TRANSACTIONS

OF

THE SOCIETY FOR MINING, METALLURGY AND EXPLORATION, INC.

Volume 334
2013

Editor

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PUBLISHED BY SME INC.

AT THE OFFICE OF THE EXECUTIVE DIRECTOR

12999 E Adam Aircraft Cir

Englewood, CO 80112

A Member of the American Institute of Mining, Metallurgical and Petroleum Engineers, Inc.

Printed in the United States of America

ISBN: 978-0-87335-271-0

FOREWORD

As the 2013 president of the Society for Mining, Metallurgy and Exploration, Inc., I am pleased to present the 2013 issue of the *Transactions of the Society for Mining, Metallurgy and Exploration*, Vol. 334. The timely publication of professional papers that promote the advancement of scientific and technical knowledge is critical for enabling technology transfer. SME plays a key role in this process through its publications. Communication within the mining community is the key to a successful profession and society. This technology exchange continues a tradition that dates back to the 1871 meeting of 22 mining engineers in Wilkes-Barre, PA, that resulted in the founding of AIME; those individuals envisioned that these transaction volumes "would form a most valuable and greatly needed addition to our professional literature." This volume fulfills that pledge.

The 2013 *Transactions* contains 73 papers covering most every aspect of the mining life cycle and encompassing the diverse sectors of our industry including coal, industrial minerals, metals, health and safety and computational methods. It includes all 18 papers published in 2013 in the Technical Papers Section of *Mining Engineering* magazine (Vol. 65) and all 33 papers published in 2013 in *Minerals & Metallurgical Processing* (Vol. 30). Additionally, this volume contains 22 papers that are being published for the first time in this issue. The papers presented in this volume were written by some of the most distinguished professionals in the industry worldwide.

Some of the many research highlights from 2013 include discussions of perennial issues, such as how to adequately prepare the next generation of mining engineering students for the workforce (Frimpong et al., pp. 44-52) and how to predict and prevent coal mine bursts and bumps (Pariseau, pp. 60-68), the highly anticipated February Rare Earths issue of *Minerals & Metallurgical Processing*, and papers analyzing electrical injuries in the U.S. Mining industry (Homce and Cawley, p. 367-375) the latest in assessing the safety and efficiency of operations.

All 73 technical papers were peer-reviewed. The process of review and publication requires much hard work by authors, reviewers and our publications staff. As the 2013 president of SME and on behalf of all our members, I would like to extend our gratitude to all whose volunteer efforts contributed to the publication of this volume.

Jessica E. Kogel
2013 SME President

Volume 334
Transactions of the Society for Mining, Metallurgy and Exploration, Inc.

Volume 334 contains three sections of technical papers:

- **Section 1:** Includes all papers published in the Technical Papers Section of *Mining Engineering* in 2013, Vol. 65, including the January through April, June, July and August, and October through December issues (no technical papers were published in the May or September issues). *Mining Engineering* papers are identified as "*Mining Engineering*, Vol. 65" in the index.

- **Section 2:** Includes all papers published in the February, May, August and November 2013 issues of *Minerals & Metallurgical Processing*, Vol. 30, Nos. 1, 2, 3 and 4. *Minerals & Metallurgical Processing* papers are identified as "*Minerals & Metallurgical Processing*, Vol. 30" in the index.

- **Section 3:** This section includes papers published only in this volume. *Transactions* papers are identified as "*Transactions*, Vol. 334" in the index.

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This section contains papers published only in this volume. All papers passed peer review and were accepted for publication between October 16, 2012 and October 15, 2013.

Section 1:

Mining Engineering

Volume 65

Technical Papers

Editor-in-chief Steve Kral

Technical editor Emily Wortman-Wunder

Mining engineering
OFFICIAL PUBLICATION OF SME

SME
Society for Mining, Metallurgy & Exploration®

Mining Engineering (ISSN 0026-5187) is published monthly by SME, Inc., 12999 E. Adam Aircraft Cir., Englewood, CO, 80112. Telephone: 1-800-763-3132 or 303-948-4200; Fax 303-973-3845; email: sme@smenet.org. Website:**http://me.smenet.org/**

2013 Mining Engineering/Transactions Editorial Board

Electrical injuries in the US mining industry, 2000-2009

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Abstract

The U.S. National Institute for Occupational Safety and Health (NIOSH) Office of Mine Safety and Health Research (OMSHR) conducted a study of mining industry electrical injuries reported to the U.S. Mine Safety and Health Administration (MSHA) for the years 2000 to 2009. The findings of that study are detailed in this paper, and serve to characterize the circumstances surrounding electrical injuries and identify causal factors. The study included three tasks: 1) a direct review of mining industry occupational injury data compiled by MSHA, 2) interpretation of the narrative descriptions available for the injuries (from MSHA data) and 3) a separate examination of fatal electrical injuries. Eight-hundred sixty-five electrical injuries were reported during the 10-year period studied, with 39 of those being fatalities. This makes electrical injuries disproportionately fatal with respect to most other types of injuries in mining. Electrical injury rates were higher in coal mining than noncoal mining and, within the coal sector, rates were higher in underground operations than in surface operations. Of the 865 total cases, electrical and machine maintenance or repair activities were involved in 580 (69%), and electricians and mechanics were injured in 362 cases (42%). Of the 39 fatal electrical injuries, 27 (69%) involved electrical maintenance or repair work, and in 21 of these 27 cases, the failure to de-energize, lock-out and tag the circuit was the cause or a contributing factor. Also, contractor employees had a much greater chance of an electrical injury being fatal than did mine operator employees. The top three root causes for fatal electrical injuries were 1) no or inadequate lock-out and tagging, 2) failure of power system components and 3) contact of overhead electrical power lines by mobile equipment.

Key words: Health and safety, Electrical injuries, MSHA

2013 *Transactions of the Society for Mining, Metallurgy and Exploration*, Vol. 334, pp. 367-375.

Introduction

Electrical accidents cause a large number of serious occupational injuries each year. The U.S. Bureau of Labor Statistics (BLS) data indicate that 1,573 workplace fatalities in the United States between 2003 and 2009 had an electrical cause, and an estimated 18,260 nonfatal electrical injuries, resulting in days away from work, occurred over the same period.[1] The electrical fatality rate for the composite of all U.S. industries averaged 0.16 deaths per 100,000 workers (annually) for 2003 to 2009.[2] Electrical fatality rates can be much higher for specific industries, however, with BLS data reporting an average rate of 1.06 for the construction industry, 1.33 for the utility sector and 1.15 for the mining industry for the same period (Cawley, 2011).

Accident data compiled by the U.S. Mine Safety and Health Administration (MSHA) corroborate BLS electrical fatality statistics, revealing electrical fatality rates for the mining industry averaging 1.36 deaths per 100,000 workers for 2003 through 2009. These statistics show mining to be among the most dangerous industries with respect to electrical hazards, and suggest a need to clearly characterize the circumstances surrounding electrical injuries and identify causal factors. With this purpose, the U.S. National Institute for Occupational Safety and Health (NIOSH) Office of Mine Safety and Health Research (OMSHR) conducted a study of mining industry electrical injuries reported to MSHA for the years 2000 to 2009. The findings of that study are detailed in this report. The most recent comprehensive NIOSH study of mining electrical accidents and injuries covered the years 1990 to 1999 (Cawley, 2003).

Presented first is a brief explanation of the data used, in-

[1] BLS occupational injury data is compiled differently than the accident and injury data collected and maintained by MSHA. For more information on BLS occupational injury data, see http://www.bls.gov/iif/.

[2] Analysis of injury frequencies, that is, the actual number of injuries over a period of time, is useful for characterizing the nature and impact of safety hazards, as when comparing injury causes or severity; however, frequencies are usually not appropriate for comparing injury records among different exposed populations or for identifying trends, because they do not account for differences in workforce size. Rates of injury normalize data and, therefore, afford a means to directly compare the safety experience of different size groups, or study changes over time for a specific group. Typically, rates are calculated as the number of injuries per some standard population size over a one-year period. This paper presents both injury frequencies and rates as appropriate.

Paper number TP-13-021. Original manuscript submitted April 2013. Revised manuscript accepted for publication September 2013. Discussion of this peer-reviewed and approved paper is invited and must be submitted to SME Publications Dept. prior to Sept. 30, 2014.

Table 1 - Injuries reported to MSHA for 2000-2009, listed by cause (*aii*).

Cause of injury (*aii*)	**Fatal and nonfatal injuries**
Handling material	42,426
Slip or fall of person (from an elevation or on the same level)	25,141
Machinery	16,556
Hand tools	15,880
Powered haulage	11,272
Fall of roof, back or brow (from in place)	3,991
Stepping or kneeling on object	1,952
Striking or bumping	1,243
Fall of face, rib, pillar, side or highwall (from in place)	1,147
Electrical	853
Exploding vessels under pressure	491
Falling, rolling or sliding rock or material of any kind	474
Nonpowered haulage	357
Fire	250
Ignition or explosion of gas or dust	185
Hoisting	135
Explosives and breaking agents	76
Inundation	7
Entrapment	5
Disorders associated with repeated trauma	2
Dust disease of the lungs	1
Other causes not listed as possible *aii* choices	3,150
Total	**125,594**

cluding their source, processing and limitations. Next are the results of the study, including 1) a detailed review of information available directly from MSHA data, 2) interpretation of the narrative descriptions supplied for each accident and 3) a separate examination of fatal electrical injuries. Finally, key points and conclusions from the study are summarized.

Data used for the study

Per provisions of the Federal Mine Safety and Health Act of 1977, MSHA collects and maintains information on accidents, injuries and illnesses occurring at mining operations, as well as information on mines, employment and production, for mine operators and mining contractors.[3] Most of the analyses described in this report used MSHA Accident, Injury and Illness (AI) data for the years 2000 through 2009.[4] Injury rate calculations also used mining industry employment numbers for 2000 to 2009 taken directly from MSHA mining industry data summary tables and annual reports.[5] In addition, most of the information used in the analysis of fatal electrical injuries came directly from MSHA fatal accident investigation reports.[6] All data include mine operator employees and contractor employees unless otherwise noted.

MSHA AI data include a variable designated as *Accident*, *Injury*, *Illness* (variable name *aii*), which is a descriptor that most closely identifies the overall cause of an accident. This study included all reported cases with injuries having the cause (*aii*) listed as *Electrical*. In a wider review of the AI data, 12 other injuries for which the actual cause appeared to be electrical were found classified under cause categories other than *Electrical*, and these were added to the cases to be studied. These 12 additional injuries were found by identifying cases for which the MSHA accident type (variable name *atype*) was listed as *Flash Burn*, and/or the MSHA nature of injury (variable name *natinj*) was listed as *Electrical burn*, *Noncontact electrical burn* or *Electrical shock/electrocution*, but the cause was not listed as *Electrical*. Except where noted, the more complete set including these 12 extra cases was used throughout this study.

MSHA AI raw data contain not only entries for accidents that resulted in an occupational injury, but also numerous accidents that did not result in an injury. This is due to the statutory requirement for mines to report certain potentially hazardous events to MSHA, irrespective of whether any injuries occurred, such as unplanned gas or dust explosions, unplanned liquid or gas inundations, unplanned underground fires not extinguished within 10 minutes of discovery and certain types of roof falls and coal or rock outbursts. Such cases (not resulting in an injury) listing the cause as *Electrical* were found to yield little insight into electrical shock or burn hazards and, thus, were not included in the analyses for this study.[7]

Study results

Overview of electrical injuries in mining. There were 125,594 mining injuries reported to MSHA for 2000 through 2009, and *Electrical* was the 10th most frequently listed cause, with 853 injuries. For comparison, the three most frequent causes of all mining injuries were *Handling material* at 42,426 cases, *Slip or fall of person* at 25,141, and *Machinery* at 16,556. Table 1 lists the number of injuries reported for all causes.

Of the 125,594 total mining injuries between 2000 and 2009, 620 were fatalities. Of the 853 mining electrical injuries for that period (those with the cause listed as *Electrical*), 39 were fatal, making electrical injuries the 6th most prevalent cause of death in mining. For comparison, the two leading causes of fatal injuries for the same period were *Powered haulage* with 186 cases, and *Machinery* with 123. Electrical fatalities were

[3] See http://www.msha.gov/30cfr/50.0.htm and http://www.msha.gov/30cfr/45.0.htm for more information.
[4] MSHA AI raw data files are available at http://www.msha.gov/STATS/PART50/p50y2k/p50y2k.HTM , and MSHA data files converted to SPSS and dBase IV formats by NIOSH are available at http://www.cdc.gov/niosh/mining/data/default.html.
[5] Historical mining industry employment data are available at http://www.msha.gov/ACCINJ/accinj.htm.
[6] MSHA mining fatal accident investigation reports are available at http://www.msha.gov/fatals/fab.htm.
[7] MSHA AI data include a variable called *degree of injury* (*deginj*) for each accident. The degree of injury categories that represent no injury or a noncountable injury, and so were excluded for this study, were: *no injury*, *occupational illness*, *employee natural cause fatal and nonfatal injury*, and *nonemployee fatal and nonfatal injury* (in the last category, nonemployee means a person other than 1) an employee of the mine operator or 2) a contractor employee working on mine property).

nearly as common as fatalities due to *Ignition or explosion of gas or dust* for the same period. Table 2 lists all mining fatalities by cause.

Although the total number of electrical injuries in mining was comparatively low for the period under study (10th highest among all injury causes, as shown in Table 1), electrical injuries were disproportionately fatal, with one death for every 21.9 injuries. Based on this parameter (the average number of injuries resulting in one fatality), *Electrical* was the fourth most deadly cause of injury in mining, 9.3 times higher than the composite average for all types of mining injuries for the period (one fatality for every 202.6 injuries). Table 3 lists the six most disproportionately fatal injury causes.

Electrical injury rates in the U.S mining industry for 2000 through 2009 exhibit some annual variation, but suggest an overall decline. For comparison, rates for all types of injuries in mining (not only electrical) were examined, and show that the drop in electrical injury rates was similar to a downward trend in rates for the composite of all injuries in mining over that period.[8] Figure 1 compares trends in electrical injury rates and all injury rates in mining for 2000 to 2009.

Table 2 — Mining fatal injuries reported to MSHA for 2000-2009, listed by cause (*aii*) .

Cause of injury (*aii*)	Fatalities
Powered haulage	186
Machinery	123
Slip or fall of person (from an elevation or on the same level)	62
Fall of roof, back or brow (from in place)	58
Ignition or explosion of gas or dust[a]	41
Electrical	39
Fall of face, rib, pillar, side or highwall (from in place)	31
Falling, rolling or sliding rock or material of any kind	29
Exploding vessels under pressure	8
Hoisting	7
Handling material	5
Hand tools	3
Fire	3
Explosives and breaking agents	2
Stepping or kneeling on object	1
Other causes (*aii*) not listed as possible choices	21
Total	**620**

[a] Note that the 41 fatalities from ignition or explosion of gas or dust include 30 deaths from three large accidents—13 at Jim Walters Resources #5 Mine on 9-23-01, 12 at the Sago Mine on 1-2-06, and 5 at Darby Mine #1 on 5-20-06.

Table 3 — Average number of injuries (fatal and nonfatal) resulting in one fatality, for the six most disproportionately fatal injury causes (*aii*), and for all mining electrical injuries combined, for 2000-2009 mining injuries reported to MSHA.

Cause of injury (*aii*)	Average number of injuries (fatal and nonfatal) resulting in one fatality
Ignition or explosion of gas or dust	1 death for every 4.5 injuries
Falling, rolling or sliding rock or material of any kind	1 death for every 16.3 injuries
Hoisting	1 death for every 19.3 injuries
Electrical	1 death for every 21.9 injuries
Fall of face, rib, pillar, side or highwall (from in place)	1 death for every 37.0 injuries
Explosives and breaking agents	1 death for every 38.0 injuries
Injuries of all types (all *aii* categories combined)	**1 death for every 202.6 injuries**

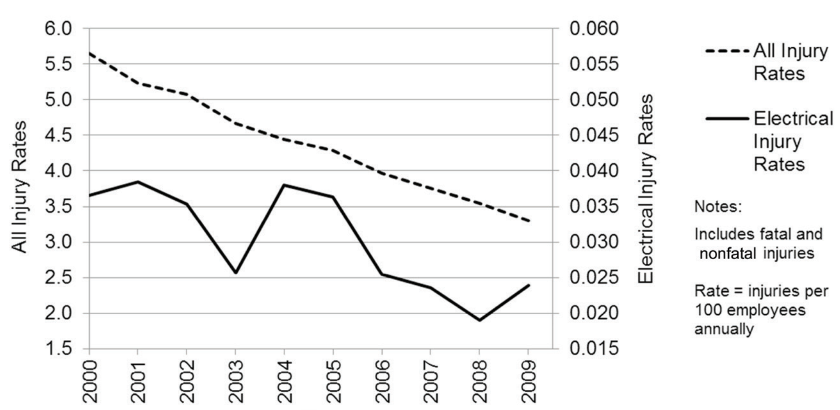

Figure 1 — Rates for all types of injuries in mining and for electrical injuries in mining, for 2000-2009.

Analysis of selected MSHA AI data variables for electrical injuries. MSHA data report 865 electrical injuries at U.S. mining operations for 2000 to 2009, including 853 with *aii* listed as *Electrical*, and 12 additional cases with apparent electrical causes for which *aii* was classified as something other than *Electrical*. The following is a summary of findings from analyses of selected MSHA AI data variables for these electrical injuries, including details on mining industry sector, general location at the mining operation, job title and activity of the injured worker, and the nature and degree of injury.

MSHA data identify a general commodity class (variable name *canvass*) for the facility associated with each incident. Table 4 shows the number of electrical injuries that occurred under each general

[8] Injury rates presented in this paper are for fatal and nonfatal injuries combined, per 100 full-time equivalent employees annually, calculated as: *Injury rate = [(number of injuries for target year) ÷ (total hours worked by exposed employees)] x [200,000]*. Electrical injury totals used to calculate electrical injury rates include only the injuries reported to MSHA for which the cause (*aii*) was listed as *Electrical*. All rates were calculated excluding office workers from the exposed populations, and assuming 2,000 hours worked annually per employee.

Table 4 — Mining electrical injuries reported to MSHA for 2000-2009, listed by general commodity class (*canvass*) (*N* = 865).

General commodity class (*canvass*)	Nonfatal electrical injuries	Fatal electrical injuries
Anthracite coal	0	0
Bituminous coal	385	21
Metal	60	5
Nonmetal	45	1
Sand and gravel	108	7
Stone	228	5

Table 5 — Mining electrical injuries reported to MSHA for 2000-2009, listed by general location (*subunit*) (*N* = 865).

General location (*subunit*)	Nonfatal electrical injuries	Fatal electrical injuries
Underground operations	292	13
Surface (strip or openpit mines)	262	9
Mill or preparation plant	213	7
Surface at underground	39	7
Dredge operations	13	3
Office	3	
Independent shops and yards	2	
Auger operations	1	
Other surface (for metal/nonmetal mines only)	1	

commodity class, with *Bituminous coal*, *Stone* and *Sand and gravel* having the most incidents. The latter two include aggregate material operations. Figure 2 shows that electrical injury rates for coal mining were higher than for noncoal from 2000 to 2009.[9]

MSHA data identify the general location at a mining operation at which each reported incident occurred (variable name *subunit*). Table 5 lists the number of electrical injuries that occurred at each of several different general locations. Focusing specifically on the coal mining sector, Fig. 3 shows that coal mine underground operations had significantly higher electrical injury rates than coal mine surface operations for 2000 to 2009.

Two other important aspects of electrical injuries are the regular job title of the worker involved (MSHA data variable *jobtitl2* was used for this study) and the worker's activity when injured (MSHA variable *mwactiv*). Not surprisingly, for electrical injuries, *Electrician/helper/wireman* and *Mechanic/repairmen/helper* were the two most common regular job title categories cited, and *Electrical maintenance/repair* and *Machine maintenance/repair* were the most common activities. Tables 6 and 7 provide more detail for regular job titles and worker activities associated with electrical injuries.

Although shock is the injury often associated with electrical accidents, for this study period burns were far more common nonfatal electrical injuries in mining, including tissue damage due to current flow through the body and burns from radiant energy. In comparison, electrical fatalities were nearly always due to shock. Table 8a lists the seven most common nature of injury categories (MSHA variable *natinj*) for coal mining injuries with the cause listed as *Electrical*, as well as the number of incidents and lost workday data for each. Table 8b provides the same information for noncoal operations. Table 9 further

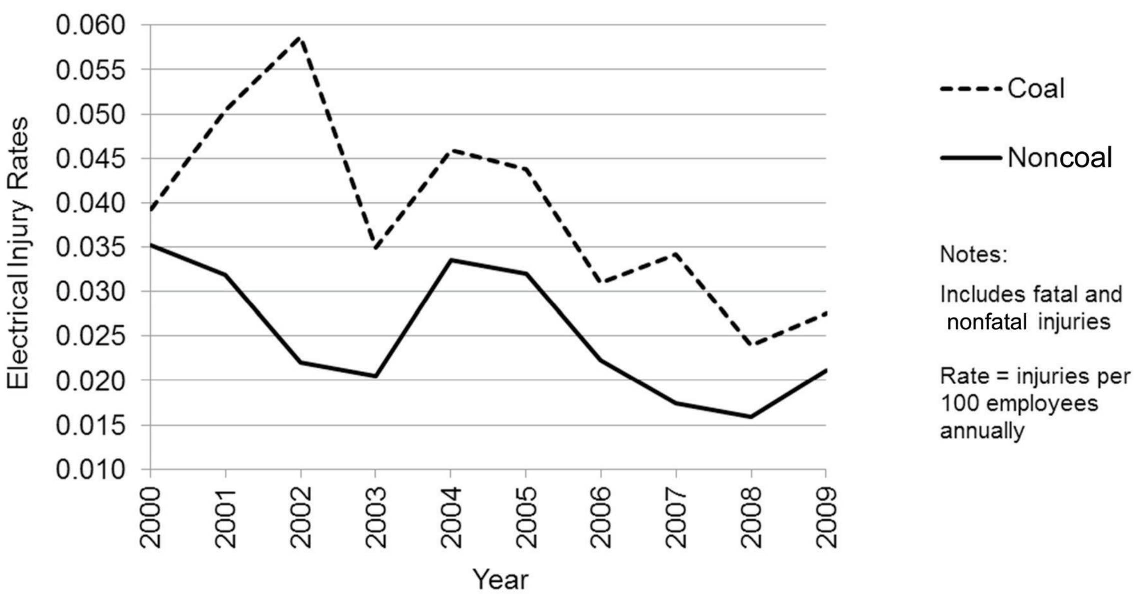

Figure 2 — Electrical injury rates for coal mining and noncoal mining, for 2000-2009.

[9] Rates cannot be calculated for general commodity classes (*canvass*) because contractor hours worked are reported to MSHA identified only as coal or noncoal locations.

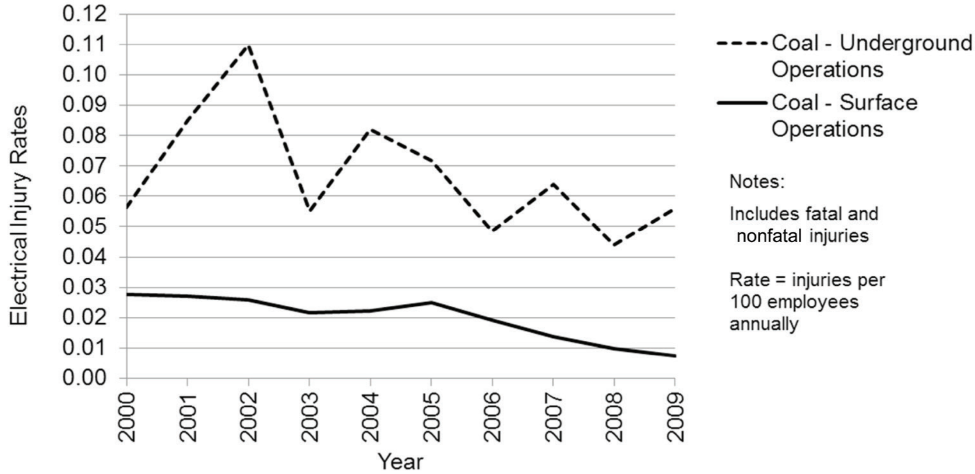

Figure 3 — Electrical injury rates for underground and surface operations of coal mines, for 2000-2009. Underground and surface locations are defined based on MSHA general location (subunit) categories. Surface operations include all general location categories except underground operations of underground mines.

Table 6 - The 20 most frequently listed regular job title categories (*jobtitl2*) for electrical injuries reported to MSHA for 2000-2009 (*N* = 865).

Job title category of injured worker (*jobtitl2*)	Nonfatal electrical injuries	Fatal electrical injuries
Electrician/helper/wireman	220	17
Mechanic/repairman/helper	123	2
Supervisory/management/foreman/boss	112	10
Laborer/utility man/bull gang	77	5
Sizing/washing/cleaning plant operator/worker	66	
Roof bolter (single head)	29	
Shuttle car/ram operator (standard side)	26	1
Bulldozer/tractor operator	20	1
Truck driver	20	1
Continuous miner operator	15	
Front-end loader/high lift operator	15	
Scoop car/tram/load haul dump operator	12	
Miner NEC/surface miner	8	1
Welder/blacksmith	8	1
Oiler/greaser	8	
Dragline/crane/backhoe operator	7	
Engineer (electrical/ventilation/mining)	7	
Trainee	6	
Inspector/fire boss/pre-shifter	5	
Unknown or not elsewhere classified	5	

characterizes mining electrical injuries by listing the number of incidents for various degrees of injury categories (MSHA variable *deginj*).

Mine operators are required to report to MSHA accidents occurring on their property and involving operator employees and contract employees. During the 2000 to 2009 period, 733 mining electrical injuries involved operator employees and 132 involved contractors. Based on the average number of electrical injuries resulting in one fatality, contractors tended to have a higher proportion of fatal electrical injuries than operator employees, as shown in Table 10.

Analysis of MSHA AI data narrative descriptions. MSHA AI database information includes a narrative description of each reported accident. Although the clarity and level of detail for these descriptions can vary widely, they are overall a valuable source of additional information about the circumstances surrounding electrical injuries, providing insight into how and why the associated accidents occurred. The narratives for the 865 mining electrical injuries occurring between 2000 and 2009 were reviewed and analyzed, with information extracted that was not available in the other MSHA data variables. The scope and content of this analysis was dictated primarily by the detail available in the narratives, rather than by any preset structure.

Based on this narrative review, Table 11 lists the frequency with which several selected causal factors were involved in electrical injuries. Note that for each causal factor listed in Table 11, not all 865 narrative descriptions provided enough

Table 7 — The 15 most frequently listed mine worker activities (*mwactiv*) for electrical injuries reported to MSHA for 2000-2009 ($N = 865$).

Mine worker activity (*mwactiv*)	Nonfatal electrical injuries	Fatal electrical injuries
Electrical maintenance/repair	489	27
Machine maintenance/repair	83	1
Move power cable	49	
Handling supplies or material, load and unload	42	2
Inspect equipment	29	3
Hand tools (not powered)	12	
Welding and cutting	12	2
Idle (eat lunch, coffee break, etc.)	8	
Observe operations	8	
Haulage truck	6	
Get on or off equip. machines, etc.	5	
Roof bolter, not elsewhere classified	5	
Surface equipment, not elsewhere classified	5	
Walking/running	5	
Conveyor belt (not riding)	4	

Table 8a — The seven most frequently cited nature of injury (*natinj*) categories, and lost workday data, for coal mining electrical injuries reported to MSHA for 2000-2009 ($N = 406$).

Nature of electrical injury (*natinj*)	Fatal	Nonfatal	Total lost workdays	Average lost workdays per nonfatal injury
Noncontact electric arc burn	1	158	3,301	21
Electric shock, electrocution	19	97	3,299	34
Electrical burn	1	52	1,595	31
Burn, chemical		33	314	10
Burn or scald (heat)		17	1,742	102
Multiple injuries		6	269	45
Fracture, chip		4	441	110

Table 8b — The seven most frequently cited nature of injury (*natinj*) categories, and lost workday data, for noncoal mining electrical injuries reported to MSHA for 2000-2009 ($N = 459$).

Nature of electrical injury (*natinj*)	Fatal	Nonfatal	Total lost workdays	Average lost workdays per nonfatal injury
Noncontact electric arc burn		205	4,317	21
Electric shock, electrocution	17	94	2,548	27
Electrical burn		58	961	17
Burn or scald (heat)		23	683	30
Burn, chemical		22	40	2
Cut, laceration, puncture		9	35	4
Asphyxia, strangulation, drowning, etc.	1	4	3	1

Table 9 — Mining electrical injuries reported to MSHA for 2000-2009, listed by degree of injury (*deginj*).

Degree of electrical injury (*deginj*)	Number of cases, coal	Number of cases, noncoal	Number of cases, total
Death, fatal	21	18	39
Permanent disability, partial or total	1	2	3
Days away AND restricted activity	16	44	60
Days away from work only	259	203	462
Days of restricted activity only	17	47	64
Injuries w/o death, days away or restricted activity	87	132	219
All other cases (including first aid)	5	13	18
Total	406	459	865

information to determine if the factor was or was not involved. Therefore, the actual number of cases on which each evaluation was based is noted. For the causal factor *Personal protective equipment (PPE) would have prevented the injury or reduced its severity*, such PPE would include not only electrically rated gloves and arc-rated clothing/equipment for electricians, but also nonelectrical-specific equipment such as leather work gloves to prevent burns while operating breakers or handling cables. Also, for each injury, a specific power system component or piece of equipment was identified as having played a primary role. The most commonly involved power system components/equipment are listed in Table 12.

Further analysis of the findings in Table 12 ultimately identified five general categories of components and equipment most often involved in mining electrical injuries, as listed below.

1. Electrical switchgear – 24.6% of 856 cases reviewed; combines the categories *Circuit breakers*, *Switches* and *Line starters*.
- 45% of injuries occurred at stone mines and 34% at coal mines.
- 59% of injuries occurred during maintenance and 36% during normal operation of devices.
- Approximately 68% of injuries were noncontact electrical burns due to arcing.

2. Trailing cables - 8.9% of 856 cases reviewed.
- 91% of injuries occurred at coal mines, primarily involving mobile underground equipment trailing cables.
- 71% of injuries occurred while personnel were handling cables (not during repair activities) and 16% occurred during cable repair.
- 54% of injuries were electrical shocks, 24% were noncontact electrical burns and 17% were electrical burns.

3. *Underground mine mobile-equipment batteries* - 7.5% of 856 cases reviewed; includes approximately one-third of the cases in the *Battery* category in Table 12, as well as selected relevant cases from the categories *Underground battery-powered equipment* (not shown in Table 12) and *Cable coupler or plug*.

Table 10 — Average number of electrical injuries (fatal and nonfatal) resulting in one fatality listed for coal and noncoal mining by employer type, and for all mining electrical injuries combined, for 2000-2009 mining electrical injuries reported to MSHA.

Industry segment and employer	Average number of electrical injuries (fatal and nonfatal) resulting in 1 fatality
Coal operators	1 death for every 23.4 injuries
Coal contractors	1 death for every 9.2 injuries
Noncoal operators	1 death for every 31.8 injuries
Noncoal contractors	1 death for every 12.8 injuries
All mining	1 death for every 21.9 injuries

Table 11— Selected causal factors for accidents resulting in mining electrical injuries, for 2000-2009.

Selected causal factors for accidents resulting in mining electrical injuries	Percent of cases (based on the number of cases out of 865 total injuries, for which enough narrative information is available to make a determination)
Improper work procedures caused or helped cause the accident	88% (based on 774 cases)
Personal protective equipment (PPE) would have prevented the injury or reduced its severity	69% (based on 777 cases)
The accident involved an arcing fault	59% (based on 775 cases)
An electrical system component failure caused the accident	49% (based on 655 cases)
Accident involved electrical troubleshooting	27% (based on 583 cases)
Accident involved use of a portable electrical meter	7% (based on 710 cases)

Table 12 — The 11 most common power system components or pieces of equipment identified as having played primary roles in mining electrical injuries for 2000-2009.

Power system components or equipment involved in mining electrical accidents resulting in injuries	Percent of cases (based on 856 of 865 total injuries)
Circuit breaker	14.5%
Battery	11.6%
Trailing cable	8.9%
Electrical components not elsewhere classified	8.1%
Switch	7.1%
Cable coupler or plug	6.9%
Cable not elsewhere classified	6.3%
Fuse or fused disconnect	5.0%
Electrical enclosure not elsewhere classified	4.1%
Overhead electrical power line	3.4%
Line starter	3.0%

The categories cited here were derived as needed for analysis of the accident narratives, and are not based on MSHA data variables.

Table 13 — Mining fatal electrical injuries for 2000-2009, listed by type of mining operation (commodity) (*N* = 39).

Type of mining operation (commodity produced) at which fatal electrical injury occurred	Number of fatal electrical injuries
Coal, bituminous (underground operations)	12
Coal, bituminous (surface mines and surface at underground mines)	9
Sand and gravel	7
Crushed limestone	5
Copper	2
Gold	1
Taconite	1
Potash	1
Tunneling operation	1

Table 14 — Mining fatal electrical injuries for 2000-2009, listed by circumstances of accident causing the electrical fatality (*N* = 39).

Circumstance of accident causing fatal electrical injury	Number of fatal electrical injuries
Electrical maintenance or repair work	27
Overhead electrical power line contact, not during electrical maintenance or repair work	6
Contact with equipment or structures that were energized due to power system damage or disrepair, during activities other than electrical maintenance or repair work	4
Welding (contact with welding leads)	2

- All injuries occurred at coal mines.
- Most injuries involved support equipment such as scoops, mantrips and locomotives.
- Injuries usually occurred during maintenance or battery changes.
- Injuries were often noncontact electrical burns due to arcing.

4. <u>*Cable couplers or plugs*</u> — 6.9% of 856 cases reviewed.

- 90% of injuries occurred in coal mines.
- 47% of injuries occurred during insertion or removal, 29% during repair of the coupler or plug and 24% while energizing the associated circuit.
- 59% of injuries involved ac circuits, primarily on power centers (balance of injuries involved dc circuits).
- 73% of injuries were noncontact electrical burns due to arcing.

5. <u>*Engine-starter batteries on surface equipment or vehicles*</u> - 6% of 856 cases reviewed; includes approximately one-half of the cases in the *Battery* category in Table 12.

- Injuries occurred at coal and noncoal operations, typically involving large off-road equipment.

Table 15 — Detail on fatal electrical accidents occurring during electrical maintenance or repair work, for mining fatal electrical injuries 2000-2009 (*N* = 27).

Specific electrical maintenance or repair work underway when fatal electrical injury occurred	Number of fatal electrical injuries
Repair work	11
Diagnostic work (troubleshooting)	8
Installing new equipment	4
Inspection of equipment	2
Operating a cable-fault-locating device	1
Unsafe temporary wiring in use	1

Table 16 — General categories of root causes for mining fatal electrical injuries for 2000-2009 (*N* = 39).

General category of root cause identified for mining fatal electrical injury	Number of fatal electrical injuries
No or inadequate lock-out and tagging procedure used during electrical maintenance or repair work	17
Faulty power system components such as damaged power cable or wiring insulation, electrical system components improperly installed or in disrepair, and switchgear not working properly	8
Overhead power line contacts by mobile equipment during activities other than overhead power line maintenance or repair	5
Unsafe diagnostic procedures (troubleshooting)	3
Mobile equipment frames energized after striking and damaging a trailing cable, during equipment operation	2
Contact with arc-welding leads	2
Inappropriate use of a 480 Vac circuit for explosives initiation	1
Improper use of a cable-fault-locating device	1

- Injuries occurred during battery maintenance or while using battery booster cables to start equipment.
- Injuries were primarily chemical burns due to battery ruptures or explosions, and noncontact electrical burns due to arcing.

Analysis of fatal electrical injuries. As noted previously, electrical injuries, although the 10th most common type of injury in mining (Table 1), rank fourth with respect to the average number of injuries resulting in one fatality (Table 3). Therefore, the 39 electrical fatalities occurring between 2000 and 2009 were examined more closely in this study, by reviewing the detailed fatal accident investigation reports produced by MSHA. These reports were analyzed, and information was compiled about how and why the deaths occurred. Table 13 lists the types of mining operations, by mined commodity, at which the fatal injuries occurred, and Table 14 categorizes the fatalities by the circumstances surrounding the associated accident. The most common circumstance was electrical maintenance and repair work, accounting for 27 deaths, and this category is detailed further in Table 15.

One frequent cause or contributing factor in electrical accidents is the failure to create an electrically safe work condition, or more specifically, failure to effectively de-energize, lock out and tag the circuit in question. In 21 of the 27 *Electrical maintenance or repair* fatal injuries detailed above, the circuits could have and should have been put in an electrically safe work condition. Although for most of the 21 cases in question, it is difficult to determine exactly why the circuit involved was not de-energized, a number of key factors seem to be common in the accidents, such as existence of an unrecognized problem or abnormal condition on the power system, unfamiliarity with the power system or a component, lack of adequate focus by the worker on the task involved, failure to use appropriate personal protective equipment (PPE) and unsafe work procedures. Interestingly, although diagnosing a power system problem is often cited as a circumstance where working on an energized circuit is necessary and allowable, six of the eight *Diagnostic work (troubleshooting)* fatalities cited above involved situations where the circuits involved could have been de-energized without hampering the work. Such cases included removing power fuses for testing, examining malfunctioning mechanical components in a high voltage switch cabinet, disconnecting a malfunctioning control circuit connection and using temporary power connections instead of appropriate instruments for motor and cable testing.

Another analysis approach used to study the MSHA electrical fatality investigation reports was an attempt to determine a *root cause* for each incident. A root cause can be defined as the basic lowest-level causal factor for an event, with the event in this case being a fatal electrical accident (Ericson, 2005). The factor can be any hazardous element, such as a component, a system condition or an activity and, in this analysis, the root cause would best be described as the element that played the most important role in the chain of events leading up to the incident. As such, the root causes identified are not necessarily the last or most obvious elements involved in each case, and certainly they are usually accompanied by several contributing factors. The root causes identified for the 39 mining electrical fatalities are summarized under several general categories in Table 16.

Summary

A study of electrical injuries occurring in the U.S mining industry between 2000 and 2009 was conducted by NIOSH to characterize the circumstances surrounding electrical injuries and identify causal factors. A total of 865 electrical injuries were reported to MSHA for this period, 39 of which were fatal. Of the total 865 electrical injuries, approximately 42% were noncontact electrical burns (due to arcing), 26% were electrical shocks and 13% were contact electrical burns (due to current flow through tissue). A summary of other important findings follows.

- Electrical accidents were the 10th most common cause of injuries in mining, the sixth most common cause of fatal injuries and ranked fourth with respect to lethality (measured as the average number of injuries (fatal and nonfatal) resulting in one fatality).
- Electrical injury rates for mining generally declined between 2000 and 2009, as did the composite rates for all types of injuries in mining over that period.
- The bituminous coal sector accounted for 47% of electrical injuries, and had a higher electrical injury rate than noncoal mining.
- In the bituminous coal sector, electrical injury rates for underground operations were notably higher than those for surface operations.
- Electricians and mechanics accounted for 42% of electrical injuries.
- Electrical and machine maintenance/repair activities were involved in 69% of electrical injuries.
- Contractor employees tended to have a higher proportion of fatal electrical injuries than did mine employees.
- Improper work procedures caused or helped cause 88% of electrical injuries.
- The use of PPE would have prevented the injury or lessened its severity in 69% of cases.
- The most common power system components or equipment involved in accidents resulting in electrical injuries were 1) electrical switchgear, 2) trailing cables, 3) batteries used in battery-powered underground mobile equipment, 4) power cable plugs and couplers and 5) surface equipment engine-starter batteries.
- Of 39 total fatal electrical injuries, 21 occurred in coal mining, with 12 in underground operations and nine at surface operations.
- Of 39 total fatal electrical injuries, 27 involved electrical maintenance or repair work, and in 21 of these 27, circuits should have been de-energized, locked out and tagged prior to work.
- The top three root causes for fatal electrical injuries were 1) no or inadequate lock out and tagging, 2) failure of power system components and 3) contact of overhead electrical power lines by mobile equipment.

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