuel fuel	9	4	4	7	5	29
Hydraulic fluid/fuel	23	16	19	12	6	76
Electrical system/batteries/collector ring/breaker	2	5	—	4	1	12
Air compressor/transmission oil	2	1	—	—	1	4
Natural gas/chemicals	1	—	—	—	1	2
Total	67	37	47	40	24	215

Table 27.—Number of fire injuries per number of fires causing injuries and total fires at surface coal mines by year, ignition source, equipment involved, and location, 1990–1999

Year	No. fires causing injuries	No. total fires	No. fire injuries	Ignition source	Equipment	Location
1990	11	38	11	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	3		3	Heat source-flammable liquid	Heater/air compressor	Refuse/maintenance areas.
	1		1	Mechanical friction	Mobile equipment[2]	Drilling area.
	3		3	Hydraulic fluid/fuel on equipment hot surfaces	Mobile equipment[2]	Haulage area.
	1		1	Flammable liquid on hot surfaces	Mobile equipment[2]	Maintenance area.
1991[3]	4	29	4	Heat source-flammable liquid	Heater/furnace	Furnace room/maintenance area.
	6		5	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas/ coal chute areas.[1]
	4		4	Hydraulic fluid/fuel on equipment hot surfaces	Mobile equipment[2]	Loading/haulage/ drilling/ mining areas.
1992	5	20	5	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	3		3	Hydraulic fluid/fuel on equipment hot surfaces	Mobile equipment[2]	Drilling/mining areas.
	1		1	Flammable liquid on hot surfaces	Mobile equipment[2]	Maintenance area.
1993	4	17	4	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	1		1	Heat source-flammable liquid	Heater	Maintenance area.
	1		1	Engine malfunction	Mobile equipment[2]	Maintenance area.
	2		2	Hydraulic fluid/fuel on equipment hot surfaces	Mobile equipment[2]	Haulage area.
1994	4	27	4	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	2		2	Heat source-flammable liquid	Heater/maintenance equipment.	Maintenance area.
	1		1	Conveyor belt friction	Beltline	Beltline area.
	2		2	Hydraulic fluid/fuel on equipment hot surfaces	Mobile equipment[2]	Mining area.
1995	2	20	2	Heat source-flammable liquid	Heater	Refuse area.
	4		4	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	4		4	Hydraulic fluid/fuel on equipment hot surfaces	Mobile equipment[2]	Drilling/haulage/mining areas.
1996	3	20	3	Hydraulic fluid/fuel on equipment hot surfaces	Mobile equipment[2]	Loading/hopper areas.
	1		1	Engine malfunction	Mobile equipment[2]	Haulage areas.
	3		3	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	2		2	Heat source-refueling fuel	Heater	Maintenance area.
1997	1	20	1	Heat source-flammable liquid	Heater	Maintenance area.
	2		2	Flammable liquid on hot surfaces	Mobile equipment[2]	Maintenance area.
	4		4	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
1998	3	13	3	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	1		1	Flammable liquid on hot surfaces	Heater	Maintenance area.
	1		1	Hydraulic fluid/fuel on equipment hot surfaces	Mobile equipment[2]	Haulage area.
	1		1	Gas explosion	Mobile equipment[2]	Mining area.
1999	2	11	2	Flammable liquid on hot surfaces	Heater	Maintenance area.
	1		1	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
Total	94	215	94			

[1]Includes beltline area, bucket and transfer houses, coal chute and dust collector areas, and mobile equipment maintenance areas.
[2]Includes trucks, dozers, loaders, drills, shovels, and buckets.
[3]During 1991, there was 1 fire fatality.

Ignition Source

The number of fires and fire injuries by ignition source and time period is shown in tables 21 and 27. The leading sources were hydraulic fluid/fuel sprayed onto equipment hot surfaces (76 fires or 35% with 22 injuries), followed by flame cutting/welding spark/slag/flames (59 fires or 27% with 44 injuries), spontaneous combustion/hot coal (21 fires or 10%), and flammable liquid/refueling fuel on hot surfaces (18 fires or 8% with 7 injuries). Other ignition sources were engine/mechanical malfunctions/friction/explosions (11 fires), heat sources (10 fires), electrical short/arcing (8 fires), overheated oil (4 fires), conveyor belt friction (3 fires), and natural gas explosions (2 fires). Three ignition sources were unknown. The flame cutting/welding spark/slag/flame ignition source caused fires usually involving welders' clothing or oxyfuel/grease (grease embedded in the equipment's mechanical components). However, in four instances undetected hot slag caused coal belt ignitions. In another instance, undetected hot slag caused a coal chute smoldering fire, which, upon application of water, produced a flashback accompanied by a gas explosion (causing one fatality).

Forty-two of the mobile equipment hydraulic fluid/fuel fires became large fires, which at times required fire brigades and fire department interventions. On at least five occasions, the cab was suddenly engulfed in flames, forcing the operators to exit under hazardous conditions, probably due to the ignition of flammable vapors and mists that penetrated the cab. Of note is that most of the hydraulic fluid/fuel fires were caused when hydraulic fluids sprayed onto equipment hot surfaces; subsequently, these fires involved the fuel lines.

During the first through fourth periods, the largest number of fires were caused by hydraulic fluid/fuel sprayed onto equipment hot surfaces. During the fifth period, the largest number of fires were caused by hydraulic fluid/fuel sprayed onto equipment hot surfaces and flame cutting/welding spark/slag/flame sources (see table 21).

Method of Detection

Table 22 shows the number of fires by method of detection and time period. The most frequent methods were operators who saw the fires when they started as flames/flash fires, welders who saw sparks, miners who saw smoke long after the fires had started, and miners who saw smoke shortly after the fires had started. Thirteen fires were undetected. Other methods of detection were miners who heard an explosion, operators who heard a popping sound, miners who saw electrical/mechanical sparks or smelled smoke, operators who saw radiator white smoke/oil mist spray or experienced power loss, and miners who heard an electrical trip warning or fire alarm. The largest number of fires were detected by flames/flash fires throughout the periods (table 22).

Suppression Method

Table 23 shows the number of fires by suppression method and time period. The most common methods were portable fire extinguishers, foam, dry chemical powder, and water. These were followed by manual methods with or without portable fire extinguishers and water or portable fire extinguishers alone. Five pieces of mobile equipment involved in fires had machine fire suppression systems. Dual activation (three activations) of machine fire suppression and engine shutoff systems succeeded in temporarily abating the fires. However, the flames reignited, fueled by the flow of pressurized fluids entrapped in the lines (not affected by the engine shutoff operation), which hindered the operators' safe escape. Most of the mobile equipment hydraulic fluid/fuel fires became large fires, which required at least 15 fire brigade and fire department interventions because of the continuous flow of fluid/fuel from the pumps due to engine shutoff failure, lack of an emergency hydraulic line drainage system, difficulty in activating available emergency systems at ground level, or lack of effective and rapid local firefighting capabilities. (Fire-resistant hydraulic fluid is not required for equipment use at surface coal operations.) Other methods included coal spread, water, compaction, and removal. Fire brigades and fire departments, which were required in at least 26 instances, fought the mobile equipment fires and other large fires with foam, dry chemical powder, and water. However, 13 fires destroyed or heavily damaged equipment (including six pieces of mobile equipment) because of failure of other firefighting methods, late fire detection, undetected fires, or fire size.

During the first through fourth periods, the largest number of fires were suppressed with portable fire extinguishers, foam, dry chemical powder, and water. During the fifth period, the largest number of fires were suppressed with portable fire extinguishers and water (see table 23).

Equipment Involved

Table 24 shows the number of fires by equipment involved and time period. The equipment most often involved was mobile equipment (trucks, dozers, loaders, drills, shovels, backhoes, buckets, scrapers, excavators, and augers). This was followed by oxyfuel torches, heaters, and maintenance equipment. Other equipment included crushers and dust collectors; beltlines, drives, and pulleys; facilities; and air compressors. The largest number of fires involved mobile equipment throughout the periods (table 24).

Location

Table 25 shows the number of fires by location and time period. The most common locations were mobile equipment working areas (mining, haulage, loading, and drilling areas). These were followed by flame cutting/welding areas (at beltline areas, shaft, coal chute and dust collector areas, bucket and transfer houses, and mobile equipment maintenance areas) and maintenance areas. Other fire locations included coal silos, loading docks, refuse piles, abandoned and coal pit areas, dust collectors, baghouses, crushers and beltline areas, and facilities. The largest number of fires throughout the periods occurred at mobile equipment working areas (table 25).

Burning Materials

Table 26 shows the number of fires by burning material and time period. The material most often involved was hydraulic fluid/fuel, followed by oxyfuel/grease/clothing, flammable liquids, coal and coal dust, and straw and refuse. Other burning materials included electrical systems, batteries, collector rings and breakers, dust collectors, baghouses, and furnaces. Belts, idlers and pulleys, air compressors, transmission oil, facilities and contents, and natural gas and chemicals also burned during fires. The largest number of fires involved hydraulic fluid/fuel throughout the periods (table 26).

Fire Injuries

Table 27 shows the number of fire injuries per number of fires causing injuries and total fires by year, ignition source, equipment involved, and location during 1990–1999. Overall, there were 93 injuries and 1 fatality caused by 94 fires.

The greatest number of fire injuries occurred in 1990 (19 injuries caused by 19 fires) and 1991 (13 injuries and 1 fatality caused by 14 fires). The ignition sources that caused most of the fire injuries were flame cutting/welding spark/slag/flames and hydraulic fluid/fuel sprayed onto equipment hot surfaces. These were followed by flammable liquid on hot surfaces and by heat sources and pressurized can explosions. Other ignition sources were engine/mechanical malfunctions/friction and conveyor belt friction. The equipment most often involved included oxyfuel torches, mobile equipment, heaters, maintenance equipment, dust collectors and samplers, and beltlines. The locations where most of the fire injuries occurred were flame cutting/welding and mobile equipment working areas. Other fire locations were maintenance, dust collector, and beltline areas.

The fire fatality in Montana in 1991 was caused by a flashback accompanied by a gas explosion that engulfed the mechanic who was hosing down a coal chute smoldering fire. The smoldering of coal was due to undetected hot slag produced during flame cutting/welding operations [MSHA 1991b].

COAL PREPARATION PLANT FIRES

Table 28 and figure 10 show the number of fires and fire injuries for coal preparation plants by state during 1990–1999. Table 28 also shows the risk rates, employees' working hours, and lost workdays by state. For coal preparation plants, 91 fires occurred in 11 states during 1990–1999. Twenty-three of those fires caused 25 injuries (the yearly average was 9.1 fires and 2.5 injuries). Ten fires and eight injuries involved contractors. The Ewhr value was 241 × 10^6 hr (Irr = 0.021), and the LWD value was 198.

Pennsylvania had the most fires (24 fires and 4 injuries), whereas West Virginia (22 fires and 7 injuries) and Kentucky (22 fires and 7 injuries) had the most fire injuries. Among these states, Kentucky had the highest injury risk rate value (Irr = 0.025).

Table 29, partly illustrated in figure 11, shows the number of fires, fire injuries, risk rates, employees' working hours, and lost workdays by time period. The number of fires decreased during most of the periods (an increase is seen only during the last period). The number of fire injuries show a decrease followed by an increase during the periods, accompanied by a decline in employees' working hours throughout the periods. The Irr values follow patterns similar to those shown by the injury values (see table 29 and figure 11).

Tables 30–35 show the number of fires by ignition source, method of detection and suppression, equipment involved, location, and burning material by time period. Figure 12 shows the major variables during 1990–1999. Table 36 shows the fire injuries per number of fires causing injuries and total fires by year, ignition source, equipment involved, and location.

Ignition Source

The number of fires and fire injuries by ignition source and time period is show in tables 30 and 36. The leading source was spontaneous combustion/hot coal (24 fires or 26%). This was followed by flame cutting/welding spark/slag/flames (15 fires or 17% with 8 injuries), hydraulic fluid/fuel sprayed onto equipment hot surfaces (10 fires or 11% with 6 injuries), and conveyor belt friction (9 fires or 10% with 1 injury). The flame cutting/welding spark/slag/flame ignition source caused fires usually involving welders' clothing or oxyfuel/grease (grease embedded in the equipment's mechanical components). However, in one instance undetected hot slag caused a storage facility fire. Other ignition sources were electrical short/arcing (nine fires), flammable liquid/refueling fuel on hot surfaces (six fires), engine/mechanical malfunctions/friction (three fires), overheated oil (two fires), and a chemical explosion (one fire). Eight ignition sources were unknown. The spontaneous combustion/hot coal fires were detected long after the fires had started due to lack of continuous and early combustion gas/smoke detection systems. Two of the mobile equipment hydraulic fluid/fuel fires became large fires, which at times required fire brigade and fire department interventions. In two instances the cab was suddenly engulfed in flames, forcing the operators to exit under hazardous conditions, probably due to the ignition of flammable vapors and mists that penetrated the cab. Of note is that most of the hydraulic fluid/fuel fires were caused when hydraulic fluids sprayed onto equipment hot surfaces; subsequently, these fires involved the fuel lines.

During the first, third, fourth, and fifth periods, the largest number of fires were caused by spontaneous combustion/hot coal. During the second period, the largest number of fires were caused by spontaneous combustion/hot coal and by flame cutting/welding spark/slag/flames (see table 30).

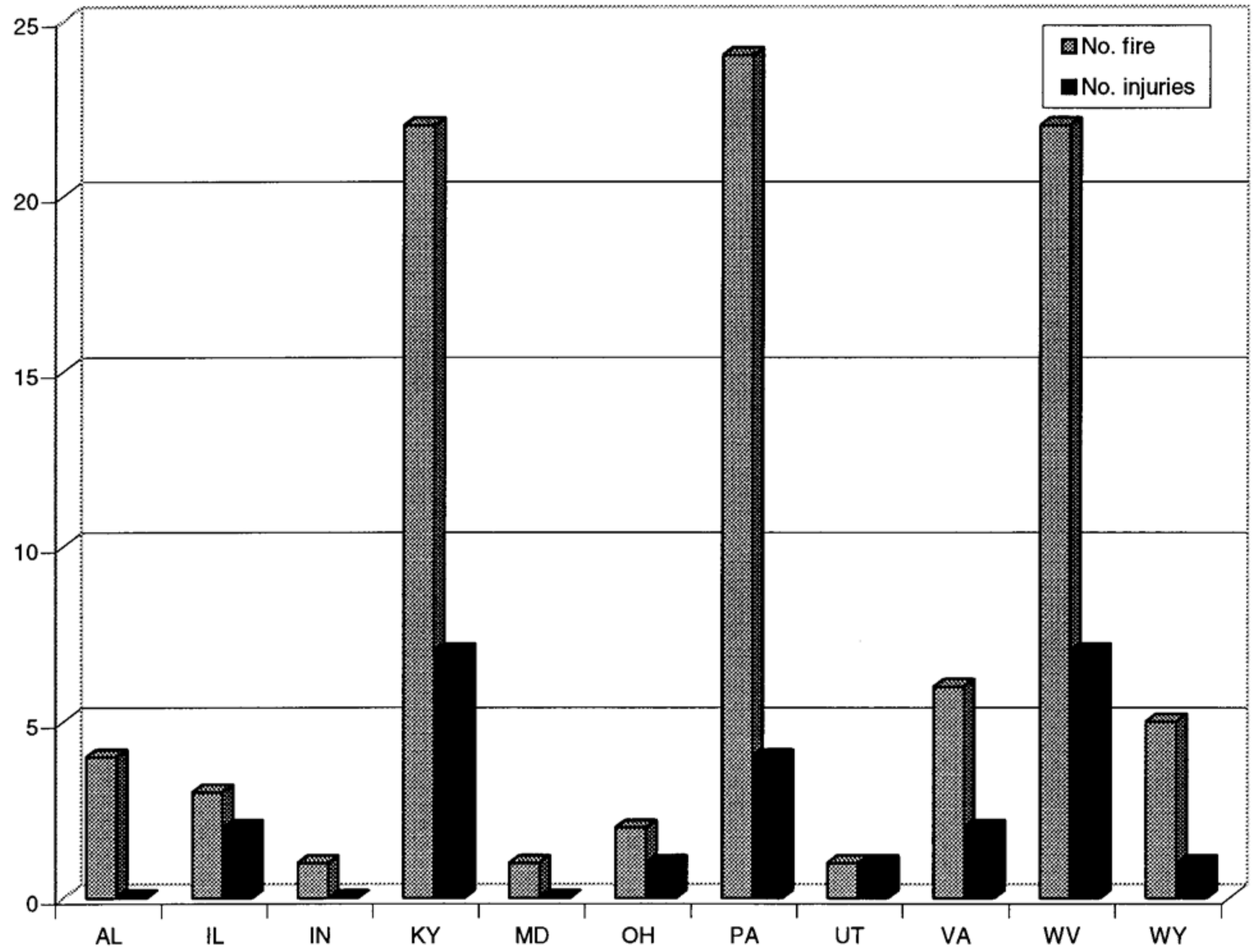

Figure 10.—Number of fires and fire injuries for coal preparation plants by state, 1990–1999.

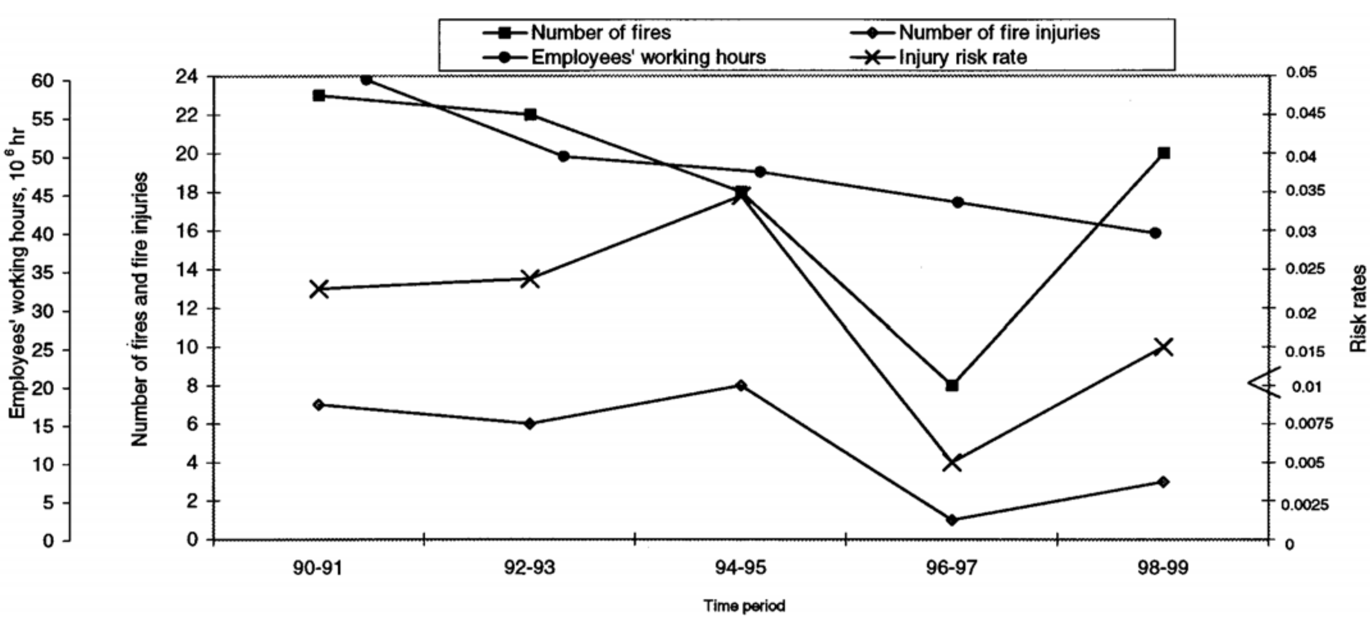

Figure 11.—Number of fires, fire injuries, and risk rates for coal preparation plants by time period and employees' working hours, 1990–1999.

Table 28.—Number of fires, fire injuries, and risk rates for coal preparation plants by state, employees' working hours, and lost workdays, 1990–1999

State[1]	No. fires[1]	No. injuries[1]	LWD[2]	Ewhr,[2] 10^6 hr	Irr[3]
Alabama	4	—	—	11	—
Illinois	3	2	14	15	0.027
Indiana	1	—	—	8.4	—
Kentucky	22	7	83	56	0.025
Maryland	1	—	—	1	—
Ohio	2	1	7	12.5	0.016
Pennsylvania	24	4	60	34.4	0.023
Utah	1	1	—	2.1	0.095
Virginia	6	2	—	21.5	0.019
West Virginia	22	7	34	59.5	0.024
Wyoming	5	1	—	4.1	0.049
Other states	—	—	—	15.3	—
Total	91	25	198	241	[3]0.021

[1]Derived from MSHA "Fire Accident Abstract" and "Fire Accident Report" publications.
[2]Derived from MSHA "Injury Experience in Coal Mining" publications.
[3]Calculated according to MSHA formula reported in the "Methodologies" section.

Table 29.—Number of fires, fire injuries, and risk rates for coal preparation plants by time period, employees' working hours, and lost workdays, 1990–1999

	Time period					
	90-91	92-93	94-95	96-97	98-99	90-99
Number of fires[1]	23	22	18	8	20	91
Number of fire injuries[1]	7	6	8	1	3	25
LWD[2]	116	19	37	—	26	198
Ewhr,[2] 10^6 hr	60	50	48	44	39	241
Irr[3]	0.023	0.024	0.033	0.005	0.016	[3]0.021

[1]Derived from MSHA "Fire Accident Abstract" and "Fire Accident Report" publications.
[2]Derived from MSHA "Injury Experience in Coal Mining" publications.
[3]Calculated according to MSHA formula reported in the "Methodologies" section.

Table 30.—Number of fires for coal preparation plants by ignition source and time period, 1990–1999

Ignition source	Time period					
	90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Heat source	1	—	2	—	1	4
Conveyor belt friction	1	2	2	—	4	9
Flame cutting/welding spark/slag/flame[1]	4	6	2	1	2	15
Chemical explosion	—	—	—	1	—	1
Spontaneous combustion/hot coal	5	6	4	4	5	24
Flammable liquid/refueling fuel on hot surfaces/ explosion	3	1	1	—	1	6
Electrical short/arcing[2]	2	4	1	—	2	9
Overheated oil	—	1	—	—	1	2
Engine/mechanical malfunctions/friction	1	—	1	1	—	3
Hydraulic fluid/fuel on equipment hot surfaces	3	2	2	1	2	10
Unknown	3	—	3	—	2	8
Total	23	22	18	8	20	91

[1]This source caused fires usually involving welders' clothing or oxyfuel/grease. However, in at least one instance undetected hot slag caused a storage facility fire.
[2]On one occasion this source caused a coal dust explosion in a dust collector.

Table 31.—Number of fires for coal preparation plants by method of detection and time period, 1990–1999

Method of detection	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Visual:						
Flames/flash fires	8	3	3	2	4	20
Smoke	2	4	4	1	3	14
Sparks	1	5	1	1	1	9
Smoldering	—	—	—	—	1	1
Late smoke detection	6	9	6	3	8	32
Dim lights	—	—	—	—	1	1
Explosion	1	—	—	1	—	2
Popping sound	1	—	—	—	—	1
Undetected	2	1	3	—	1	7
Touched hot spots	1	—	1	—	—	2
Other	—	—	—	—	1	1
Total	23	22	18	8	20	91

Table 32.—Number of fires for coal preparation plants by suppression method and time period, 1990–1999

Suppression method	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Manual/FE[1]	3	5	4	1	1	14
FE-foam/water/dry chemical powder	8	7	2	1	8	26
Water	7	3	4	1	5	20
Coal spread-water-compaction removal[2]	2	5	4	3	4	18
Destroyed/heavily damaged[3]	3	2	4	2	2	13
Total	23	22	18	8	20	91

FE Portable fire extinguisher.
[1]Methods used by welders to extinguish clothing or oxyfuel/grease fires.
[2]Methods used to extinguish spontaneous combustion/hot coal fires. In one case, a CO_2 permanent fire extinguishment system was used.
[3]Due to failure of other firefighting methods, late fire detection, or undetected fires.

Table 33.—Number of fires for coal preparation plants by equipment involved and time period, 1990–1999

Equipment	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Electrical control/power system	2	3	1	—	1	7
Oxyfuel torch	4	6	2	1	2	15
Heater/maintenance equipment	2	—	3	—	—	5
Airlock gate	1	—	—	—	—	1
Dust sampler/collector/dryer/washer	4	—	—	1	1	6
Beltline/drive/pulley	1	3	2	—	5	11
Facility	1	—	3	—	1	5
Chemical tank	—	—	—	1	—	1
Hopper	—	—	—	—	2	2
Mobile equipment[1]	5	4	3	2	3	17
Air compressor	—	1	—	—	—	1
Other[2]	3	5	4	3	5	20
Total	23	22	18	8	20	91

[1]Includes loader, dozer, and haulage/utility trucks.
[2]Includes nonequipment (mostly coal piles).

Table 34.—Number of fires for coal preparation plants by location and time period, 1990–1999

Location	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Flame cutting/welding areas[1]	4	6	2	1	2	15
Beltline/rail dump areas	3	2	3	—	4	12
Coal silos/stock pile/coal feeder	4	5	5	4	5	23
Power station	—	1	—	—	1	2
Maintenance areas	3	1	2	—	1	7
Thermal dryer/dust collector/washer/hopper areas	3	2	—	—	2	7
Airlock gates	1	1	—	—	—	2
Charging station	—	—	—	1	—	1
Mobile equipment working areas[2]	3	3	3	2	3	14
Facility area	2	1	3	—	2	8
Total	23	22	18	8	20	91

[1]Includes packing material building, plastic material storage, coal bypasses, loadout facilities, raw coal silos, drawoff tunnels, coal feeders, shops, coal hoppers, and mobile equipment maintenance areas.
[2]Includes loading and haulage areas.

Table 35.—Number of fires for coal preparation plants by burning material and time period, 1990–1999

Burning material	Time period 90-91 No. fires	92-93 No. fires	94-95 No. fires	96-97 No. fires	98-99 No. fires	90-99 No. fires
Oxyfuel/grease/clothing	2	4	1	1	1	9
Alcohol/chemicals	1	—	—	1	—	2
Flammable liquids/oil/grease	2	2	3	—	1	8
Belt/drive/pulley	3	3	3	—	4	13
Facility/content	1	—	3	—	1	5
Coal/coal dust/wood/insulation/rubber tires/ packing materials	8	7	7	4	7	33
Electrical systems/wires/cables	1	4	—	—	2	7
Hydraulic fluid/fuel	3	2	1	1	3	10
Equipment mechanical components	2	—	—	1	1	4
Total	23	22	18	8	20	91

Table 36.—Number of fire injuries per number of fires causing injuries and total fires at coal preparation plants by year, ignition source, equipment involved, and location, 1990–1999

Year	No. fires causing injuries	No. total fires	No. fire injuries	Ignition source	Equipment	Location
1990	2	11	3	Refueling fuel on hot surfaces	Pump/heater	Pump housing/maintenance areas.
	1	—	1	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
1991	1	12	1	Electrical short/arcing-coal dust explosion	Dust sampler	Dust collector area.
	1		1	Heat source	Heater	Maintenance area.
	1	—	1	Hydraulic fluid/fuel on equipment hot surfaces	Mobile equipment[2]	Loading area.
1992	3	11	3	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	1	—	1	Electrical short-flammable liquid	Thermal dryer	Dryer area.
1993	1	11	1	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	1	—	1	Hydraulic fluid/fuel on equipment hot surfaces	Mobile equipment[2]	Loading area.
1994	1	10	1	Heat source-flammable liquid	Heater	Maintenance area.
	1	—	1	Refueling fuel on hot surfaces	Maintenance equipment	Maintenance area.
	1	—	1	Conveyor belt friction	Beltline	Beltline area.
1995	1	8	1	Flame cutting welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
	2	—	3	Hydraulic fluid/fuel on equipment hot surfaces	Mobile equipment[2]	Loading/haulage areas.
	1	—	1	Mechanical malfunction	Mobile equipment[2]	Haulage area.
1996	1	5	1	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
1997	—	3	—	—	—	—
1998	1	10	1	Flame cutting/welding spark/slag/flame	Oxyfuel torch	Flame cutting/welding areas.[1]
1999	1	10	1	Hydraulic fluid/fuel on equipment hot surfaces	Mobile equipment[2]	Loading area.
	1		1	Heat source-flammable liquid	Thermal dryer	Dryer area.
Total	23	91	25			

[1]Includes loadout facilities, sump and coal feeder areas, shops, packing material building, and plastic material storage.
[2]Includes loaders and trucks.

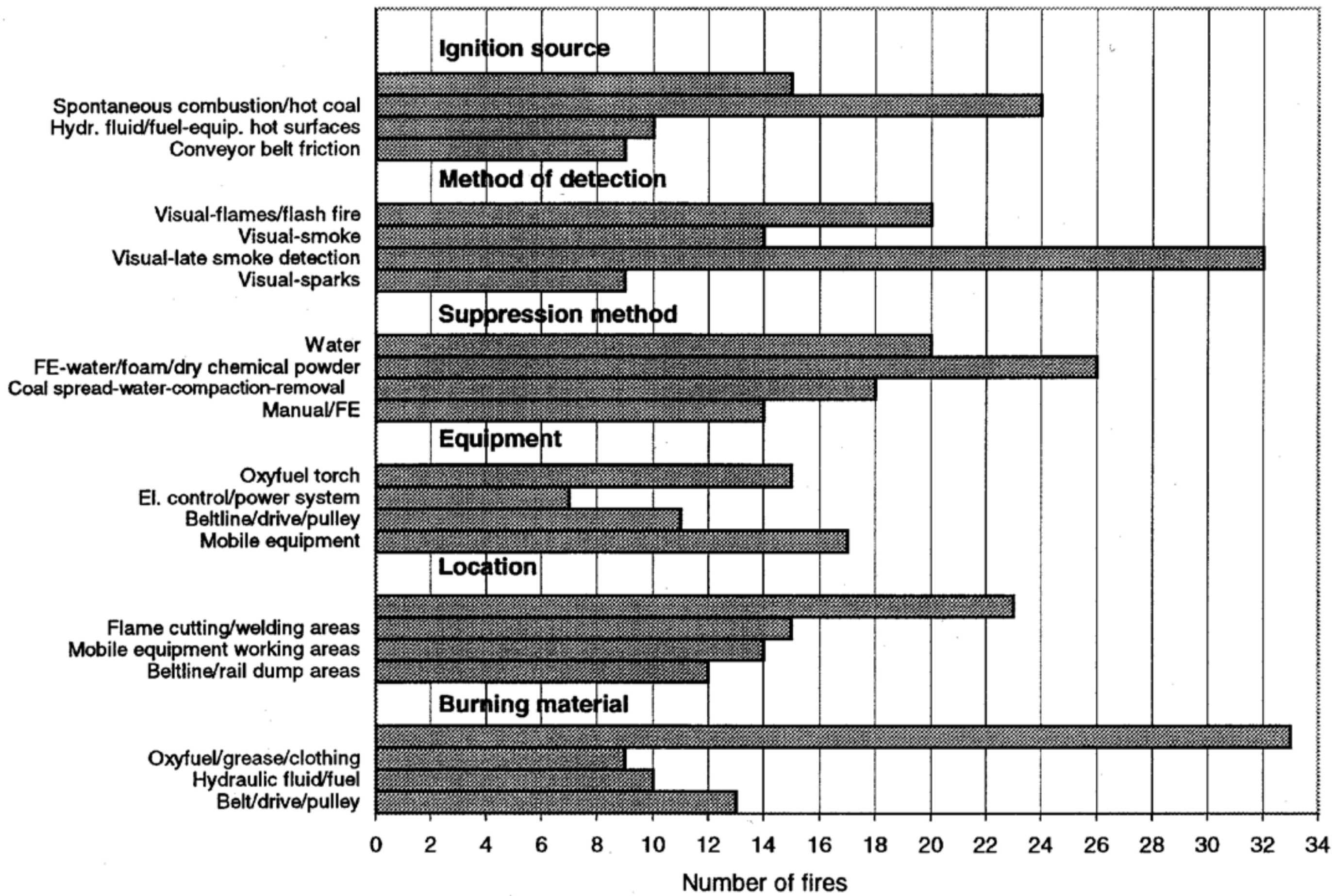

Figure 12.—Major variables for coal preparation plant fires, 1990–1999. (FE = portable fire extinguisher)

Method of Detection

Table 31 shows the number of fires by method of detection and time period. The most frequent method was miners who saw smoke long after the fires had started, followed by operators who saw the fires when they started as flames/flash fires, miners who saw smoke shortly after the fire had started, and welders who saw sparks. Other methods of detection were miners who touched hot spots, miners who saw smoldering of coal or heard an explosion, and operators who heard a popping sound or saw dimming of equipment lights. In one instance, a coal sampler detected a coal silo smoldering fire. Seven fires were undetected.

During the first period, the largest number of fires were detected when they started as flames/flash fires. During subsequent periods, the largest number of fires were detected late by smoke (see table 31).

Suppression Method

Table 32 shows the number of fires by suppression method and time period. The most common methods were water alone and coal spread, water, compaction, and removal. These were followed by portable fire extinguishers, foam, dry chemical powder and water, manual techniques with or without portable fire extinguishers, and dry chemical and water alone. In one instance, a permanent CO_2 fire-extinguishing system was used to put out a coal silo smoldering fire. None of the mobile equipment involved in fires had machine fire suppression systems. Most of the hydraulic fluid/fuel fires became large fires, which in one instance required a fire brigade and fire department intervention because of the continuous flow of fluid/fuel from the pumps due to engine shutoff failure, lack of an emergency hydraulic line drainage system (the flow of pressurized fluids entrapped in the lines was not affected by the engine shutoff operation), difficulty in activating available emergency systems at ground level, or lack of effective and rapid local firefighting response capabilities. (Fire-resistant hydraulic fluid is not required for equipment use at surface coal operations.)

Fire brigades and fire departments (required on at least nine occasions) fought the mobile equipment fires and other large fires with foam, dry chemical powder, and water. However, 13 fires destroyed or heavily damaged equipment (including four pieces of mobile equipment) because of failure of other firefighting methods, late fire detection, undetected fires, or fire size.

During the first, second, and fifth periods, the largest number of fires were suppressed with portable fire extinguishers, foam, dry chemical powder, and water. During the third period, the largest number of fires were extinguished by coal spread, water, compaction, and removal; manually with or without portable fire extinguishers; and water alone. During the fourth period, the largest number of fires were extinguished by coal spread, water, compaction, and removal (see table 32).

Equipment Involved

Table 33 shows the number of fires by equipment involved and time period. The equipment most often involved included mobile equipment (loaders, dozers, and trucks); oxyfuel torches; and beltlines, drives, and pulleys. Other equipment included electrical control and power systems, dust collectors and samplers, dryers and washers, heaters and maintenance equipment, hoppers, airlock gates, chemical tanks, and air compressors.

During the first period, the largest number of fires involved mobile equipment. During the second period, the largest number of fires involved oxyfuel torches. During the third period, the largest number of fires involved heaters, maintenance equipment, facilities, and mobile equipment. During the fourth and fifth periods, the largest number of fires involved mobile equipment (see table 33).

Location

Table 34 shows the number of fires by location and time period. The most common locations were coal silos, stockpile, and coal feeder areas and flame cutting/welding areas (at packing material buildings, plastic material storage, coal bypasses, loadout facilities, raw coal silos, drawoff tunnels, coal feeders, shops, coal hoppers, and mobile equipment maintenance areas). Other fire locations were mobile equipment working areas (loading and haulage areas), beltline and rail dump areas, facilities, and maintenance areas. Also affected by fires were thermal dryer, dust collector, washer, and hopper areas; power stations; airlock gates; and charging stations.

During the first and second periods, the largest number of fires occurred at flame cutting/welding areas. During the third, fourth, and fifth periods, the largest number of fires occurred at coal silo, feeder, and stockpile areas (see table 34).

Burning Materials

Table 35 shows the number of fires by burning material and time period. The materials most often involved were coal and coal dust, insulation material, rubber tires, wood, and packing materials, followed by belts, drives, and pulleys and hydraulic fluid/fuel. Other burning materials were flammable liquids, oil/grease, oxyfuel/grease/clothing, electrical systems, wires and cables, facilities and contents, equipment mechanical components, and alcohol and chemicals. Throughout the periods the largest number of fires involved coal, coal dust, wood, insulation, rubber tires, and packing materials (table 35).

Fire Injuries

Table 36 shows the number of fire injuries, number of fires causing injuries, and total fires by year, ignition source, equipment involved, and location during 1990–1999. Overall, there were 25 injuries caused by 23 fires.

The greatest number of fire injuries occurred in 1995 (five injuries caused by four fires) and 1992 (four injuries caused by four fires). The ignition sources that caused most of the fire injuries were flame cutting/welding spark/slag/flames, hydraulic fluid/fuel sprayed onto equipment hot surfaces, and flammable liquid/refueling fuel on hot surfaces. Other ignition sources were heat sources, mechanical malfunctions, electrical short/arcing and coal dust explosion, and conveyor belt friction. The equipment most often involved included oxyfuel torches, mobile equipment, heaters, maintenance equipment, dust collectors and samplers, pumps, and beltlines. The fire locations where most of the fire injuries occurred were flame cutting/welding areas and mobile equipment working areas. Other fire locations were maintenance areas, dust collector areas, thermal dryer and beltline areas, and pump housings.

SUMMARY OF MAJOR FIRE AND FIRE INJURY FINDINGS FOR ALL COAL MINING CATEGORIES

The major fire and fire injury findings for all coal mining categories for 1990–1999 are reported in tables 37–38. Table 39 and figure 13 show the number of fires, fire injuries, risk rates, employees' working hours, and coal production (underground and surface coal mines only) by time period for all coal mining categories. Table 40 shows major findings (for underground coal mines only) for 1978–1992.

For all coal mining categories, 458 fires occurred during 1990–1999; 157 of those fires caused 164 injuries and 2 fatalities (Ewhr = 2,070 × 10^6 hr, Irr = 0.016; CP (for underground and surface coal mines only) = 10,363 × 10^6 st, Frr = 0.044, LWD = 14,753). Twenty-nine fires and 17 injuries involved contractors.

Sixty-six fires required firefighting interventions by mine rescue teams (25 times in underground mines) and fire brigades and fire departments (at least 41 times at surface coal operations). In all, 51 fires destroyed or heavily damaged equipment (including 16 pieces of mobile equipment) because of failure of other firefighting methods, late fire detection, undetected fires, or fire size. A total of 114 fires were detected late, and 42 fires were undetected. The greatest number of fires and fire injuries occurred at surface coal mines; the highest risk rate values were also calculated for this category.

For all coal operations, the ignition sources that caused the greatest number of fires were flame cutting/welding spark/slag/flames (103 fires or 23% with 69 injuries), hydraulic fluid/fuel sprayed onto equipment hot surfaces (98 fires or 21% with 29 injuries), spontaneous combustion/hot coal (62 fires or 14%), electrical short/arcing (49 fires or 11% with 18 injuries), and conveyor belt friction (31 fires or 7% with 6 injuries).

Table 37.—Major fire findings for all coal mining categories, 1990–1999

Variables	Underground coal mines	Surface of underground coal mines	Surface coal mines	Coal preparation plants
GT: No. fires: 458 CP, 10^6 st: 10,363 Frr: 0.044 No. fires causing injuries: 157	No. fires: 87 CP, 10^6 st: 4,008 Frr: 0.022 No. fires causing injuries: 27	No. fires: 65 No. fires causing injuries: 13	No. fires: 215 CP, 10^6 st: 6,355 Frr: 0.034 No. fires causing injuries: 94	No. fires: 91 No. fires causing injuries: 23
Ignition source	Electrical short/arcing/explosion Flame cutting/welding/spark/slag/flame Conveyor belt friction Spontaneous combustion	Hydraulic fluid/fuel on equipment hot surfaces Flame cutting/welding spark/slag/flame Spontaneous combustion/hot coal Heat source	Hydraulic fluid/fuel on equipment hot surfaces Flame cutting/welding spark/slag/flame Spontaneous combustion/hot coal Flammable liquid-refueling fuel on hot surfaces	Spontaneous combustion/hot coal Flame cutting/welding spark/slag/flame Hydraulic fluid/fuel on equipment hot surfaces Conveyor belt friction
Method of detection	Late smoke detection Visual-sparks Visual-smoke CO/H_2 gas sample	Late smoke detection Visual-flames/flash fires Visual-smoke Visual-sparks	Visual-flames/flash fires Visual-sparks Late smoke detection Visual-smoke	Late smoke detection Visual-flames/flash fires Visual-smoke Visual-sparks
Suppression method	FE/water FE-DCP-rock dust/water Portable fire extinguisher Sealing/flooding/CO_2/N_2 gas injections	FE-foam/water/DCP Manual/FE Coal spread-water-compaction-removal Portable fire extinguisher	FE-foam/DCP/water Manual/FE FE/water Portable fire extinguisher	FE-foam/DCP/water Water Coal spread-water-compaction-removal Manual/FE
Equipment involved	Mobile equipment[1] Oxyfuel torch Beltline/drive/pulley/feeder Electrical system/units/other	Facility Mobile equipment[1] Oxyfuel torch Beltline/drive/pulley	Mobile equipment[1] Oxyfuel torch Heater/maintenance equipment Dust collector/crusher	Mobile equipment[1] Oxyfuel torch Beltline/drive/pulley Electrical control/power system
Location	Belt entries/feeder/slope/portal branch areas Flame cutting/welding areas[2] Gobline/sealed/abandoned coal pit areas Mining face/crosscut/intersection areas	Facility areas Mobile equipment working areas Flame cutting/welding areas[2] Beltline/drawoff tunnel areas	Mobile equipment working areas Flame cutting/welding areas[2] Maintenance area Coal silo/pit areas/other	Coal silos/feeder/stockpile Flame cutting/welding areas[2] Mobile equipment working areas Beltline/rail dump areas
Burning material	Electrical wires/cables/units/other Coal/coal dust Belt/drive/pulley/feeder Oxyfuel/grease/clothing	Facility/content/other Hydraulic fluid/fuel Coal/methane Belt/drive/pulley	Hydraulic fluid/fuel Oxyfuel/grease Flammable liquid/refueling fuel Coal/coal dust	Coal/wood/insulation material/other Belt/drive/pulley Hydraulic fluid/fuel Oxyfuel/grease/clothing

DCP Dry chemical powder.
FE Portable fire extinguisher.
[1]Includes scoops, bolters, shuttle cars, ore carts, 3-wheelers, trolleys, locomotives, rail runners, shearers, continuous miners, loaders, dozers, shovels, scrapers, drills, highlifts, excavators, backhoes, buckets, trucks, auger/miners, hoists, and power scalers.
[2]Includes longwall face and headgate; belt entries; beltline areas; drive, pulley, and feeder areas; overcasts; shops; storage silos; plastic/packing material buildings; shafts; coal chutes; dust collectors; elevator shafts; bucket/transfer housing; coal bypasses; drawoff tunnels; raw coal hoppers; and mobile equipment maintenance areas.
NOTE.—Variables are listed in descending order of occurrence.

Table 38.—Major fire injury findings for all coal mining categories, 1990–1999

Variables	Underground coal mines	Surface of underground coal mines	Surface coal mines	Coal preparation plants
Grand total: No. fire injuries: 164 No. fire fatalities: 2 Ewhr, 10^6 hr: 2,070 Irr: 0.016 LWD: 14,753	No. fire injuries: 34 Ewhr, 10^6 hr: 1,003 Irr: 0.0068 LWD: 208	No. fire injuries: 12 No. fire fatalities: 1 Ewhr, 10^6 hr: 97 Irr: 0.025 LWD: 6,206	No. fire injuries: 93 No. fire fatalities: 1 Ewhr, 10^6 hr: 729 Irr: 0.026 LWD: 8,141	No. fire injuries: 25 Ewhr, 10^6 hr: 241 Irr: 0.021 LWD: 198
Ignition source	Electrical short/arcing Flame cutting/welding spark/slag/flame Conveyor belt friction Heat source	Flame cutting/welding spark/slag/flame Heat source Battery explosion Hydraulic fluid/fuel on equipment hot surfaces	Flame cutting/welding spark/slag/flame Hydraulic fluid/fuel on equipment hot surfaces Flammable liquid on hot surfaces Heat source	Flame cutting/welding spark/slag/flame Hydraulic fluid/fuel on equipment hot surfaces Refueling fuel on hot surfaces Electrical short/arcing-coal dust explosion
Method of detection	Visual-smoke Visual-sparks Late smoke detection	Visual-sparks Visual-flames Explosion Visual-flames/flash fire	Visual-sparks Visual-flames/flash fires Visual-smoke/explosion	Visual-sparks Visual-flames/flash fires Explosion
Suppression method	FE-rock dust/DCP/water Manual/FE Portable fire extinguisher	FE/manual Portable fire extinguisher FE-foam/DCP/water	FE-manual FE-foam/DCP/water Portable fire extinguisher	FE-manual FE-foam/water/DCP Portable fire extinguisher
Equipment involved	Electrical power cables/systems/starter/voltage box/mobile equipment Oxyfuel torch Beltline/drive/pulley Heater	Oxyfuel torch Heater Mobile equipment[1]	Oxyfuel torch Mobile equipment[1] Heater	Oxyfuel torch Mobile equipment[1] Heater/maintenance equipment Dust collector/sampler
Location	Pump/power/charging stations/mobile equipment working areas Flame cutting/welding areas[2] Trolley track rails/transportation areas Belt entries	Flame cutting/welding areas[2] Maintenance area Mobile equipment working areas Charging station	Flame cutting/welding areas[2] Mobile equipment working areas Maintenance areas	Flame cutting/welding areas[2] Mobile equipment working areas Maintenance area Dust collector area
Burning material	Electrical units/wires/cables Oxyfuel/grease/clothing Belt material Mobile equipment mechanical components	Oxyfuel/grease/clothing Hydraulic fluid/fuel Batteries	Oxyfuel/grease/clothing Hydraulic fluid/fuel Flammable liquids Pressurized can	Oxyfuel/grease/clothing Hydraulic fluid/fuel Flammable liquids/refueling fuels Dust collector liners

DCP Dry chemical powder.
FE Portable fire extinguisher.
[1]Includes scoops, shuttle cars, bolters, rail runners, jeeps, trucks, loaders, dozers, scrapers, shovels, highlifts, excavators, buckets, backhoes, drills, and tractors.
[2]Includes conveyor belt entries, beltline areas, longwall mining face, shops, loadout facilities, bucket/transfer houses, coal chutes, dust collectors, storage silos, sump areas, and mobile equipment working and maintenance areas.
NOTE.—Variables are listed in descending order of occurrence.

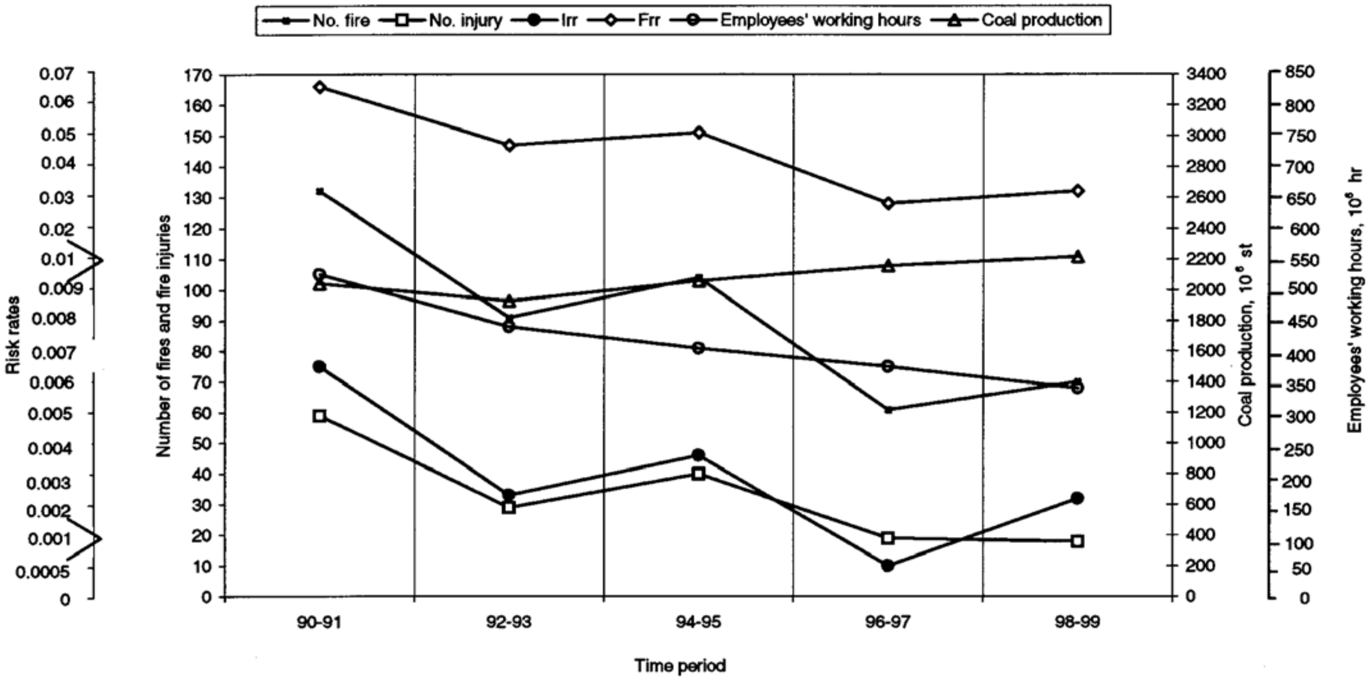

Figure 13.—Number of fires, fire injuries, risk rates, and coal production (underground and surface coal mines only) for all coal mining categories by time period and employees' working hours, 1990–1999.

Table 39.—Number of fires, fire injuries, fire fatalities, and risk rates for all coal mining categories by time period, employees' working hours, lost workdays, and coal production, 1990–1999

	Time period					
	90-91	92-93	94-95	96-97	98-99	90-99
Number of fires[1]	132	91	104	61	70	458
Number of fire injuries[1]	59	29	39	19	18	164
Number of fire fatalities[1]	2	—	—	—	—	2
LWD[2]	12,847	734	421	345	406	14,753
Ewhr,[2] 10^6 hr	521	434	405	370	340	2,070
CP,[2] 10^6 st	2,004	1,928	2,059	2,155	2,218	10,363
Frr[3]	0.066	0.047	0.051	0.028	0.032	[3]0.944
Irr[3]	0.023	0.013	0.019	0.01	0.011	[3]0.016

[1]Derived from MSHA "Fire Accident Abstract" and "Fire Accident Report" publications.
[2]Derived from MSHA "Injury Experience in Coal Mining" publications.
[3]Calculated according to USBM and MSHA formulas reported in the "Methodologies" section.

Table 40.—Major findings for underground coal mine fires, 1978–1992

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 air course, track entry.	Track entry, working face, belt entry, longwall.	Shaft bottom, intake air course, belt entry, working face.
Successful extinguishing agent	Water, dry chemicals, rock dust.	Water, dry chemicals, rock dust.	Water, dry chemicals.

Source: Pomroy and Carigiet [1995].

The flame cutting/welding spark/slag/flame source caused fires usually involving welders' clothing or oxyfuel/grease (grease embedded in the equipment's mechanical components). However, in at least two instances sparks/hot slag/flames caused methane ignitions followed by large fires (which on one occasion required firefighting interventions and mine/section evacuation and sealing), in six cases undetected hot slag caused coal belt fires, in one instance undetected hot slag caused a storage facility fire, in another instance undetected hot slag caused a large fire that required firefighting intervention and mine evacuation and sealing followed by a methane explosion, and in another instance undetected hot slag caused a coal chute smoldering fire, which, upon water application, produced a flashback accompanied by a gas explosion (causing one fatality). The spontaneous combustion/hot coal fires, accompanied in two instances by methane explosions, usually were detected late (by gas sampling, smoke, or coal removal) due to lack of continuous and early combustion gas/smoke detection systems. This source caused fires involving goblines, sealed and abandoned areas, coal silos, coal chutes, dust collectors, and beltlines. Forty-eight of the mobile equipment hydraulic fluid/fuel fires and 12 equipment electrical fires (the latter occurred mostly in underground coal mines) became large fires, which required 24 firefighting interventions (5 interventions by mine rescue teams in underground coal mines and 19 interventions by fire brigades and fire departments at surface coal operations) because of continuous flow of fluid/fuel from the pumps due to engine shutoff failure, lack of an emergency line drainage system (the flow of pressurized fluids entrapped in the lines was not affected by the engine shutoff operation), difficulty in activating available emergency systems at ground level, or lack of effective and rapid local firefighting response capabilities. (Fire-resistant hydraulic fluid is not required for equipment use at surface coal operations.) During these fires,on at least seven occasions the cab was suddenly engulfed in flames, probably due to the ignition of flammable vapors and mists that penetrated the cab. Of note is that most of the hydraulic fluid/fuel fires were caused when hydraulic fluids sprayed onto equipment hot surfaces; subsequently, these fires involved the fuel lines. In all, 10 pieces of equipment involved in fires had machine fire suppression systems. Dual activation (six activations) of machine fire suppression and engine shutoff systems temporarily succeeded in abating the fires, which reignited due to the flow of fluids embedded in the lines.

The number of fires show decreases followed by increases during the five time periods. The number of fire injuries decreased during most of the periods (an increase is seen only during 1994–1995), accompanied by a decline in employees' working hours throughout the periods and an increase in coal production during most of the periods. The Irr and Frr values follow patterns similar to those shown by the injury and fire values (see table 39 and figure 13).

The major findings for each coal mining category are discussed below.

1. In underground coal mines, 87 fires occurred; 27 of the fires caused 34 injuries (Ewhr = $1,003 \times 10^6$ hr, Irr = 0.007, CP = $4,008 \times 10^6$ st, Frr = 0.022, LWD = 208). The leading ignition source (table 1) was electrical short/arcing (28 fires or 32% with 17 injuries) involving electrical power and cable systems, power circuits, breakers, belt transformers, grounded wires and cables, batteries, high-voltage boxes, generators, rectifiers, and mobile equipment electrical cable systems. This was followed by the flame cutting/welding spark/slag/flame source (18 fires or 21% with 10 injuries); conveyor belt friction involving pulleys, drives, rollers, idlers, and bearings (16 fires or 18% with 4 injuries); and spontaneous combustion (15 fires or 17%). The flame cutting/welding spark/slag/flame ignition source caused fires usually involving welders' clothing or oxyfuel/grease (grease embedded in the equipment's mechanical components). However, in one instance sparks/hot slag/flames caused a methane ignition followed by a large fire, which required firefighting intervention and mine/section evacuation and sealing. In another instance, undetected hot slag caused a large coal fire, which required firefighting intervention and mine evacuation and sealing followed by a methane explosion. The spontaneous combustion ignition source caused fires involving goblines and sealed and abandoned areas, which were accompanied in two instances by methane explosions. In all, five fires destroyed or heavily damaged equipment (including two pieces of mobile equipment) because of failure of other firefighting methods, late fire detection, undetected fires, or fire size. Thirty-six fires were detected late by smoke, and two fires were undetected.

Of note is that a large number of fires caused by electric short/arcing, belt friction, and spontaneous combustion sources were detected long after the fire had started due to lack of continuous and early combustion gas/smoke detection systems. By contrast, 12 of the mobile equipment electrical fires (which in at least one instance affected the hydraulic lines) and 1 hydraulic fluid fire became large fires shortly after they started. Five of these fires required mine rescue team interventions because of unavailability of effective machine fire suppression systems, lack of an emergency hydraulic line drainage system (the flow of pressurized fluids entrapped in the lines was not affected by the motor deenergization operation), or lack of effective and rapid local firefighting response capabilities. Three pieces of mobile equipment involved in fires had machine fire suppression systems. Dual activation (two activations) of machine fire suppression and motor deenergization systems succeeded in temporarily abating the fires. However the flames reignited, fueled by the fluids entrapped in the lines.

Upon mine/section evacuation (required 30 times), mine rescue teams (required 25 times), which were greatly hindered by intense smoke in reaching the fire location, fought the mobile equipment fires and other fires with dry chemical, rock dust, and water. In two instances, foam was also used. However, five fires destroyed or heavily damaged equipment. Thirteen times mine/section sealing/flooding/CO_2/N_2 gas injections were required.

The equipment most often involved in fire injuries included electrical cable systems, voltage boxes, mobile equipment, oxyfuel torches, beltlines, drives, and pulleys. The most common locations where fire injuries occurred were electrical power, pump, and charging stations, mobile equipment working areas, flame cutting/welding areas, trolley track and transportation areas, and belt entries.

A comparison of underground coal mine fire data for 1978–1992 [Pomroy and Carigiet 1995] and 1990–1999 shows that during the latter period fire fatalities declined dramatically from a yearly average of 2 to 0. However, 27 of the 1978–1992 fire fatalities occurred during a single fire caused by an overheated air compressor. There was also a decline in the number of fires (from a yearly average of 10.8 to 8.7) and a small increase in fire injuries (from a yearly average of 2.9 to 3.4), accompanied by a slight increase in coal production (from a yearly average of 356×10^6 to 401×10^6 st). Other comparisons show that during both periods similar methods of detection and suppression were used. Very few fires were detected by gas sampling, CO/smoke belt fire detection systems, or mine-wide monitoring systems.

Fires and fire injuries show decreases followed by increases during the five time periods. This was accompanied by a decline in employees' working hours throughout the periods and an increase in coal production during some of the periods. The Irr and Frr values follow patterns similar to those shown by the injury and fire values (see table 2 and figure 1).

2. At surface of underground coal mines, 65 fires occurred; 13 of the fires caused 12 injuries and 1 fatality (Ewhr = 97×10^6 hr, Irr = 0.025, LWD = 6,206). The leading ignition sources (table 1) were hydraulic fluid/fuel sprayed onto equipment hot surfaces (11 fires or 17%), flame cutting/welding spark/slag/flames (11 fires or 17% with 1 injury), spontaneous combustion/hot coal (11 fires or 17%), and electrical short/arcing (4 fires or 6%). Twenty ignition sources were unknown. In all, 20 fires destroyed or heavily damaged equipment (including two pieces of mobile equipment) because of failure of other firefighting methods, late fire detection, undetected fires, or fire size. Eighteen fires were detected late, and 20 were undetected. The flame cutting/welding spark/slag/flame source caused fires usually involving welders' clothing or oxyfuel/grease (grease embedded in the equipment's mechanical components). However, in one instance sparks/hot slag caused a methane ignition followed by a large fire, and in two other instances undetected hot slag caused coal belt fires. The spontaneous combustion/hot coal fires were usually detected long after the fire had started due to lack of continuous and early combustion gas/smoke detection systems. Three mobile equipment hydraulic fluid/fuel fires became large fires, which required fire department interventions because of the continuous flow of fluid/fuel from the pumps due to engine shutoff failure, lack of an emergency hydraulic line drainage system (the flow of pressurized fluids entrapped in the lines was not affected by the engine shutoff operation), difficulty in activating available emergency systems at ground level, or lack of effective and rapid local firefighting response capabilities. In at least two instances flames erupted in the cab, probably because of the ignition of flammable vapors and mists that penetrated the cab. Two pieces of mobile equipment involved in fires had machine fire suppression systems. Dual activation (one activation) of machine fire suppression and engine shutoff systems failed to temporarily abate the fires because of the flow of fluids entrapped in the lines. Fire departments (required in at least six instances) fought the mobile equipment fires and other large fires with foam, dry chemical powder, and water.

The equipment most often involved in fire injuries included oxyfuel torches, heaters, and mobile equipment. The most common locations where fire injuries occurred were flame cutting/welding, maintenance, and mobile equipment working areas and charging stations.

The number of fires and fire injuries show decreases followed by increases during the five time periods, accompanied by a decline in employees' working hours throughout the periods. The Irr values follow patterns similar to those shown by the injury values (see table 11 and figure 5).

3. At surface coal mines, 215 fires occurred; 94 of the fires caused 93 injuries and 1 fatality (Ewhr = 729×10^6 hr, Irr = 0.026, CP = $6{,}355 \times 10^6$ st, Frr = 0.034, LWD = 8,141). The leading ignition sources (table 2) were hydraulic fluid/fuel sprayed onto equipment hot surfaces (76 fires or 35% with 22 injuries), flame cutting/welding spark/slag/flames (59 fires or 27% with 44 injuries), spontaneous combustion/hot coal (21 fires or 10%), and flammable liquid/refueling fuel on hot surfaces (18 fires or 8% with 7 injuries). Three ignition sources were unknown. In all, 13 fires destroyed or heavily damaged equipment (including six pieces of mobile equipment) because of failure of other firefighting methods, late fire detection, undetected fires, or fire size. Twenty-eight fires were detected late, and 13 were undetected. The flame cutting/welding spark/slag/flame source caused fires usually involving welders' clothing or oxyfuel/grease (grease embedded in the equipment's mechanical components). However, on four occasions undetected hot slag caused a coal belt ignition, and in one instance undetected hot slag caused a coal chute smoldering fire, which, upon application of water, produced a flashback accompanied by a gas explosion (causing one fatality). The spontaneous combustion/hot coal fires were usually detected long after the fires had started (by smoke or coal removal) due to lack of continuous and early combustion gas/smoke detection systems. Forty-two of the mobile equipment hydraulic fluid/fuel fires became large fires, which required at least 15 fire brigade and fire department interventions because of the continuous flow of fluid/fuel from the pumps due to engine shutoff failure, lack of an emergency hydraulic line drainage system (the flow of pressurized fluids entrapped in the lines was not affected by the engine shutoff operation), difficulty in activating available emergency systems at ground level, or lack of effective and rapid local firefighting response capabilities. On at least five occasions the cab was suddenly engulfed in flames, forcing the operators to exit under hazardous conditions, probably due to the ignition of flammable vapors and mists that penetrated the cab. Five pieces of equipment involved in fires had machine fire suppression systems. Dual activation (three activations) of machine fire suppression and engine shutoff systems succeeded in temporarily abating the fires; however, the flames reignited, fueled by the flow of fluids entrapped in the lines. Fire brigades and fire departments, which were required in at least

26 instances, fought the 15 equipment fires and other large fires with foam, dry chemical powder, and water.

The ignition sources causing most of the fire injuries were flame cutting/welding spark/slag/flames (44 injuries), hydraulic fluid/fuel sprayed onto equipment hot surfaces (22 injuries), flammable liquids on hot surfaces (7 injuries), and heat sources (7 injuries). The equipment most often involved included oxyfuel torches, mobile equipment, and heaters. The most common locations where fire injuries occurred were flame cutting/welding areas, mobile equipment working areas, and maintenance areas.

Fires and fire injuries decreased during most of the periods (an increase is seen during 1994–1995). This was accompanied by a decline in employees' working hours throughout the periods and an increase in coal production during most of the periods. The Irr and Frr values follow patterns similar to those shown by the injury and fire values (see table 20 and figure 8).

4. At coal preparation plants, 91 fires occurred; 23 of the fires caused 25 injuries (Ewhr = 241 × 10^6 hr, Irr = 0.021, LWD = 198). The leading ignition sources (table 2) were spontaneous combustion/hot coal (15 fires or 17%), flame cutting/welding spark/slag/flames (15 fires or 17% with 8 injuries), hydraulic fluid/fuel sprayed on equipment hot surfaces (10 fires or 11% with 6 injuries), and conveyor belt friction (9 fires or 11% with 1 injury). In all, 13 fires destroyed or heavily damaged equipment (including four pieces of mobile equipment) because of failure of other firefighting methods, late fire detection, or undetected fires. Thirty-two fires were detected late by smoke, and seven fires were undetected. The flame cutting/welding spark/slag/flame source caused fires usually involving welders' clothing or oxyfuel/grease (grease embedded in the equipment's mechanical components). However, in one instance undetected hot slag caused a storage facility fire. The spontaneous combustion/hot coal fires were detected long after they had started (usually by coal removal, gas sampling, or smoke) due to lack of continuous and early combustion gas/smoke detection systems. Two of the hydraulic fluid/fuel fires became large fires because of the continuous flow of fluid/fuel from the pumps due to engine shutoff failure, lack of an emergency hydraulic line drainage system (the flow of pressurized fluids entrapped in the lines was not affected by the engine shutoff operation), difficulty in activating available emergency systems at ground level, or lack of effective and rapid local fire response capabilities (none of the equipment involved in fires had a machine fire suppression system). In at least two instances, the cab was suddenly engulfed in flames, forcing the operators to exit under hazardous conditions, probably due to the ignition of flammable vapors and mists that penetrated the cab. Fire brigades and fire departments (required in at least nine instances) fought the equipment fires and other large fires with foam, dry chemical powder, and water.

The equipment most often involved in fire injuries included oxyfuel torches, mobile equipment, heaters and maintenance equipment, and dust collectors and samplers. The most common locations where fire injuries occurred were flame cutting/welding areas, mobile equipment working areas, maintenance areas, and dust collector areas.

Fires decreased during most of the periods (an increase is seen during 1998–1999). The data on fire injuries show decreases followed by increases during the periods, accompanied by a decline in employees' working hours throughout the periods. The Irr values follow patterns similar to those shown by the injury values (see table 24 and figure 11).

CONCLUSIONS

During 1990–1999, a total of 458 fires occurred in all coal mining categories; 157 of those fires caused 164 injuries and 2 fatalities. The greatest number of fires and fire injuries occurred at surface mines, which also had the highest risk rate values. A total of 66 firefighting interventions were required. Of these, there were 25 mine rescue team interventions in underground mines, including 5 mobile equipment firefighting interventions, and 41 fire brigade and fire department interventions at all surface operations, including 19 mobile equipment interventions. In all, 50 fires destroyed or heavily damaged equipment (including 16 pieces of mobile equipment) because of failure of other firefighting methods, late fire detection, undetected fires, or fire size. A total of 114 fires were detected late by smoke, and 42 fires were not detected.

In the future, coal mine fires might be prevented or detected and extinguished at their earliest stage by adopting existing/improved technologies and/or by developing new technologies. Several strategies for reducing the number of fires and fire injuries follow.

1. *Adopt existing/improved safety procedures and develop new technologies for flame cutting/welding operations. Require safety training for welders (including contractors) working in gaseous environments.*

At all coal operations during 1990–1999, flame cutting/welding operations caused 102 fires (22% of total fires with 69 injuries). These fires usually involved welders' clothing or oxyfuel/grease (grease embedded in the equipment's mechanical components). However, in two instances sparks/hot slag/flames caused methane ignitions followed by large fires (one of these fires required firefighting interventions and mine/section/facility evacuation and sealing), in six cases undetected hot slag caused coal belt fires, in one instance undetected hot slag caused a storage facility fire, in another instance undetected hot slag caused a large coal fire that required firefighting intervention and mine evacuation and sealing followed by a methane explosion, and in another instance undetected hot slag caused a coal chute smoldering fire, which, upon water application, produced a flashback accompanied by a gas explosion (causing one fatality), which required firefighting interventions and mine/section evacuations. By adopting existing/improved safety procedures, the flame cutting/welding fires due to the ignition of oxyfuel/grease might be prevented. By developing new technologies to contain sparks/slag, the flame cutting/welding fires due to sparks and hot slag might also be prevented.

2. *Adopt existing/improved inspection programs for mobile equipment hydraulic, electrical, and fuel systems. Adopt an optimal ground level location for the activation of emergency systems. Develop new emergency technologies for engine/pump shutoff, hydraulic line drainage, line safeguards, and fire barriers. Develop rapid equipment/cab fire detection and effective fire prevention/suppression systems. Develop effective and rapid local firefighting capabilities. Schedule more frequent fire emergency preparedness training for equipment operators.*

At all coal operations during 1990–1999, there were 98 (21% of total fires with 29 injuries) mobile equipment hydraulic fluid/fuel fires (mostly at surface operations) and 12 equipment electrical fires in underground mines, which in at least one instance affected the hydraulic lines. Most of the hydraulic fluid/fuel fires became large fires because of the continuous flow of fluid/fuel from the pumps due to engine shutoff failure, flow of pressurized fluids entrapped in the hydraulic lines (not affected by the engine shutoff operation), difficulty in activating emergency systems at ground level, or lack of effective and rapid local firefighting capabilities. Of note is that most of the hydraulic fluid/fuel fires were caused when hydraulic fluids sprayed onto equipment hot surfaces; subsequently, these fires involved the fuel lines. In at least seven instances the cab was suddenly engulfed in flames, probably due to the ignition of flammable vapors and mists that penetrate the cab during the spraying of pressurized hydraulic fluid onto equipment hot surfaces. Also, most of the mobile equipment electrical fires became large fires because of unavailability of effective machine fire suppression systems, lack of an emergency hydraulic line drainage system, or lack of effective and rapid local firefighting capabilities. In all, 10 pieces of mobile equipment involved in fires had machine fire suppression systems. Dual activation (six activations) of machine fire suppression and engine shutoff systems succeeded in abating the fires, but the flames reignited, fueled by the flow of fluids entrapped in the lines (not affected by the engine, or motor, shutoff operation).

By adopting existing/improved mobile equipment inspection programs, hydraulic line and electrical cable wear and tear might be detected early, thereby preventing hydraulic fluid/fuel and electrical cable fires. By adopting an optimal location for ground level activation of machine fire suppression and engine shutoff systems, these emergency operations might be performed safely and in a timely manner, thus stopping the continuous flow of fluid/fuel from the pumps. By developing new technologies for the emergency draining of pressurized fluids entrapped in lines, the hydraulic fluid fires might not reignite, thus allowing the operators to exit the cab safely. By developing/adopting cab fire detection and cab fire inerting/suppression systems, the cab fires might not occur. By preparing local miners to fight mobile equipment fires, when detected, with large, contained quantities of suppressant agents on vehicles for ease of deployment to the fire site, these fires might be extinguished in their early stage.

3. *Adopt existing/improved continuous and early combustion gas/smoke detection systems.*

At all coal operations during 1990–1999, there were 71 (16% of total fires) spontaneous combustion/hot coal fires involving goblines, sealed and abandoned areas, coal silos, coal chutes, dust collectors, and beltlines. The spontaneous combustion/hot coal fires were usually detected late due to lack of continuous and early combustion gas/smoke detection systems; however, twice they were accompanied by methane explosions. By adopting existing continuous and early combustion gas/smoke detection systems, the spontaneous combustion/hot coal fires might be detected and suppressed at their earliest stage.

4. *Adopt existing/improved technologies to monitor equipment operations.*

At all coal mining operations during 1990–1999, there were 30 fires (7% of total fires with 6 injuries) caused by the operational failure of beltlines, drives, and pulleys. By adopting existing/improved technologies to monitor equipment operations, failures might be detected early, thereby preventing these types of equipment fires.

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