Electrical Accidents in the Mining Industry, 1990–1999

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Abstract—**This National Institute for Occupational Safety and Health study was conducted to focus future research on the most significant electrical problems in the mining industry. Data from 1926 mine electrical accidents (including 75 fatalities) that occurred between 1990 and 1999 were studied. Coal and metal–nonmetal operator- and contractor-reported data are presented. All data used in this analysis were Mine Safety and Health Administration closeout data, except 1999, which were preliminary data.**

Electricity was the fourth leading cause of death reported in mining despite being the 14th leading cause of injuries. During the 1990s, one of every 26 mine electrical accidents was fatal. Burns were the leading Nature of Injury in electrical accidents, but were rarely fatal. Electrical shock caused 70 of the 75 electrical fatalities reported. About one-half of mine electrical accidents and fatalities were sustained during electrical maintenance. The injury severity for victims of nonfatal mine electrical injuries does not increase with age in victims 50 years and older, unlike many other types of occupational accidents. High-reaching mobile equipment is involved in about 20% of mine electrical fatalities, indicating that overhead power line hazards need to be addressed. Electrical accident narratives containing the six most frequently mentioned keywords were isolated for further analysis. Technical suggestions for mitigating electrical hazards are proposed.

Index Terms—**Electric shock, electrical safety, electrocution, maintenance, mining, traumatic injury.**

I. Introduction

THIS STUDY was conducted to focus future research on the most significant electrical problems in the mining industry. In addition, it formed the first phase of a larger effort to identify electrical hazards common to both mining and other industries.

The Mine Safety and Health Administration (MSHA) is empowered by statute to collect detailed information on accidents, injuries and illnesses that occur in the mining industry. MSHA also collects information about mines, employment and production. The accident data are compiled from information on the MSHA Form 7000–1, *Mine Accident, Injury, and Illness Report*. Data on mines (active, inactive and abandoned), employment and production (for coal mines) are reported on the MSHA Form 7000–2, *Quarterly Mine Employment and Coal Production Report*. Mine operators are required to report accidents, injuries, illnesses and certain other "reportable accidents" [1] that occur to both employees and nonemployees on mine property. This statutory reporting requirement has allowed MSHA to amass one of the best publicly accessible occupational injury databases available in the U.S. The Mine Accident and Injury (AI) and Mine Address and Employment (AE) databases consolidate several MSHA raw databases to provide, for example, ready association of accident narratives with other accident information. Information for this paper was compiled from the AI and AE databases covering the period from 1990 to 1999. All data used in this report were MSHA closeout data except 1999, which used preliminary data available through the fourth quarter of 1999.

II. Background

Between 1990 and 1999, mining operators and contractors reported 260 510 accidents, injuries and illnesses from all causes, including 959 fatalities. Mines reported 1,926 electrical accidents, including 75 fatalities. Electricity was the fourth leading cause of death in mining despite ranking 14th overall as an accident cause. Nonfatal mining electrical accidents were responsible for 31 370 lost work days (LWDs).

The coal industry is made up of two Standard Industrial Classifications (SICs), anthracite coal and bituminous coal. Anthracite (hard coal) is a small segment of the coal industry in terms of both production and total accidents. During the study period, coal operators reported 129 553 accidents, injuries and illnesses from all causes, including 379 fatalities. The number of active coal mines (those characterized by reporting one or more hours of work in a given year) fell each year from 4320 in 1990 to 2301 in 1999 and coal operator employment decreased 43%, from 145 887 to 82 907. Coal contractor employment, however, increased by 40%, from 21 938 in 1990, to 30 812 in 1999, peaking at 32 201 in 1997. LWD accidents from all causes reported by coal operators showed a decline of 73%, from 11 381 cases in 1990 to 3055 in 1999.

The metal–nonmetal (MNM) sector is made up of 86 different SICs representing a wide range of commodities, mining methods and machines. From 1990 to 1999, MNM operators reported 115 350 accidents, injuries and illnesses from all causes, including 373 fatalities. The number of active MNM mines fell from 11 838 in 1990 to a low of 10 843 in 1996. It then increased each year to 11 821 in 1999. MNM operator employment declined by only 7%, from 207 515 in 1990, to 192 907 in 1999. MNM contractor employment, however, increased by 69%, from 26 460 in 1990 to 44 793 in 1999. LWD accidents

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[1]For a more precise definition of "reportable accidents" see [1].

TABLE I
PERCENT OF MINING ACCIDENTS THAT RESULTED IN A FATALITY, 1990–1999

Category	Percent Fatal
Falling/rolling/sliding rock or material of any kind	10.69%
Explosives and breaking agents	7.92%
Electrical	3.89%
Fall of face/rib/side/highwall	2.39%
Exploding vessels under pressure	2.03%
Ignition/explosion of gas or dust	1.85%
Haulage (powered)	1.42%
Fall of roof or back	0.54%
Fire (not electrical or explosion)	0.53%
Machinery	0.44%
Not Elsewhere Classified and not an occ. illness	0.44%
Inundation	0.37%
Slip or fall of person	0.15%
Hoisting	0.13%
Hand tools	0.05%
Handling material	0.01%
Average percent fatal from all causes	**0.37%**

Notes: 1. Aggregated data for all mining SICs.
2. Categories shown produced 1or more fatalities per 10,000 accidents.

TABLE II
RATIO OF MINING ACCIDENTS TO FATALITIES FROM ALL CAUSES AND FROM ELECTRICAL CAUSES, 1990–1999

	Ratio of All Accidents to All Fatalities	Ratio of Electrical Accidents to Electrical Fatalities
All Mining	272:1	26:1
Coal Operators	342:1	34:1
Coal Contractors	131:1	7:1
MNM Operators	309:1	28:1
MNM Contractors	93:1	10:1

from all causes reported by MNM operators declined by 64%, from 7129 cases in 1990 to 2544 in 1999.

Certain types of mining accidents occur infrequently but cause a high number of fatalities per accident. Table I shows types of accidents ranked by the percent that resulted in a fatality. Mine electrical accidents are fatal in disproportion to their frequency. They rank third in the overall ratio of total accidents to total fatalities. Many high-frequency accident types (i.e., handling materials, slips and falls, etc.) have a low likelihood of resulting in a fatality.

Table II shows the accident-to-fatality ratio for each category of employer in the mining industry. Both coal and MNM contractors reported a higher ratio of electrical fatalities to electrical accidents than did their respective operators.

III. MINE ELECTRICAL INJURY DATA

Mining accident data can be sorted in many useful ways that allow some insight into accident causes and can indicate where specific types of solutions (engineering controls, work place reengineering, training, etc.) might mitigate the number and/or severity of accidents.

TABLE III
DEGREE OF INJURY FOR MINE ELECTRICAL ACCIDENTS, 1990–1999

Degree of Injury	Total Cases
Fatality	75
Permanent disability (partial or total)	9
Days away from work only	1,109
Days away and restricted activity	80
Days of restricted activity only	105
Injury without death, days away, or restricted activity	441
Occupational illness	0
Fatal/nonfatal injury due to natural causes	0
Fatal/nonfatal injury - nonemployee on mine property	5
NEC (first aid only, nonchargeable death/ disability	14
No injury	88
Total	**1,926**

TABLE IV
MINE ELECTRICAL ACCIDENTS BY SIC, 1990–1999

SIC	Sector Description	Injuries	Fatalities
12110	Coal, Bituminous	982	33
14220	Limestone (crushed and broken)	240	8
14410	Sand and gravel	202	7
10210	Copper ore	64	6
32410	Cement	54	1
10410	Gold (lode and placer)	50	3
14550	Clay (common)	43	2
14230	Granite (crushed and broken)	34	2
14750	Phosphate rock	28	2
14294	Traprock (crushed and broken)	22	2
14742	Potash	20	2
10310	Lead and/or zinc ore	17	1
14290	Stone (crushed and broken, NEC)	17	2
10110	Iron Ore	15	0
28191	Alumina (Mill)	13	0
14743	Trona	13	1
11110	Coal, Anthracite	12	3
	Total	**1,826**	**75**

Notes: 1. Injury totals include fatalities.
2. 100 additional injuries from SIC's that reported 10 or fewer electrical injuries are not shown.
3. All fatalities are shown.

A. *Degree of Injury for Mining Electrical Accidents*

Table III shows the Degree of Injury (injury outcome) that resulted from each of the 1926 reported electrical accidents. 75 (3.9%) were fatalities. 58% of electrical injuries resulted in LWDs only and 23% resulted in an injury without death, days away, or restricted activity. Only 4.6% resulted in no injury.

B. *Standard Industrial Classification*

Electrical injuries and fatalities can be categorized by SIC, which allows association of injuries and fatalities with specific commodities. Table IV shows each mining sector that reported more than ten electrical injuries between 1990–1999.

TABLE V
NATURE OF INJURY RESULTING FROM MINE ELECTRICAL ACCIDENTS, 1990–1999

Nature of Injury	Injuries	Fatalities
Radiation effects (burn from electrical arc - not contact)	770	3
Electric shock, electrocution	447	70
Burn (electrical)	164	0
Burn or scald (heat - not radiation)	128	2
Burn (chemical)	126	0
Multiple injuries	45	0
Sprains/strains/ruptured disc/whiplash/torn knee cartilage	32	0
Cut/laceration/puncture/infection	28	0
Asphyxia/strangulation/drowning/smoke inhalation/suffocation	17	0
Fracture, chip	16	0
Contusion, bruise	11	0
Scratches, abrasions (superficial wounds)	9	0
NEC	9	0
Amputation or enucleation	7	0
Poisoning, systemic	6	0
Dust or other particles in eyes	3	0
Concussion - brain, cerebral	2	0
Dislocation	2	0
Hearing loss or impairment (industrial)	1	0
Hernia, rupture	1	0
Radiation effects, not elsewhere classified	1	0
Radiation effects (sunburn)	1	0
Total	1,826	75

Notes 1. Injury totals include fatalities.

TABLE VI
NATURE OF INJURY RESULTING FROM MINE ELECTRICAL ACCIDENTS, 1990–1999

Nature of Injury	Average LWD per LWD Injury	No. of Cases	Total LWDs
Amputation or enucleation	179	7	1,250
Fracture, chip	86	13	1,122
Dislocation	44	2	87
Asphyxia/ strangulation/ drowning/ smoke inhalation/ suffocation	43	10	428
Sprains/strains/ruptured disc/whiplash/torn knee cartilage	35	23	814
Burn or scald (heat - not radiation)	34	87	2,984
Burn (electrical)	34	107	3,600
NEC	31	3	92
Electric shock, electrocution	31	263	8,054
Scratches, abrasions (superficial wounds)	25	6	152
Concussion - brain, cerebral	23	1	23
Multiple injuries	21	32	677
Radiation effects (burn from electrical arc - not contact)	21	512	10,740
Hernia, rupture	16	1	16
Contusion, bruise	11	8	87
Burn (chemical)	10	74	745
Cut/laceration/puncture/infection	8	7	57
Dust or other particles in eyes	5	1	5
Poisoning, systemic	4	5	20
Hearing loss or impairment (industrial)	3	1	3
Radiation effects (sunburn)	2	1	2
Radiation effects, not elsewhere classified	1	1	1
Average LWD per LWD Injury (All Causes)	26.6		

C. Effect of Mine Size On Electrical Injuries

Electrical injuries were examined to learn how mine size affected their frequency. Mines that reported 1 or more employees for a given year were separated into two categories—"small" (1 to < 50 employees) and "large" (50 or more employees) for this analysis. Approximately 75% of electrical accidents reported all of the required information. Small mines reported 311 (34% of) LWD electrical accidents; 25 were fatal. Large mines reported 611 (66% of) LWD electrical accidents; 35 were fatal. Small mines reporting electrical accidents accounted for only 8% of the total average annual employment during the study period while large mines employed 92%.

D. Nature of Injury

Nature of Injury data describes the specific medical injury resulting from an accident. Table V shows that burns of all types are the most common form of electrical injury. These burns, which account for 65% of nonfatal electrical injuries, are the cause of only 7% of electrical fatalities. Electrical shock causes 24% of electrical injuries but 93% of electrical fatalities.

Table VI shows nonfatal injury severity based on the Nature of Injury for LWD electrical accidents. Nonfatal Injury severity is measured as the average number of LWDs incurred per LWD injury. Electrical shock, the leading cause of electrical fatalities, ranks ninth in nonfatal injury severity. Radiation burns from electrical arcing, the leading cause of nonfatal electrical injury, ranks 13th.

E. Regular Job Titles of Electrical Accident Victims

Regular Job Titles reporting ten or more electrical injuries during the 1990s and their associated fatalities are shown in Table VII. Overall, 84% of electrical injuries and 89% of electrical fatalities reported by Regular Job Title are shown in the table.

F. Work Activities Resulting in Electrical Accidents

Table VIII shows the Work Activity that was being performed when an electrical accident occurred. Each Work Activity that recorded ten or more electrical injuries is shown in the table. The activities shown account for 89% of electrical injuries and 85% of electrical fatalities. *Maintenance/repair (electrical)* was the most hazardous electrical Work Activity, accounting for 50% of electrical accidents and 48% of electrical fatalities reported by Work Activity. *Maintenance/repair (machinery—not electrical)* was the second most hazardous electrical Work Activity accounting for 13% of electrical accidents and 7% of electrical fatalities.

TABLE VII
REGULAR JOB TITLE OF MINING ELECTRICAL ACCIDENT VICTIMS, 1990–1999

MSHA Code	Regular Job Title	Injuries	Fatalities
302	Electrician (surface)	287	14
304	Mechanic/repairman (surface)	193	4
102	Electrician (off section)	126	6
374	Cleaning plant/ media/ crusher/	118	4
104	Mechanic/repairman (off section)	95	1
316	Laborer/utility man/pumper (surface)	87	3
116	Laborer/muck machine operator/pipe	58	2
50	Shuttle car operator/ram car (on	53	2
449	Mine foreman/mine manager/owner	47	2
2	Electrician (on section/face)	46	2
494	Prep plant foreman/mill foreman	46	3
376	Truck driver (surface)	42	3
46	Roof bolter/rock bolter (on	40	0
149	Labor foreman/bullgang foreman (off	38	1
418	Maintenance foreman (supv/staff)	34	3
368	Bulldozer operator/ tractor/ heavy	33	1
382	Highlift/ front end loader operator	33	0
481	Superintendent (supv/staff)	33	2
489	Outside foreman (supv/staff)	33	3
319	Welder (surface)	25	2
4	Mechanic/repairman (on section/face)	24	3
269	Motorman/ swamper/ switchman (UG	21	0
36	Continuous miner operator/ mole (on	18	0
101	Belt/conveyor man (off section)	18	0
402	Master electrician (supv/staff)	18	3
456	Engineer - EE/ ventilation/ mining	15	1
318	Oiler/greaser (surface)	12	0
54	Scoop car/unitrac operator (on	11	1
301	Belt/conveyor man (surface)	11	0
372	Barge/boat/dredge attendant (surface)	11	1
	Total	1,626	67

Notes: 1. Regular Job Title shown for each RJT reporting 10 or more electrical accidents during the period.
2. 71 fatalities reported Regular Job Title.
3. 1,801 accidents reported Regular Job Title
4. Injury totals include fatalities

TABLE VIII
WORK ACTIVITY BEING PERFORMED WHEN AN ELECTRICAL ACCIDENT OCCURRED, 1990–1999

Work Activity	Injuries	Fatalities
Maintenance/repair (electrical)	907	35
Maintenance/repair (machinery - not electrical)	240	5
Handling supplies/material (not timber) - load/unload	133	4
Inspect equipment (not maintenance/repair)	104	3
Move power cable (includes reeling)	82	3
Hand tools (not powered)	30	2
Welding and cutting	28	0
Escaping a hazard	25	0
Rerail equipment (includes replace trolley pole)	20	1
Operate surface equipment nec	19	5
Observe operations	17	1
Walking/running	15	0
Move equipment (fans/pumps, not operating machinery)	14	1
Idle (lunch, coffee break, etc.)	13	0
Operate locomotive (air trammer)	13	0
Operate mill equipment	13	0
Hand tools (powered)	12	2
Get on/off equipment, machines, etc.	11	2
Operate continuous miner	10	0
Total	1,706	64

Notes: 1. Work Activities shown reported 10 or more injuries during the reporting period.
2. 73 fatalities reported Work Activity.
3. 1,831 accidents reported Work Activity
4. Injury totals include fatalities.

G. Machines Involved in Electrical Accidents

Table IX shows the Machine Types involved in mine electrical accidents and fatalities. Machine Type was reported for 846 electrical accidents (44% of all mine electrical accidents) and 39 electrical fatalities (52% of all mine electrical fatalities). 92% of electrical accidents and 95% of the electrical fatalities that reported Machine Type are shown in Table IX. Unfortunately, for analysis purposes, the leading Machine Type reported was the *Machine NEC* (Not Elsewhere Classified) category accounting for 12% of the electrical injuries and 10% of the fatalities reporting Machine Type. Second most reported was the *Continuous miner, tunnel borer, DOSCO* category with 6% of the electrical injuries and 8% of the fatalities.

Of the 39 fatalities reporting Machine Type, 13 involved the category *Crane, Derrick, Cherry picker, Boom hoist, etc.*, representing 33% of the total in this category and 17% of all mine electrical fatalities. However, this category reported only 5% of total mine electrical injuries reporting Machine Type.

Overhead power lines are a major causal factor in fatal mine electrical accidents involving cranes and other high-reaching, mobile mining equipment. Mine electrical accidents involving overhead power lines are a disproportionately fatal accident category within the overall electrical accident category which, in itself, is disproportionately fatal.

Electrical accidents reporting *Pumps* as the Machine Type also showed a disproportionate number of fatalities when compared with the number of injuries. Pumps are involved in 8% of electrical fatalities but only 2% of electrical injuries that reported a Machine Type.

H. Accident Severity Versus Age of the Victim

A Bureau of Labor Statistics (BLS) study of nonfatal industrial injury severity showed that increasing age is highly correlated to increasing injury severity (average LWDs per LWD accident). [2] Fotta analyzed this trend for the mining industry and found similar results. [3] While true for accidents in general, not all accident categories follow this trend. Average nonfatal injury severity for mine electrical injuries peaks at 21 LWDs per LWD injury for the 40–49 age group and *decreases* to 20 and 13 LWDs per LWD injury for the 50–59 age group and 60+ age groups, respectively. Workers less than 20 years old average about 19 LWDs per LWD injury.

Nonfatal injury categories that dominate the LWD mining injury total include slips and falls, handling materials, etc. These accidents produce injury types (back injuries, strains,

TABLE IX
MACHINE TYPES INVOLVED IN MINE ELECTRICAL ACCIDENTS, 1990–1999

Machine	Injuries	Fatalities
Machine, NEC (Not Elsewhere Classified)	99	4
Continuous miner, tunnel borer, DOSCO	53	3
Mancar, mantrip, personnel carrier, portabus, jeep, jitney	49	1
Front-end loader, payloader, highlift, etc.	47	0
Hand tools (not powered) - wrench, jacks, etc.	46	1
Welding machine, bonder, torch	45	1
Shuttle car - buggy, torkar, ram car	43	2
Crane, derrick, cherry picker, boom hoist, etc.	42	13
Ore haulage trucks - off highway and underground	38	2
Conveyor, belt feeder, mobile bridge carrier, ROSCO	34	2
Locomotive, rail-mounted, lorry car	34	0
Rock or roof bolting machine	34	0
Crusher, breaker, mills (ball and rod)	31	0
Shovel or dragline (mining and stripping)	29	2
Load-haul-dump/ scoop tram/ CAVO/ transloader/ ram car	28	0
Bulldozer, dozer, crawler tractor, etc.	19	0
Trucks - pickup/dump/water/service (not ore haulage)	19	0
Drills (electric/hydraulic/coal - not impact drills)	18	0
Fan	16	0
Pump	16	3
Milling machinery, nec	15	1
Hand tools (powered) - drill, impact wrench, etc.	14	2
Drill (carriage-mounted) on track/rail/rubber tired	10	0
Total	779	37

Notes:1. Machine Types shown reported 10 or more injuries during the reporting period.
2. 39 fatalities reported Machine Type.
3. 846 accidents reported Machine Type
4. Injury totals include fatalities.

sprains, contusions, etc.) that may take longer to heal with increasing age. Electrical injuries, however, produce burns, electrical shocks, nerve and muscular damage to body systems and multiple body parts, where recovery time may be less sensitive to the victim's age.

IV. ELECTRICAL ACCIDENT NARRATIVE ANALYSIS

A. General Observation Regarding Accident Narratives

MSHA requires a descriptive narrative to be filed for each mining accident, injury, or illness reported. These narratives vary widely in their information content, grammar and spelling. Some are so brief as to be unusable for analyzing an accident situation while others contain a significant amount of information. In addition, MSHA subject matter experts document each fatality with a more detailed fatality report. When completed, these fatality reports are publically available on the MSHA website (http://www.msha.gov).

Capelli-Schellpfeffer recommended integrating accident narratives with statistical information to increase the reliability of electrical accident causal analyses. [4] That approach was adopted for this analysis. Automated keyword searches of the MSHA database narrative information proved of significant value in the identification of causal factors in the narratives examined. Although some undercounting may occur, computerized text string searches can help investigators with subject matter familiarity rapidly key in on important problem areas. Care must be exercised to ensure that keywords are used only within their relevant contexts. Therefore, reading and manual classification of narratives selected by keywords is imperative. The narratives from 1,926 electrical accidents (including 75 fatal accidents) were examined and the frequency of in-context relevant word usage was determined.

B. Information From Selected Electrical Accident Narratives

Several factors rapidly emerged from the analysis of accident narratives. Circuit voltage was mentioned in only 279 of 1926 narratives. In addition, the keywords "breaker(s)" (313 of 1926 narratives), "cable(s)" (309 accidents), "batter(y)(ies)" (242 accidents), "energize(d)" (i.e., working live) (163 accidents), "grounds/grounding" (204 accidents), and electrical "meter(s)" (90 accidents) were involved in about two-thirds of mine electrical accidents. A total of 1321 narratives containing these six keywords were analyzed and their causal factors determined.

1) Circuit Voltage: The circuit voltage is specifically mentioned in only 279 (14%) of all mine electrical accident narratives, limiting its usefulness in determining possible accident mitigation strategies. 57% of the 243 alternating current accidents occurred at or below 600 Vac, 3% between 601–1000 Vac, and 40% at more than 1000 Vac. Accidents involving dc circuits mention specific voltages in only 36 cases, covering the range from common battery voltages to trolley circuit voltages (6–750 Vdc). The reliability of voltage data in accident narratives could be improved by always reporting the nominal circuit voltage of an electrical accident and by specifying whether the accident occurred via phase-to-phase or phase-to-ground contact.

2) Circuit Breakers: 313 circuit "breaker" accidents were grouped into eight causal categories:

- electrical maintenance or repair working live (either intentionally or unintentionally)—125 cases;
- operating/resetting a circuit breaker—108 cases;
- equipment failure—22 cases;
- shocked /burned while plugging/unplugging connectors—15 cases;
- working in proximity to a live circuit—15 cases;
- energized/de-energize the wrong circuit breaker—14 cases;
- unknown cause—8 cases;
- misclassified—6 cases.

3) Cables: 309 cable accidents were grouped into ten causal categories:

- handling or moving live cable, plugs, or running over live cable—86 cases;
- jumper cables and batteries—65 cases;
- electrical maintenance or repair working live (either intentionally or unintentionally) and plugging/unplugging live connectors—59 cases;
- shocked or burned unexpectedly—31cases;

- equipment failure (cause unknown)—27 cases;
- power-off electrical repair accident (energizing cable after repair, working in proximity to live circuits)—12 cases;
- touching bad splices—12 cases;
- contact with overhead power lines—11 cases;
- unclassifiable—4 cases;
- misclassified accidents—2 cases.

Only 12 accidents mentioned that a worker contacted a bad cable splice while 86 accidents involved workers handling cables containing *previously unknown* cuts and abrasions that apparently exposed live conductors.

4) Batteries: 242 battery accidents were grouped into eight causal categories:

- battery exploded during or immediately after maintenance or repair—110 cases;
- while using jumper cables, battery exploded—46 cases;
- battery exploded while charging battery or plugging or unplugging charger cable—28 cases;
- other cables arced or exploded during maintenance—15 cases;
- battery exploded spontaneously—15 cases;
- jumper cables arced or exploded during use—5 cases;
- other—21 cases;
- misclassified—2 cases.

5) Grounding: Of the 204 accidents containing the text string "ground," only 129 represented cases that were not either double-counted from another keyword category or truly represented a grounding problem. These 129 grounding accidents were grouped into nine causal categories:

- failure to de-energize equipment (intentionally or unintentionally) prior to grounding work—47 cases;
- grounding system, component, or insulation defects in stationary equipment—29 cases;
- using grounding test equipment, meters, leads—13 cases;
- grounding defects in mobile equipment—13 cases;
- ground conductor defects—12 cases;
- grounding defects in portable cords—3 cases;
- unknown causes—8 cases;
- welding—4 cases.

6) Working on Energized Circuits: 163 accidents occurred while working on energized electrical circuits. Injuries resulting from working on energized electrical circuits were grouped into nine causal categories:

- knowingly failed to de-energize the circuit before beginning work—78 cases;
- equipment failure (includes cut and abraded cables)—37 cases;
- de-energized the wrong circuit or did not de-energize adjacent circuits—16 cases;
- working under or near energized trolley line—9 cases;
- using improper tools/equipment/test leads or improper use of same—8 cases;
- circuit reenergized by another person during work—6 cases;
- working under or near energized power line—4 cases;
- improper cable repair (leads reversed)—1 case;
- unknown cause—4 cases.

7) Using Meters and Test Leads for Troubleshooting: 90 accident narratives mentioned that the victim was using a meter to troubleshoot an electrical circuit. Injuries resulting from using meters on energized electrical circuits were grouped into eight causal categories:

- meter exploded (cause unspecified)—30 cases;
- test leads/probes shorted, arced—21 cases;
- meter used on wrong function (e.g., measured volts on ohms scale)—13 cases;
- meter of wrong voltage used (e.g., used a 1000-V meter on a 4160-V circuit)—10 cases;
- dropped/misused meter—8 cases;
- victim wearing metal jewelry—1 case;
- unknown cause—4 cases;
- misclassified—3 cases.

V. Implications for Mine Electrical Research

Rossignol points out that while training solutions are often suggested for electrical hazards, intervention efforts must shift toward engineering control solutions "to reduce the hazard at its source" [5]. This is practical in many situations. Simple, cost effective engineering control solutions exist to reduce fatalities and mitigate severity of nonfatal electrical injuries. Manuele notes that 60% of identified barriers to safe work behaviors arise from shortcomings in facilities and equipment and 13% from management systems. [6] "That suggests," he contends, "that the greatest risk reduction will come from attention to those two subjects". While suitable kinds and levels of training cannot be overlooked, over dependence on training at the expense of engineering control interventions, where appropriate, is a serious error.

Safety strategies common to many electrical accident prevention programs include:

1) working live only as a last resort;
2) training in the use of proper lockout–tagout procedures;
3) training in the use of appropriate personal protective equipment (PPE), including:
   a) UV-limiting eye or full-face protection;
   b) lightweight, fire-retardant work clothes for electrical maintenance personnel and arc protection suits where needed;
   c) the use of dry electrical gloves, insulating blankets, and other situation-specific PPE as needed.

A. Mitigating the Frequency and Severity of Flash Burn Injuries

"Radiation effects (burn from electrical arc)" type injuries caused 40% of all mining electrical injuries and accounted for 34% of electrical LWDs. Such injuries are largely a consequence of working live and account for a high percentage of electrical eye and hand injuries. Only three fatalities were directly attributed to this Nature of Injury.

Possible mitigations for electrical arc burn injuries include limiting the available arc blast energy, therefore injury severity, by using current-limiting circuit protection, eliminating or reducing intentional time delays in protective devices, and using high-resistance grounding where practical.

B. Mitigating the Frequency and Severity of Electrical Shock Injuries

"Electrical shock, electrocution" injuries caused 23% of all mine electrical injuries and accounted for 26% of electrical LWDs. Such injuries are often the consequence of working live or in proximity to unguarded live conductors. They account for 63% of the LWDs attributed to "body systems" and "multiple body parts" from electrical injuries. In addition, 93% of mine electrical fatalities were attributed to "electrical shock, electrocution." Possible mitigations for electrical shock/electrocution injuries include the increased use of ground-fault circuit interrupters (GFCIs), maintaining the proper clearance when working near overhead electric power lines, the use of insulating load link devices, and the use of power line proximity and/or contact warning systems.

C. Mitigating the Frequency and Severity of Electrical Injuries in Maintenance Work Activities

The Work Activity "maintenance/repair—electrical" caused 50% of nonfatal mine electrical accidents and 48% of the fatalities reported by Work Activity. The Work Activity "maintenance/repair—machinery" caused 13% of nonfatal mine electrical accidents and 7% of fatalities. Collectively "maintenance/repair—..." represents 60% of *all electrical accidents* and 53% of *all electrical fatalities*. Obviously electrical maintenance is a hazardous Work Activity deserving special attention.

Possible mitigations for maintenance worker electrical injuries include the increased application of GFCIs and the use of "dead-front" type equipment to isolate maintenance personnel from electrical hazards during troubleshooting. Overall, the safety of electrical maintenance workers could be improved by requiring that each electrical enclosure have a single disconnect mechanism or interlock that de-energized *all* circuits within an enclosure. This could reduce accidents caused by unintentional contact with adjacent circuits thought to be de-energized or locked out.

Electrical maintenance/repair workers frequently use meters to troubleshoot live electrical circuits. Examination of accident narratives shows a need for an improved method of accurately verifying meter capabilities and functions in the field to avoid using meters of improper voltage rating or meters set to measure the wrong function.

Suggestions for improving the safe use of electrical meters during live troubleshooting procedures include:

1) color coding or clearly marking meters with their maximum safe voltage and/or current ratings; alternatively, using only single function meters that are color coded or clearly indicate their function (e.g., voltage, current, ohms, etc.). The use of multifunction meters makes it easier for workers to use the wrong meter function or scale;
2) using meters that autorange up to their maximum voltage and/or current to prevent range selection problems;
3) using test leads rated for the maximum voltage and/or current of the associated meter;
4) using safety test leads with minimal tip exposure to preclude accidental contact with adjacent circuits, not uninsulated or oversized alligator clips.

VI. Summary

Electrical accidents are the fourth leading cause of death in mining and are disproportionately fatal compared with most other types of mining accidents. It can be argued that every electrical accident is a potential fatality except for some serendipitous set of circumstances that combine to prevent the victim's death.

About one-half of all mine electrical injuries and fatalities occur during electrical maintenance work. Injury severity (average LWDs per LWD accident) increases with age for mining accidents from all causes, but decreases after age 40–49 for mine electrical accident victims. Burns are the leading cause of electrical injuries by a nearly 2-to-1 margin, but electrical shock caused 93% of all mine electrical fatalities. On average, nonfatal electrical shock injuries were more severe (31 LWDs/LWD injury) than nonfatal burn injuries (21 LWDs/LWD injury). Small mines may be more electrically hazardous workplaces than large mines based on total average employment.

Analyzing accident narratives using computerized keyword searches allows rapid identification of core problem areas. Core areas so identified involve "breaker(s)" (313 of 1926 accidents), "cable(s)" (309 accidents), "batter(y)(ies)" (242 accidents), "energize(d)" (i.e., working live) (163 accidents), "grounds/grounding" (204 accidents), and electrical "meter(s)" (90 accidents).

Improved system design, improved electrical maintenance procedures and schedules, use of power line avoidance devices, power line awareness training, training targeted at known problem areas and vigorous electrical enforcement can combine to improve electrical safety substantially.

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