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: No. fire fatalities: Ewhr, 10^6 hr: Irr: LWD:	164 2 2,070 0.016 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.

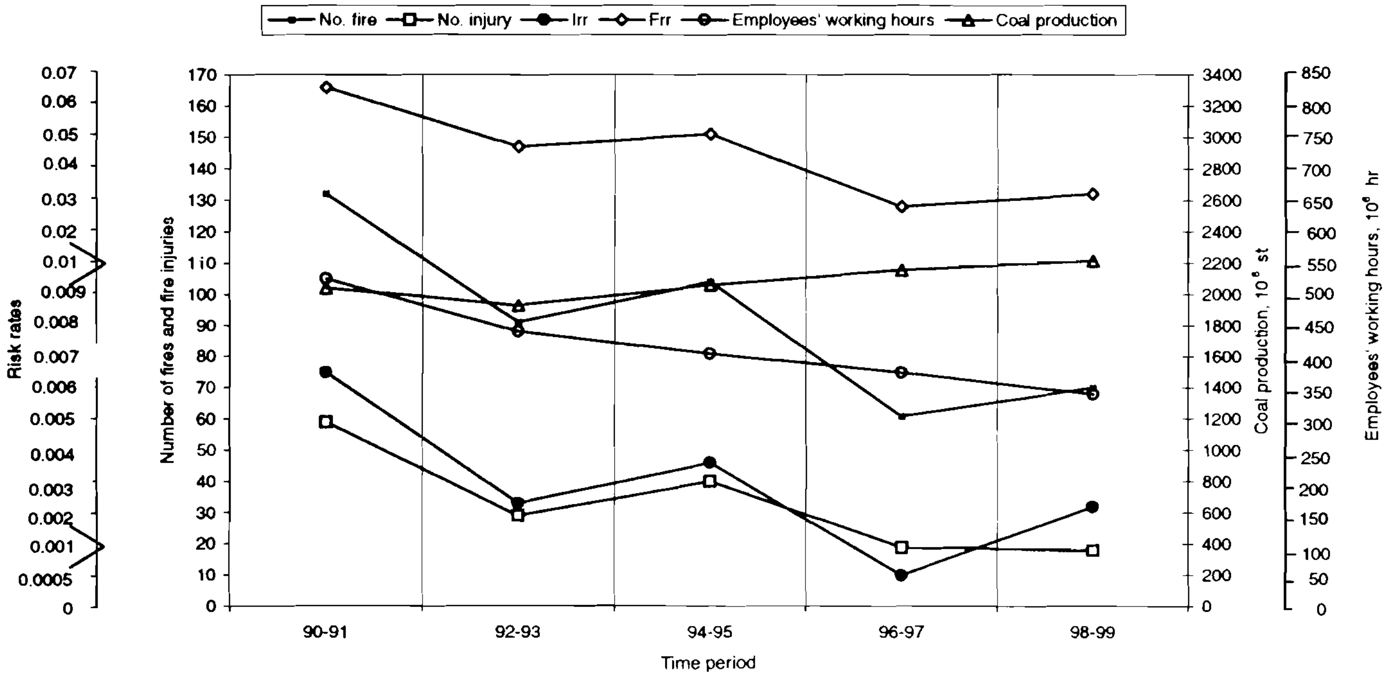

Figure 13.—Number of fires, fire injuries, risk rates, and coal production (underground and surface coal mines only) for all coal mining categories by time period and employees' working hours, 1990–1999.

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 × 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,