Occupational electrical injuries in the United States, 1992–1998, and recommendations for safety research

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Abstract

Problem: CFOI and SOII data show that 2,287 U.S. workers died and 32,807 workers sustained days away from work due to electrical shock or electrical burn injuries between 1992 and 1998. *Method*: The narrative, work activity, job title, source of injury, location, and industry for each fatal electrical accident were examined. A primary causal factor was identified for each fatality. *Results*: Electrical fatalities were categorized into five major groups. Overall, 44% of electrical fatalities occurred in the construction industry. Contact with overhead power lines caused 41% of all electrical fatalities. *Discussion*: Electrical shock caused 99% of fatal and 62% of nonfatal electrical accidents. Comprising about 7% of the U.S. workforce, construction workers sustain 44% of electrical fatalities. Power line contact by mobile equipment occurs in many industries and should be the subject of focused research. Other problem areas are identified and opportunities for research are proposed. *Impact on Industry*: Improvements in electrical safety in one industry often have application in other industries.

Keywords: Electrical; Injury; Fatality; Electrocution; Shock; Electrical burn

1. Introduction

On-the-job accidents in the United States are a serious occupational problem. No one expects to be injured, much less killed on the job. Yet each calendar day on average in the United States, more than 15,000 workers sustain on-the-job injuries or illnesses and 17 are killed. Electrical incidents cause an average of 13 days away from work injuries[1] and nearly one fatality every day.

1.1. Data sources

The U.S. Labor Department's Bureau of Labor Statistics (BLS) compiles the Census of Fatal Occupational Injuries (CFOI) from death certificates and other information for U.S. workers killed on the job.[2] The 1992–1998 CFOI database contains information on 43,921 occupational fatalities from all injury-related causes.[3] Such information includes incident narratives, the source of injury, victim's occupation, location of the incident, work activity at the time of death, and other details. By analyzing such objective information, a reasonable understanding of most incidents can be achieved. Analogous to CFOI, BLS's Survey of Occupational Illnesses and Injuries (SOII) provides an estimate of the more than five million nonfatal occupational injuries and illnesses that occur in the United States each year. A statistical estimate based on a stratified sample,[4] the SOII does not contain narrative or work activity information on individual nonfatal incidents. Recent upgrades to the BLS's online search capability for both CFOI and SOII allow improved limited public access to selected U.S. occupational injury and illness information.[5] The SOII information presented in this paper

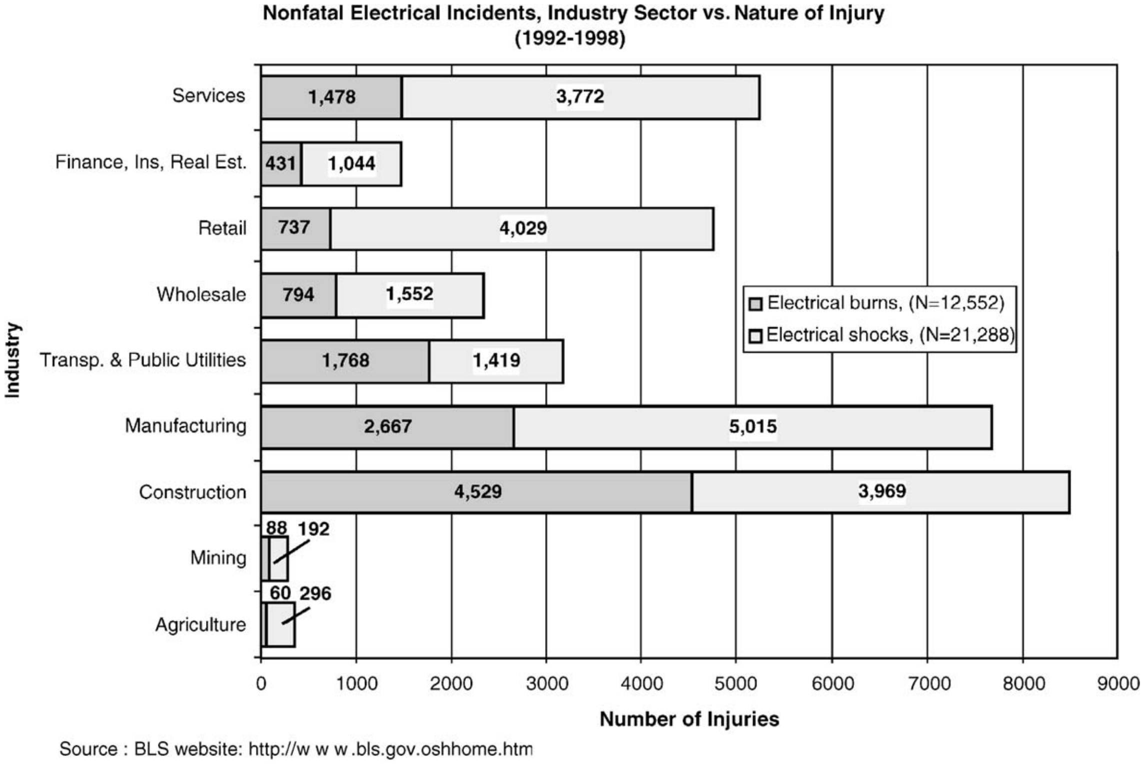

Fig. 1. Number of nonfatal electrical injuries in each major industrial sector that resulted in days away from work between 1992 and 1998 (some of the data were not available for some years).

was obtained from this publicly available source. The CFOI information was obtained from direct access to the CFOI database through special arrangement between the National Institute for Occupational Safety and Health (NIOSH) and BLS. The combination of CFOI and SOII data can provide a useful glimpse into the details of occupational electrical injury in the United States.

1.2. Selecting data for analysis

Occupational incidents often involve several events that cascade into a fatality. Consider the case where a worker is nonfatally shocked, causing a fall with a resulting fatal head injury. As a result, BLS established rules for selecting how occupational injuries and illness are classified, which are detailed in the Occupational Injury and Illness Classification System (OIICS) Manual.[6] In general, a case is coded according to the most serious nature of injury. As an example, a case in which electric shock causes a worker to fall and suffer a fatal head injury is coded as: nature = intracranial injury; part = brain; source = floor; event = fall; secondary source = electric wire or apparatus that caused the electric shock. In addition, the following events take precedence over other events or exposures: assaults and violent acts, transportation incidents, and fires and explosions. Event code counts have been used in this paper except where noted.

When event codes are used to select CFOI narratives, 2,267 electrical injuries can be isolated for the period from 1992 to 1998. When sorted by nature of injury codes *0930 (electrocution, electrical shock)* and *0520 (electrical burns)*, 2,287 cases can be found. These additional electrical fatalities stem mainly from burns resulting from electrical explosions and electrocutions from an overhead power line after a vehicular incident. The SOII shows that private industry recorded 32,309 nonfatal electrical injuries by event code and 32,807 by nature of injury codes 0930 (electrocution, electrical shock) and 0520 (electrical burns). An analysis of electrical injuries by either event or nature of injury data does not produce significantly different results.

1.3. Significance of including fatal and nonfatal injury data

Two previous studies (Cawley, 2001; Homce, Cawley, Yenchek, & Sacks, 2001) of fatal and nonfatal electrical incidents in the mining industry using data from the U.S. Labor Department's Mine Safety and Health Administration (MSHA) showed that both fatal and nonfatal occupational incidents must be studied to obtain an accurate picture of the circumstances that surround mine electrical incidents.

Similarly, CFOI data show that 98.5% of the 2,287 occupational electrical fatalities selected by nature of injury code that occurred between 1992 and 1998 were attributed to

[6] A detailed description of how BLS classifies incident data is available on its website at http://www.bls.gov/iif/oshoiics.htm.

electrocution, electric shock. However, 62% of an estimated 32,807 nonfatal occupational electrical injuries were classified as electrocution, electric shock and 38% as electrical burns. Fig. 1 shows that the ratio of nonfatal electrocution, electric shock to electrical burn injuries varies substantially among the nine industrial sectors tracked by BLS.

Thus, analysis based solely on fatal or nonfatal electrical incidents could lead to an inaccurate overall picture of the interventions needed to provide the greatest impact in a particular industry. Remediations that address electrical burns will have more impact on nonfatal injuries, while those that address electrical shock will primarily affect fatal injuries.

2. Electrical incident data

2.1. Background data

The top 10 CFOI event code categories for occupational fatalities from all causes from 1992 to 1998 are shown in descending order in Table 1. Fatal incidents involving electricity rank sixth among all causes of occupational fatality in the United States, totaling 2,267 (5.2%) during the study period. The number of fatal electrical incidents by CFOI event code is shown in Table 2. The event code with the most fatalities is code 3130, contact with overhead power lines, with 933 fatal cases. Contact with overhead power lines caused 41% of all occupational electrical fatalities.

The number of private industry nonfatal electrical incidents that caused days away from work between 1992 and 1998 is shown in Table 3. The two event codes with the highest number of days away injuries are code 3110, contact with electric current of a machine, tool, appliance, or light fixture, with 12,189 cases (38%) and code 3120, contact with wiring, transformers, or other electrical components, with 10,782 cases (33%). These data imply that nonfatal electrical injury occurs most often to those who work with machines or tools and around electrical wiring other than power lines. Median days away for nonfatal electrical incidents are shown in Table 4.

Table 1
Rank of top 10 CFOI causal categories by event code

CFOI event code range	Description	No. of incidents	Percentage of incidents
4000–4330	Transportation (except railway)	14,713	33.5
6000–6390	Violent acts	8,447	19.2
1000–1900	Falls	4,643	10.6
0100–0290	Struck by, against	4,043	9.2
0300–0490	Caught in	2,909	6.6
3100–3190	Electricity	2,267	5.2
4600–4690	Aircraft	2,163	4.9
3200–3900	Exposure to (except electricity)	1,838	4.2
4500–4590	Water craft	749	1.7
5200–5290	Explosions	702	1.6
All other causes		1,447	3.3
Total fatal incidents		43,921	

Table 2
Fatal electrical incidents for all industries by event code, 1992–1998

Year	Event code							
	3100	3110	3120	3130	3140	3150	3190	Total
1992	32	60	66	140	X	15	19	334
1993	32	44	100	115	5	16	12	324
1994	23	63	98	132	6	15	11	348
1995	32	55	94	139	5	17	6	348
1996	22	46	70	116	5	18	X	281
1997	14	41	71	138	5	22	7	298
1998	10	51	84	153	9	21	6	334
Total	165	360	583	933	37	124	65	2,267

X means no data or insufficient data available for this year.
Event code descriptions are as follows:

3100—Contact with electric current, unspecified
3110—Contact with electric current of machine, tool, appliance, or light fixture
3120—Contact with wiring, transformers, or other electrical components
3130—Contact with overhead power lines
3140—Contact with underground, buried power lines
3150—Struck by lightning
3190—Contact with electric current, n.e.c.

Row may not sum to total.
Source: BLS, CFOI 1992–1998.

Table 3
Nonfatal electrical incidents involving days away, private industry, by event code, 1992–1998

Year	Event code							
	3100	3110	3120	3130	3140	3150	3190	Total
1992	507	1,795	1,614	174	36	170	509	4,806
1993	453	2,111	1,531	133	74	71	620	4,995
1994	506	2,966	1,607	273	38	214	415	6,018
1995	769	1,506	1,571	155	47	172	522	4,744
1996	405	1,037	1,751	92	153	223	465	4,126
1997	365	1,413	1,390	79	52	X	386	3,710
1998	506	1,361	1,318	314	40	50	322	3,910
Total	3,511	12,189	10,782	1,220	440	900	3,239	32,309

X means no data or insufficient data available for this year.
Event code descriptions are as follows:

3100—Contact with electric current, unspecified
3110—Contact with electric current of machine, tool, appliance, or light fixture
3120—Contact with wiring, transformers, or other electrical components
3130—Contact with overhead power lines
3140—Contact with underground, buried power lines
3150—Struck by lightning
3190—Contact with electric current, n.e.c.

Rows may not sum to total.
Source: BLS website: http://www.bls.gov/iif/.

Table 4
Nonfatal electrical injuries, median days away by event code, private industry, 1992–1998

Year	Event code							
	3100	3110	3120	3130	3140	3150	3190	Total
1992	13	3	7	33	21	6	2	5
1993	10	3	8	8	2	3	5	4
1994	4	5	4	30	15	14	6	5
1995	3	2	5	13	10	2	2	3
1996	3	4	22	5	2	3	12	7
1997	1	4	4	60	14	X	8	4
1998	10	4	6	14	137	3	2	5

X means no data or insufficient data available for this year.
Event code descriptions are as follows:

3100—Contact with electric current, unspecified
3110—Contact with electric current of machine, tool, appliance, or light fixture
3120—Contact with wiring, transformers, or other electrical components
3130—Contact with overhead power lines
3140—Contact with underground, buried power lines
3150—Struck by lightning
3190—Contact with electric current, n.e.c.

Source: BLS website: http://www.bls.gov/iif/.

2.2. Occupational electrical incidents are disproportionately fatal

Electrical incidents, although a small portion of total incidents, are disproportionately fatal when they occur. During 1997, for example, there were 6.1 million nonfatal injuries and illnesses reported from all causes. Of those, 1.83 million injuries (30%) caused one or more days away. There were 3,710 days away electrical injuries reported during 1997, comprising only 0.2% of the total days away injuries reported from all causes. However, of the 6,238 fatal incidents reported from all causes during 1997, 298 (4.8%) were attributed to electricity. During 1997, approximately 1 in 494 days away injuries and illnesses were caused by electricity, but nearly 1 in 20 occupational fatalities were from electrical causes.

2.3. Voltage data

CFOI reported voltages in 623 (27%) of the electrical narratives studied. The following tallies were compiled for nominal voltage categories:

- 0–600 V—198 cases (32%) including:
  - 480 V—50 cases
  - 440 V—18 cases
  - 277 V—24 cases
  - 220/240 V—36 cases
  - 110/120 V—42 cases;
- 601–5000 V—50 cases (8%);
- 5001–10,000 V—215 cases (35%) including:
  - 7200 V—149 cases;
- 10,001–15,000 V—81 cases (13%) including:
  - 12,000 V—35 cases; and
- 15,001 and over—79 cases (13%).

Incident voltage was 15,000 V or less in 87% of reported cases.

3. CFOI narrative analysis

The objective of analyzing occupational electrical incidents is to identify problem areas and to develop strategies and techniques to reduce their frequency and severity. Many aspects of the circumstances surrounding fatal incidents are available directly from the CFOI database, such as victim, location, and activity information. It is useful, however, to attribute a primary "cause" to each incident. This is feasible for fatal electrical incidents because CFOI supplies a brief narrative description of each case. Researchers familiar with electrical safety issues in commercial/industrial work environments initially attempted to create a uniform and comprehensive analysis structure with which to assess each narrative, but this approach proved too cumbersome. Ultimately, a more subjective approach was used wherein each narrative was read and a primary cause assigned that may have been related to the work activity, personnel, or the equipment involved. This process in some cases required inference and engineering judgment by the authors, but from it emerged groupings that efficiently categorized and described the incidents under study. Fatal electrical incident narratives were divided into those incidents that occurred in the construction industry (about 44% of all fatal electrical incidents) and those that occurred in the nonconstruction industries. Additionally, the review identified each incident that occurred during "electrical work," regardless of the cause, and those incidents that occurred during nonelectrical work. These preconditions created a useful framework for the analysis due to the large number and high rate of electrical incidents in the construction industry and the disparity between circumstances surrounding incidents that occurred during electrical installation/maintenance work and those that occurred during other activities.

There were 43,921 fatal occupational incidents in the United States between 1992 and 1998. After selection by nature of injury codes for 0930 (electrocution, electrical shock) and 0520 (electrical burns), 2,287 fatal electrical incidents remained. Based on the review of CFOI narratives for these incidents, 91% of fatal occupational electrical injuries were classified into one of the following five categories:

- *Installation and maintenance of electrical systems and equipment (excluding overhead or buried power transmission/distribution lines)* (506 incidents, 22%). This group includes residential, commercial, and industrial environments, as well as personnel of varying backgrounds, and so will encompass a seemingly wide range of incident situations. The strong common thread however is that work was being performed on or adjacent to live circuits of which the worker may or may not have been aware. The activities most frequently cited were installation or maintenance of power system components (e.g., cables, transformers, and breakers), lighting fixtures, and heating, ventilating, and air conditioning (HVAC) equipment.

- *Contact with an overhead electric power line through a handheld object during activities other than electrical system installation and maintenance* (495 incidents, 22%). These incidents involved workers contacting overhead power lines with long, conductive, handheld items while performing work activities unrelated to electrical systems or components. The most common object in use was a ladder, but construction materials, tools, and scaffold members were also mentioned in numerous accounts.
- *Contact with an overhead electric power line indirectly through a piece of high-reaching mobile equipment during activities other than electrical system installation and maintenance* (387 incidents, 17%). In these incidents, mobile equipment contacted a line and was either simultaneously or subsequently contacted by workers who unintentionally completed the circuit to ground. These were incidental contacts in that work underway at the time was unrelated to the power lines. The types of equipment most commonly involved were cranes, boom trucks (light cranes on flatbed truck chasses), dumpbed trucks, and drill rigs.
- *Incidental contact with energized circuits (excluding overhead or buried power transmission/distribution lines)* (424 incidents, 19%). This category by definition covers work activities other than electrical system installation and maintenance. The electrocutions most frequently resulted from contacting bare wires and faulty or inappropriate power tools (including equipment with ineffective grounding).
- *Installation/construction and maintenance of overhead or buried power transmission/distribution lines* (253 incidents, 11%). This is a relatively narrowly defined category and includes some of the most inherently hazardous activities. In most cases, personnel were working on or adjacent to overhead high-voltage circuits from a pole/tower or elevated platform (bucket truck).

Of the remaining occupational electrical fatalities recorded in CFOI, approximately 5% were due to lightning strikes and the remainder could not be classified with the information provided.

4. Prior NIOSH research that addressed electrical hazards

NIOSH Alerts briefly present information about occupational illnesses, injuries, and deaths. Alerts urgently request assistance in preventing, solving, and controlling newly identified occupational hazards. Alerts ask workers, employers, and safety and health professionals to take immediate action to reduce risks and implement controls.

A number of NIOSH Alerts have studied various electrical problem areas (U.S. Department of Health and Human Services [US DHHS], 1984, 1986a, 1986b, 1986c, 1987, 1989). Some of the recommendations made in these NIOSH Alerts include:

- The use of ground fault circuit interrupters to prevent electrocutions among fast food restaurant workers;
- Improved training and signage to prevent grain auger electrocutions;
- Improved training in hazard recognition and cardiopulmonary resuscitation (CPR) to prevent fatalities among those workers who contact electrical energy;
- Improved hazard recognition training, use of personal protective equipment (PPE), and improved work procedures for power line workers;
- Strict adherence to Occupational Safety and Health Administration (OSHA) regulations and improved training in hazard recognition and work practices to prevent electrocutions with ladders and, in the case of scaffolds, recommendations for nonconductive scaffolding and improved signage;
- Strict adherence to OSHA and American National Standards Institute (ANSI) regulations and improved safety and CPR training to prevent electrocutions during tree-trimming operations;
- Strict adherence to OSHA regulations and improved inspection of equipment by a “competent person” to ensure that the insulation characteristics of aerial bucket trucks are adequate;
- Strict adherence to OSHA and ANSI regulations, improved hazard recognition training, use of utility services to deenergize lines, and encouragement of private industry to improve equipment to prevent electrocution of crane operators and ground crews by overhead power lines;
- Strict adherence to child labor laws, parental involvement, and improved hazard recognition training to protect adolescent workers against electrocution;
- Strict adherence to OSHA regulations, improved signage, deenergization, lockout–tagout, and grounding of electrical systems prior to beginning work on electrical systems to protect all workers from uncontrolled releases of electrical energy.

NIOSH’s Fatality Assessment and Control Evaluation (FACE) program is a research program designed to identify and study fatal occupational injuries. The goal of the FACE program is to prevent occupational fatalities across the nation by identifying and investigating work situations at high risk for injury and then formulating and disseminating prevention strategies to those who can intervene in the workplace.

FACE is a research program. Investigators do not enforce compliance with state or federal occupational safety and health standards nor do they determine fault or blame.

U.S. Department of Health and Human Services (UD DHHS, 1998) examined 224 occupational electrical incidents that resulted in 244 fatalities between 1982 and 1994 using NIOSH's FACE reports and made recommendations to reduce the number of electrical incidents. Recommendations included improvements to training procedures, adherence to existing OSHA regulations, and improved warning signage.

One logical extension of past NIOSH electrical safety studies is research to develop effective engineering control solutions to address the recommended interventions. This could include work to adapt existing successful solutions from one industry to another, as well as research to conceptualize, build, and test prototype electrical safety devices.

5. Mine electrical safety research by the U.S. Bureau of Mines

The U.S. Bureau of Mines began an extensive mine electrical safety research program in response to the 1969 Coal Mine Safety and Health Act. A wide variety of electrical safety topics were addressed that were relevant not only to mining, but other industries as well. The bureau emphasized an engineering approach to electrical safety problems, working to produce, test, and document a wide variety of practical solutions for identified mine electrical hazards. Electrical system studies, trailing cable splicing improvements, mine trailing cable life studies, electrical maintenance practices, grounding practices, arcing fault detection, explosion-proof enclosure and intrinsic safety research, mitigating overhead power line hazards, and system and personnel protection devices were some of the areas studied. The interested reader can find a searchable archive of Bureau of Mines' research at the Common Information Service System (CISS) Website maintained by NIOSH.[7] This research continued until the bureau was closed in 1996. Shortly thereafter, the former bureau's mine safety and health research functions, as well as some of its remaining resources, were assumed by NIOSH.

6. Research opportunities

As the analysis in this study revealed, occupational electrical injuries occur in many industries, under widely varying circumstances, and involve nearly all occupations. This suggests that research directed toward reducing electrical injuries should include an equally diverse array of complimentary intervention concepts, each targeting a well-defined aspect of the problem, suitable for practical applications, and with potential for measurable success. Ideally, efforts should focus on the most prevalent accident scenarios, represent different approaches for reducing electrocutions, and draw on the expertise of researchers from different disciplines. No single "silver bullet" approach will solve the problem of electrical death and traumatic injury, but innovative ideas for engineering controls, workplace management, and training can combine to have a positive impact.

With the acquisition of the facilities and personnel of the former Bureau of Mines' Pittsburgh Research Center, NIOSH now has additional resources for electrical safety research, especially in the area of engineering controls. Indeed, the bureau's history of focused practical solutions for specific safety problems compliments the analysis and identification of hazards that typify much past NIOSH research.

To decrease the number and severity of nonfatal electrical burn injuries, direct worker exposure to electrical arc energy must be reduced. One possible approach to this problem involves engineering hazards out of electrical systems; studying and improving (where needed) management controls over electrical work; developing improved electrical hazard recognition and avoidance training focused on the injury potential of electrical arcing; implementing and evaluating such training; and identifying PPE appropriate to recognized arcing hazards and communicating its benefits to affected workers, especially in the mining industry.

While it comprises only about 7% of the U.S. workforce, the construction industry accounted for 44% of all fatal electrical injuries. Approximately one in eight construction fatalities involved electricity. As shown in Fig. 1, 25% of all nonfatal electrical injuries between 1992 and 1998 occurred in the construction industry. Of fatal incidents, 56% involved power lines. Significant effort should be expended to improve the electrical safety of construction workers, especially in the area of overhead power line hazards. About 45% of electrical fatalities in nonconstruction industries also involved power lines. Such research would have a synergistic effect in other industrial sectors as well, principally in mining where 20% of electrical fatalities during the 1990s involved cranes, trucks, and drill rigs contacting power lines (Cawley, 2001). Contact with high-reaching mobile equipment was a significant cause of electrical fatalities involving power lines. Construction industry incidents usually involved cranes, boom trucks, and drill rigs. Nonconstruction industry incidents most often involved boom trucks. Engineering control research that builds on past work in this area is needed. Research to develop a warning device to alert ground crews and equipment operators of accidental power line contact was conducted at NIOSH's Pittsburgh research laboratory. Several simple modifications to vehicles and associated equipment could significantly reduce the number of incidents in this category. For example, boom truck operator electrical safety could be improved by the increased use of remotely controlled hoisting devices or by moving the manual hoisting controls to a position that requires the operator to stand on the truck to operate them.

[7] http://outside.cdc.gov:8000/ciss/Welcome.html.

Contacting an overhead electric power line through a handheld object was another significant cause of occupational electrical fatalities. Construction industry incidents usually involved ladders, scaffolds, metallic pipes, rods, and poles, and siding, gutters, and sheet metal. Nonconstruction industry incidents typically involved landscaping and tree-trimming operations often associated with utility contractors conducting tree-trimming operations. The need to exercise safe work practices (maintenance of safe work distances, the use of insulating blankets, the use of nonconducting handheld poles/handles, ladders, etc.) must continue to be reinforced with hazard recognition and avoidance training. Engineering control research should be undertaken to provide additional protection for workers using ladders and scaffolds. Improved methods for safely handling long conductive objects (poles, antennas, pipes, etc.) in the presence of power lines also needs closer examination.

Installation, maintenance, and repair of electrical equipment were the leading causes of occupational fatality incidents that did not involve power lines. The activities most frequently cited were installation or maintenance of power system components (e.g., cables, transformers, and breakers), lighting fixtures, and HVAC equipment. Improved maintenance work practices and engineering control devices to remove hazards, where practical, are needed. Supplemental research into improved electrical lockout–tagout procedures is one potential research area. Research into arc-detecting circuit breaker technology, now emerging in residential and industrial applications for fire protection, could be more fully explored for its possible application to high-energy arcing faults. Application of sensitive ground fault protection on light fixtures could save lives of non-electrical personnel who change bulbs and fixtures in commercial establishments.

Another approach to protecting electrical maintenance workers is to limit their exposure to hazardous circuits, where possible. The use of computerized motor control center maintenance interfaces, as described by Blair, Doan, Jensen, and Kim (2001), precludes the need for a worker to open a motor control center in order to perform routine electrical maintenance. Similar maintenance techniques could be investigated for their potential to reduce exposure to electrical hazards during routine maintenance.

7. Summary

This report has presented the results of an analysis of CFOI and SOII data revealing that electricity is a serious occupational injury problem. Noteworthy among the findings is that although electrical shocks and burns do not occur as frequently as many other types of occupational injuries, they are disproportionately fatal. Analysis also concluded that the causes of most fatal electrical incidents fall into one of five categories: (a) installation and maintenance not involving power lines; (b) incidental contact of an overhead power line with a handheld object; (c) incidental contact of an overhead power line through mobile equipment; (d) incidental contact with energized circuits other than overhead or buried power lines; and (e) power line installation and maintenance work. Past electrical safety research by NIOSH and by the former U.S. Bureau of Mines was briefly reviewed, and recommendations for future electrical safety research were outlined.

8. Notes

NIOSH Alerts are available via the Internet at http://www.cdc.gov/niosh/alerts2.html or by contacting: National Institute for Occupational Safety and health, Publications Dissemination, 4676 Columbia Parkway, Cincinnati, OH 45226-1998, USA. Tel.: 1-800-35-NIOSH (1-800-356-4674); fax: +1-513-533-8573. E-mail: pubstaft@cdc.gov.

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