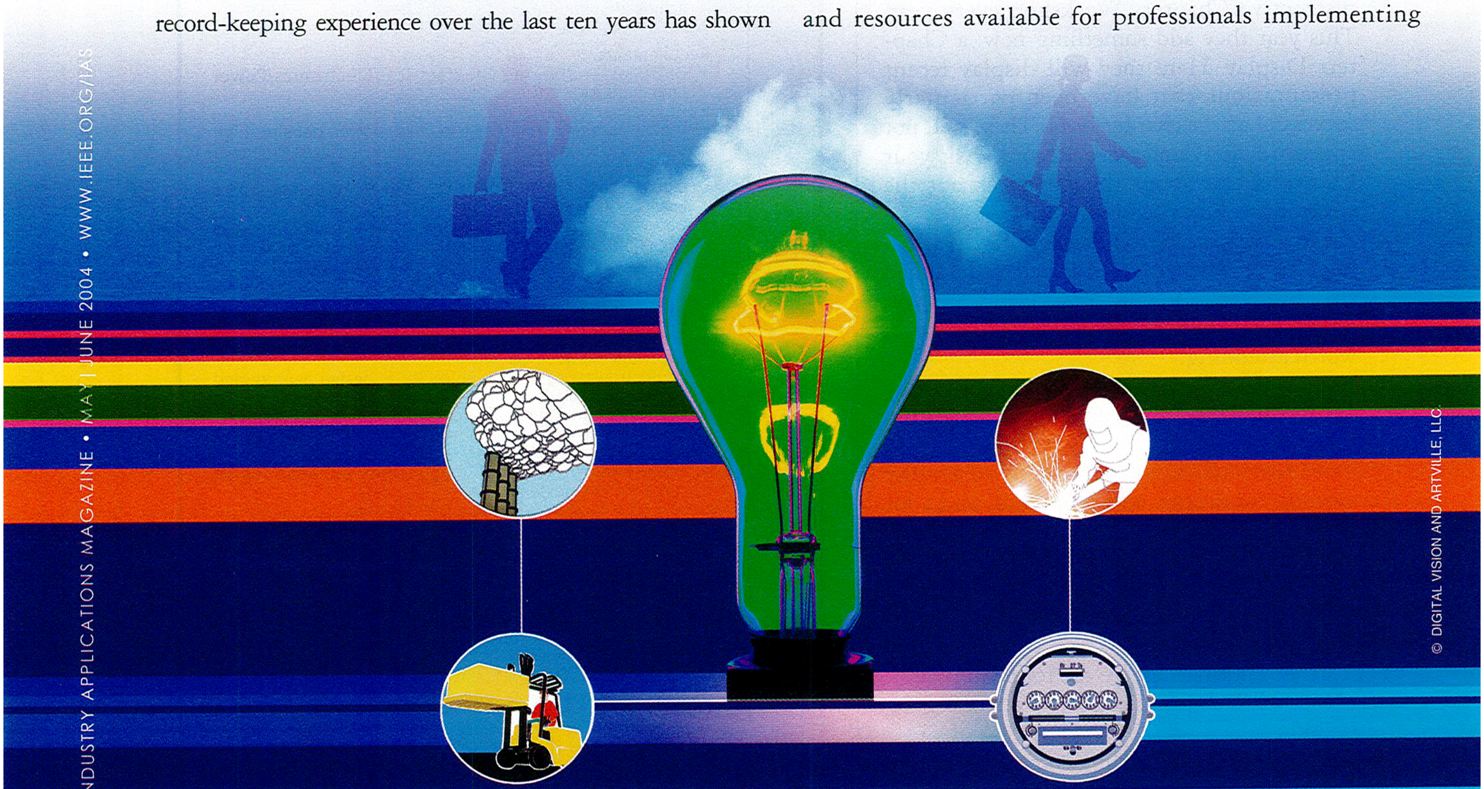
SAFEGUARDING THE ELECTRIC WORKPLACE

An overview of the state-of-the-art in electrical safety technology, work practices, and management systems

ELECTRICAL INCIDENTS DO NOT have to result in injury or death. Every health effect, including death, amputation, burn, crush, blast, blindness, hearing loss and brain injury, is unnecessary. Engineering, scientific, and record-keeping experience over the last ten years has shown that electrical incidents are not random or rare. Safety professionals and electrical safety leaders are uniquely positioned to respond to every unintentional workplace exposure to electrical energy as a potentially fatal or environmentally threatening scenario. To enhance the fund of knowledge and resources available for professionals implementing



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safe electrical work practices, we present a historical overview of electrification and electrical safety management, followed by a survey of recent developments to reduce the frequency and severity of electrical incidents and their consequences. In the worlds of business, manufacturing, engineering, behavioral safety, and regulatory compliance, the financial case for improving electrical safety can be justified through measurable improvement by preventing injury to people, minimizing energy and raw materials waste, preventing process safety and environmental incidents, protecting capital investment from damage, and increasing uptime of operations.

Beginning in the last decade of the 19th century and escalating rapidly during the first quarter of the 20th century, virtually every facet of our civilization integrated electrical applications. Through the 20th century, electrification became the single most important engineering achievement, according to the U.S. National Academy of Engineering. Power generation and distribution, communication, mass transportation, agriculture and food production, and diagnostic medicine are examples of the domains that were transformed by electrification. Other significant engineering accomplishments of the past century, such as space travel and automobiles, were dependent on electrical technologies.

It is difficult to imagine life without the conveniences of electricity. However, the electrification of all aspects of society has had the negative attribute of exposing people to potential injury and property loss from electrical hazards.

Dramatic inventions and more uses in electrical technology have come at the expense of many lives and limbs. The most common hazards associated with electrical energy include:

- *Fire:* The National Electrical Code was originally developed because of this hazard.
- *Converted Energy:* Electricity in its raw form has little use to us. We must convert electricity into a form we can use such light, heat, or magnetic forces to drive motors, which present potential hazads.
- *Shock:* The hazard we most hear about, but not everyone understands or appreciates this hazard as much as they should.
- *Electrochemical Hazards:* The chemicals used in batteries are hazardous.
- *Flash Burn and Blast:* The hazards from the intense thermal, acoustic, blast, light, and electromagnetic energy release in an electric arc.

The U.S. National Institute for Occupational Safety and Health has consistently reported electrocution as one of the top five leading causes of occupational fatalities. Bureau of Labor Statistics data for 1994 show 11,153 cases of reported days away from work due to electrical burns, electrocution/electrical shock injuries, and fires and explosions. In 1994, the Census of Fatal Injuries noted 548 employees died from the causes of electrical current exposure, fires, and explosions out of a total 6,588 work-related fatalities nationwide. Electrocution is the second most common cause of construction-related fatality. In the U.S. chemical industry, 56% fatalities over a five-year period were attributable to burns, fires, and explosions. Many times the ignition source for these events was related to an electrical activity. In practical terms, the data means there are roughly two deaths from electrical hazards *each day*. With regard to electricians, according to the Bureau of Labor Statistics (U.S. Department of Labor, 25 January 2001), between 1993–1998, there were 101,884 reported nonfatal occupational injuries and illnesses in U.S. private industry. These numbers do not capture consumer related or recreational electrical incidents or incidents affecting workers who are not electricians.

Historically, interest in technology, the invention of machines to solve problems and meet specific needs, has outpaced our ability to safeguard lives and the environment from electrical hazard exposures. However, as hazard recognition has escalated, leadership has emerged to champion safe electricity use. If the progress in electrical safety during the past century was a journey, the work spanning the past ten years has been a sprint. Advancing codes, standards, information and management technology, and work practices critical for improving electrical safety in industrial work environments have created the expertise and strategies to further eliminate electrical incident occurrences.

Evolution in Standards and Regulations

In the United States, there are a number of standards and regulations related to electrical safety. They cover both electrically safe equipment conditions and electrical safety-related work practices.

The Occupational Safety and Health Administration (OSHA) Regulations (Standards—29 CFR) are federal law and must be followed under penalty of fines and/or imprisonment. Part 1910, *Occupational Safety and Health Standards,* applies to general industry. Subpart S, 1910.331 through 1910.335, *Electrical Safety-Related Work Practices*, and Subpart R, 1910.269, *Electric Power Generation, Transmission, and Distribution*, contain regulations that dictate safe electrical work practices. Other OSHA standards directly related to electrical safety include 1910, Subpart I, *Personal Protective Equipment*; 1910, Subpart J, *General Environmental Controls*; 1910.147, *The Control of Hazardous Energy*; 1910, Subpart S, *Electrical*. Part 1926, *Safety and Health Regulations for Construction*, applies to the construction industry. Standards in this Part include; Subpart K, *Electrical*, and Subpart V, *Power Transmission and Distribution*.

The National Fire Protection Association (NFPA) has been involved with electrical safety for almost a century. Today the NFPA publishes standards covering both safe electrical installations and safe electrical work practices, including:

- NFPA 70, *The National Electrical Code (NEC),* contains provisions that are necessary for electrically safe installations within or on public and private buildings or structures. It does not cover safe work practices.
- NFPA 70E, *Standard for Electrical Safety Requirements for Employee Workplaces*, addresses the safety aspects of both conditions and activities that apply for an employee to work safely in an electrical environment. In the 1995 and 2000 editions, this standard

took giant leaps forward in providing guidance for personnel protection from the arc-flash hazard.

- Other NFPA standards that contain information relative to electrical safety include NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance,* and NFPA 79, *Electrical Standard for Industrial Machinery.*

The IEEE publishes many documents covering the design of safe and reliable electrical facilities and equipment. Standards specifically addressing electrical safety include:

- ANSI C2, *National Electrical Safety Code (NESC),* covers basic provisions for the safeguarding of persons from hazards arising from the installation, operation, or maintenance of conductors and equipment in electric supply stations and overhead and underground electric supply and communications lines. It also includes work rules for the safe construction, maintenance, and operation of electric supply and communication lines and equipment.
- IEEE 902 *(The IEEE Yellow Book), Guide for Maintenance, Operation and Safety of Industrial and Commercial Power Systems,* provides guidelines for operating industrial and commercial electric power facilities. It contains six chapters devoted specifically to electrical safety.
- IEEE 1584, *Guide for Performing Arc-Flash Hazard Calculations,* provides techniques for designers and facility operators to apply in determining the arc-flash hazard distance and the incident energy to which employees could be exposed during their work on or near electrical equipment.

The American Society for Testing and Materials (ASTM) standards cover such things as protective rubber goods, temporary protective grounds, plastic guards, insulated tools, and other electrical protective equipment. Several relatively new standards measure or identify thermal performance of materials and protective clothing for use by workers who may be exposed to thermal hazards from electric arcs. These include:

- ASTM F1506, *Standard Performance Specification for Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards.*
- ASTM F1958, *Standard Test Method for Determining the Ignitability of Non-flame-Resistance Materials for Clothing by Electric Arc Exposure Method Using Mannequins.* This method is used to measure the arc exposure energy level that will cause untreated cotton fabrics or other flammable cothing materials to ignite.
- ASTM F1959, *Standard Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing.* This test method will measure the arc thermal performance value (ATPV) of materials in calories per centimeter.
- ASTM F2178, *Standard Test Method for Determining the Arc Rating of Face Protective Products.* This test method is used to measure the arc rating of face shields and hoods.

Electrical Safety Technology

In addition to an accelerated pace in the development of electrical safety related standards, new technologies and attributes of existing technologies have been brought to the forefront to further reduce hazards in the home and workplace. These technologies include:

- the ground fault circuit interrupter, credited for reducing residential electrocutions by 50% since first introduced in the late 1960s
- the arc fault circuit interrupter, designed to detect arcing faults that are attributed to causing more than 40,000 residential and commercial fires annually in the United States
- high-resistance grounding for low voltage power distribution systems enhances reliability and uptime of power distribution equipment and is proven effective in significantly reducing the frequency and severity of arc flash accidents
- arc-resistant switchgear, a technology that protects personnel from exposure to electric arc flash and blast injury by directing and venting the explosive and thermal hazards away from personnel
- current limiting fuses and circuit breakers, based on technologies that detect and disconnect power to short circuits within 1/120 s, contributes to personnel protection by significantly reducing incident energy in arc flash accidents
- touch-safe technology limits finger access to exposed terminals and energized parts by sufficiently recessing the terminal or energized part such that it can be contacted by a test instrument or tool, but not by a human finger
- fiber optic and other data highway technologies provide opportunities to reduce shock exposure by using nonlethal light or safe low voltages for control and measurement circuits.

Emergence of Electric Arc Flash as a Unique Electrical Hazard

Historically, electrical hazards were viewed as primarily electric shock or electrocution hazards. While the electric shock hazard is certainly important, it has masked a second important and unique electrical hazard associated with the intense radiant and convective energy released during an electric arc flash event. In some cases, the presence of multiple exposure conditions in an electrical incident (i.e., shock, radiation, heat transfer) makes it difficult to determine which hazard is responsible for fatal and nonfatal injuries. Burn injury may be sustained even in the absence of an exposure to electrical shock from the radiant and convective energy released in an electric arc event. Ralph Lee first reported in 1982 on this non-contact electrical hazard in his paper, "Other Electrical Hazard: Electric Arc Blast Burns." It has taken the intervening two decades to quantify the arc exposure energy, determine the protective performance of clothing, and develop work practices and protective clothing guidelines for dealing with this hazard. Recognizing that electrical contact avoidance is not sufficient to protect against injury and death, a new electrical safety approach evolved. Recent work has addressed how to integrate protective strategies for electric shock and electric arc exposures into an electrical safety management process. The 2000 edition of NFPA 70E was the first comprehensive approach to deal with both the electric shock hazard and the noncontact arc exposure hazard.

A significant number of second- and third-degree injuries result from the intense radiant and convective energy of an electric arc. These injuries can frequently occur without electrical contact with the burn victim. The most serious of these burn injuries involve the ignition of the victim's clothing by the arc exposure. The relatively long time, e.g., 30–60 s of continued burning of conventional work clothing, increases both the burn depth and the total body area suffering burn injury. This directly affects trauma severity and survivability. The total area of body burn injury is a key survival factor for burn victims based on the 1991–1993 American Burn Association study, along with inhalation injury. Flame-resistant (FR) clothing can significantly reduce burn injury resulting from electric arc exposure first by minimizing or avoiding clothing ignition and second by creating a thermal barrier, which reduces the arc exposure energy reaching the victim's body surface. Consequently, over the past decade, there has been increased emphasis by OSHA and the ASTM and NFPA standards organizations on the use of FR clothing by workers exposed to the electric arc flash hazard.

Electric arc exposure intensity is typically more severe than flame exposure. Consequently, there is a high probability that an arc exposure will be sufficient to ignite conventional work clothing. Conventional work clothing is typically made of 100% cotton fabrics or fabrics made of a polyester/cotton fiber blends or a nylon/cotton fiber blend. All of these fabric types are flammable, and in addition, the nylon and polyester fibers can melt into the skin causing a more serious burn injury. Fabrics containing polyester and nylon should be avoided due to this melting hazard. The ASTM F1958 test method can be used to determine the arc exposure incident energy that will ignite conventional work clothing. The incident energy required for ignition increases as would be expected with fabric weight. Darker colors tend to ignite at lower incident energy levels than lighter colors. The primary point on ignition is that all conventional work clothing fabrics can ignite, will continue to burn on the wearer's body and will cause more severe burn injury to greater areas of the body. If clothing is ignited, burn injury can quickly spread to areas of the body that were not exposed in the electric arc flash accident.

The primary benefit of FR clothing is that it will self extinguish upon ignition, usually within a few seconds. Consequently, FR clothing will not add to the burn injury by continuing to burn on the wearer's body like conventional work clothing. In addition, each layer of FR clothing also provides a thermal barrier which can be designed to reduce or minimize bum injury for skin under the FR clothing single- or multiple-layer system. The ASTM F1959 Test Method is used to quantify the thermal performance of single and multiple layers of FR fabrics or coated materials. This method exposes FR fabric to heat energy from an electric arc and measures the ATPV of the fabric. Fabric performance is determined from the amount of heat energy transmitted by the fabric and the observed effect of the electric arc exposure on the fabric. Similarly, ASTM F2178 measures the arc rating of face shields and hoods used to protect workers from the heat of an arc flash event.

Incident energy can be estimated for each specific task involving an arc hazard, provided the arc exposure parameters can be defined. The workday of an industrial electrician may involve a wide range of arc exposure hazards. Some tasks, high current switching for example, may involve the potential for very high arc exposure energy for the short time required to carry out the task. Other routine tasks performed by the same worker may involve much less severe arc exposure hazards. Thousands of laboratory tests have been conducted per ASTM F1959 and F2178 to define the performance of FR fabrics, face shields, and hoods used for arc flash personal protective equipment (PPE).

Typically, the large range of potential arc exposures within the scope of electrical tasks performed by a group of workers requires that a comprehensive task-by-task analysis be done. This hazard analysis will provide the predicted exposure needed to determine whether routine electrical tasks require workers to wear FR clothing and which specific tasks require more protection, e.g., multilayer FR clothing systems. The arc hazard analysis generally consists of three main steps:

1) estimating the potential incident energy available at the work location
2) evaluation of engineering options
3) selecting appropriate protective clothing and PPE to protect the worker.

NFPA 70E provides guidance on conducting hazard analyses, but this must be combined with a detailed analysis of the electrical system parameters where electrical work will be performed. The use of an FR clothing system does not preclude the possibility of sustaining a burn injury. For more severe arc exposures, additional layers of FR clothing, as well as face and head protection, are indicated. Real arc exposures may be more or less severe than laboratory arc exposures, due to greater arc movement toward or away from the exposed worker, unknown arc length, system reclosure, secondary explosions or fires, weather conditions, and a host of other factors.

Work is underway in other standards and regulations to incorporate these advancements in understanding arc flash hazards. For the first time, the 2002 edition of the NEC required field labeling of certain electrical equipment to warn personnel of risks.

Advances in the Evaluation and Treatment of Electrical Injury

Advances in the evaluation of electrical and thermal injuries suggest that the mechanisms of injury in electrical trauma can be appreciated as consequences of the multiple incident hazards. The clinical spectrum of electrical injury ranges from the absence of any external physical signs to severe multiple trauma. Reported neuropsychiatric sequelae can vary from vague complaints, which may seem unrelated to the injury in their occurrence over time or by their apparent severity, to sequelae consistent with brain injury accompanying an electrical trauma.

Because of the statistical occurrence and geographic distribution of these incidents in the United States, rural or community-based hospitals may evaluate an electrical trauma survivor as infrequently as once a year. When major burns are not involved, the nature of the patient's presentation may be unimpressive to busy clinicians, compared to other multitrauma patients who might also be in the local emergency setting. The patient's post-injury neurologic and cognitive status may contribute to the assessment difficulty. To the extent that the patient is amnestic or confused about the details on how they were hurt, clinicians may not be able to elicit facts about the injury scenario that would be reasonably expected to guide the aggressiveness of their diagnostic evaluation. Electrical incident survivors tend to be primarily male workers of relatively young age. While the frequency of trauma is low (relative to back injury for example), the challenges in rehabilitation suggest a high social cost.

The nature of electrical work, as well as most industrial and construction activities, can be characterized generally as requiring secure and reliable use of the extremities bilaterally. When an electrical incident occurs with a worker present, typically the worker has been engaged in an activity that relies on their extremities (such as in a reaching action in the use of a hand tool or in the hands touching a surface in an inspection activity). This explains the frequent involvement of at least one extremity in an injury event, and the basis of the disability that may be experienced with peripheral neuropathy symptoms: when a patient has difficulty in their use of their limbs, their security in completing tasks (like exerting a forceful grip, climbing a ladder, using two hands to lift a load, assisting a coworker in a hazardous activity) may be unacceptably compromised.

Complaints commonly described in electrical injury survivors including weakness, pain, headache, memory changes, disorientation, slowing of mental processes, agitation, confusion, irritability, affective disorders, and post-traumatic stress disorders. Patients require a thorough and ongoing assessment by an expert multidisciplinary team to optimize their medical, psychosocial and occupational status. The key clinical question to address for each patient is "What is preventing the patient from being successful in their recovery?" A seriously injured high-voltage electrical shock patient can be re-employed following a potentially fatal workplace electrical incident, however, the rehabilitation period may extend months beyond the time of the patient's acute hospitalization and surgical management, and may not lead to the return of the patient to their pre-injury job.

When a trauma patient presents acutely for medical care after an electrical incident, their diagnostic evaluation is recommended to include a comprehensive examination of their neurologic condition and neuromuscular function, including at least the determination of the exposure circumstances and the documentation of the physical findings. Depending on the patient's presentation, further evaluation may be warranted with radiology and electrophysiology studies. Central nervous system damage is distinguished from peripheral nerve injury as follows.

In a 20-year survey of a major electrical utility's disability experience with electrical injury and its sequelae, Gourbierre and her colleagues reported on 717 sequelae in 510 electrical injury victims. Sequelae affected 25% of survivors. Sequelae from burns in 63% cases with 5% amputations, neuropsychiatric sequelae in 18%, and sense organ sequelae in 12% were noted. Previously reported amputation rates following electrical injury have ranged between 37–65%. The disability impact of electrical injury is disproportionate to the incidence of this preventable condition, meaning for relatively few injuries there is a relatively high frequency of permanent disability. For example, by contrast to the above cited amputation rates, in the U.S. population of persons aged older than 15 years reporting selected conditions as the cause of their disability, 0.7% of the sample noted disability from missing legs, feet, arms, hands or fingers (from Table 2 for the period of 1991–1992 presented in the Morbidity and Mortality Weekly Report of the U.S. Centers of Disease Control and Prevention, 14 October 1994, p. 738). Because of the relative youth of those injured in electrical accidents and the loss of potential productivity in economic terms, electrical injury carries significant costs for victims, their families, and their employers.

Electrical arcs occur frequently in the electrical trauma setting and can create destructive air pressure waves due to the subsecond thermal expansion of air. In survivors of electrical incidents where the likelihood of mechanical electrical contact or entrapment in the arc plasma is low, neurologic, neuropsychologic and psychiatric symptoms experienced by survivors may be the consequences of blast injury from the thermo-acoustic effect of the arc blast. However blast trauma may not be readily appreciated in survivor triage because of the subsecond time course of these scenarios and the absence of significant external wounds.

Barotrauma leading to brain injury, tissue damage at air-fluid boundaries internally (e.g., lungs, ears, bowel), as well as concussions from explosion shrapnel may not be accompanied by electrical contact sites or burns. In relation to electrical arc events, the energy input can be expected to equal the sum of the energy released in its various forms. Conceptually this can be represented in watts as electrical power = electrical power out + plasma formation + heat flow (including acoustic waves and shock waves) + light power (including optical, infrared and ultraviolet).

The percentage distribution of the forms of energy in the output consequent to an electrical arc is variable, described by physics and influenced by environmental considerations, i.e., geometry, altitude, humidity, geology, and meteorologic factors such as ambient pressure, temperature, and winds. Theoretically, the potential for bystander injury is directly related to the energy output from an electrical arc; however, it is the actual energy exposure, i.e., *the energy transferred to the individual,* that provokes a biologic effect. Critical in predicting the extent of injury after an electrical incident are the quantity and form of energy transfer and the biologic characteristics of the individual.

From the perspective of injury research, the classical definition of an injury suggested by James Gibson and detailed by William Haddon considered that an injury was the specific result of a specific type of energy exchange. Cristoffel and Gallagher have summarized the modern concept of injury as "commonly defined as the transfer of energy to human tissues in amounts and at rates that damages the cellular structure, tissues, blood vessels, and other bodily structures." In electrical incidents, the dose or amount of energy transferred to an individual involved in an unintended exposure is a function of the current, time exposed, distance from the source, surface area of the body exposed, and the material properties of biologic tissues, including the conductance, impedance, resistance and absorbance of human "biomaterials," i.e., the water, lipids, fats, proteins, minerals that constitute the human body. Historically, the industrial focus on electrical injury prevention as burn prevention had its basis in the mechanistic view that an electrical injury was caused by current exposure leading to heating and resulting in burns. In the 1920s, the medical appreciation of electrical current's biologic effects was similar; Dr. Harvey Cushing, in his discussion of electrical cautery techniques in neurosurgery in 1928, commented that comparatively large amounts of alternating current could be passed through tissue without producing any physiological effect other than heating. However, converging medical and engineering research insights on the complexity of electrical events, as well as their consequences, have been fundamental to a changing appreciation of the physical forces released at the time of an electrical event, as noted in the preceding sections.

Electrical Work Zones, Task Creep, and Safe Boundaries

After more than a decade of regulations emphasizing the critical role of lockout/tagout for controlling personnel exposure to hazardous electrical energy, a subtle, but complex problem is being recognized. Solutions and intervention strategies based on human factors engineering are at the forefront of opportunities to have significant impact in prevention of electrical injuries. Simply stated, investigations of accident scenarios are finding an alarming common thread in a significant number of cases. The common thread involves presumably knowledgeable, competent personnel making decisions or taking actions that unintentionally move themselves outside the boundary of the isolated and de-energized safe working zone. Industrial and commercial control equipment and power distribution equipment are complex systems. These complex systems allow for portions to be isolated and de-energized to create a safe working condition. However, other portions of the system adjacent to, coupled to, in the same room, or in the same fenced area may remain energized. While the physical limits may appear apparent in two dimensional documents and drawings, personnel must use a broad set of cognitive skills to transfer the two dimensional image into the real world of 3-D, having potential discrepancies in signage, audio and visual diversions, personal distractions, and wide variation of internal configurations of equipment that from the outside may appear identical.

The vulnerability for people unintentionally and without recognition to get outside the boundary of safety zones exists in nearly all types of tasks involving electrical hazards. The design of intervention strategies should be based on the assumption that expert, knowledgeable, and competent people can and will make judgment decisions, based on the information they have available, that could take themselves outside the safe work zone. Considering this assumption, job and task planning could include additional written, verbal, and physical communication tools, and additional emphasis on voltage testing. Examples include physical walk through of a job, in addition to review of written job plans; temporary signage on energized compartments adjacent to the isolated and de-energized compartments; permanent signs on the rear of switchgear that matches compartment identification on the front; barricading adjacent energized compartments or equipment; and emphasis on a fundamental safe electrical work practice of *testing every circuit, every conductor, every time before touching*.

Electrical Safety Paradigms, Myths, and Opportunities

Electrical injury prevention depends, in part, on the ability to assess the number, severity and underlying causes of electrical incidents in the workplace. Counting electrical incidents is difficult to accomplish. Coding of incidents varies depending on available event information. Employers vary in their effort or ability to report incidents, given that incidents may happen very quickly with little notice. Workplace cultures tend to exert peer pressure that favors not recording electrical incidents. Often, management is not rewarded for reporting; rather, a track record of difficulties on a manager's time can take away from promotion and pay opportunities. Drawing attention to an unsafe act may not appreciated as in employees' best interest either because employees are expected to conduct themselves safely. While incident data is not widely available, survey information suggests electrical hazards are recognized as potentially fatal. Tkachenko and colleagues reported their results from 480 respondents to a survey of 1,200 electricians. Their average age was 40.2 years ±10.3 years. They were predominantly male (477/480). Remarkably, 465 of the 477 (97%) respondents had experienced an electrical shock at work, and 123 of the 477 (26%) respondents had witnessed an injury. When asked how often the possibility of an electrical injury was considered by the surveyed electricians, 278 of 477 (58%) respondents indicated "every day."

The quality of incident data impacts everyone involved in managing the hazards associated with electrical forces including:

- educators and trainers
- writers of codes, standards, and regulations
- decision-makers establishing safety related goals and objectives for an organization
- manufacturers of electrical products
- designers, engineers, electricians, and others applying their skills everyday in the workplace.

Electrical safety leaders are strategically important in enhancing the collection, analysis, and distribution of incident experiences. With improvement in incident data, transparent communications about incident frequency, prevalence, and consequences are possible. Better data can also support vertical training, so that there is continuity in the information about electrical hazards held from the top of the enterprise to the bottom, or, in personnel terms, from the CEO to the contractor coming in to change the light bulbs. Incident data, to be meaningful, must be "fluid" in flow, that is, not barricaded or blocked in its sharing by infrastructure issues (e.g., lack of meetings, reports, simple access, communications patterns), hierarchy (e.g., only certain people get to know what happened), or intellectual property constraints. Finally, with better incident record-keeping, in an intimate or personally meaningful way, coworkers, colleagues, comparable locations, vendors, and consultants can "keep the memories alive" of success stories (i.e., what works in electrical safety) and the price for failure (e.g., funerals, amputations, disfigurement, lost careers, environmental destruction).

Electrical safety presents unique challenges. First, as a hazard, electricity is silent, odorless, and invisible, even though the equipment that conducts it may be huge and located in difficult environments (which by themselves may be potentially hazardous, as with explosive chemicals, moving machines, or construction activities). Second, electricity use is routinely viewed as a safe experience: every time a light is turned on or a computer mouse points a cursor on a video display, electrons flow and injury or damage rarely if ever occurs. In other words, there are numerous common experiences in each person's daily life where electricity is essential but not noticeable in the completion of work.

For electrical safety educators, the obligation is to raise awareness of electrical risk even though truly no risk may be perceived. After raising risk awareness, the challenge is to modify risk acceptability. This is more difficult when at the same time an employee personally, or an organization generally, may be friendly to the mentality or spirit that is captured by the notion of "once an employee can discern an electrical risk as unacceptable, he or she then can take the position of being in charge of their personal response to the hazard." Similarly, with greater knowledge, businesses can adapt their infrastructure and work management decisions. When hazards are identified and appreciated for their injury and damage possibilities, accountability to respond through engineering, administrative, and individual actions is more obvious.

Modifying how an individual understands the acceptability of a risk, such as testing a circuit with a screwdriver or wet finger, is a different safety approach than making a rule of how an individual must behave, such as requiring the use of electrical tester to check the possible energy flow of a circuit. The approaches are not mutually exclusive, however, public health practice has numerous examples of how difficult it is to legislate behavior. Ultimately, a safety professional must grapple with the reality that there is no way to control all the individual acts that comprise electrical work operations. Education is the only way to constructively and pro-actively focus and channel a corporation's safety goals. Learning, as demonstrated through changed individual and organization practices, is the education-based mechanism that can optimize safety performance in electrical work environments.

Financial benchmarks regarding the cost of electrical incidents are not readily available within the process industries. However, Wyzga and Lindroos have summarized the measured and estimated direct and indirect costs of the electrical injuries at a U.S. public utility employing union electricians from 1990–1992. In 1998, the reported cost experience per case was found to be US$15.75 million. For the utility's study period, the cases in the study accounted for 2% of the company's incidents but 52% of the costs. Lutton noted the economic impact of injuries associated with electrical events in his estimates of the average total direct costs of work-related injury. Based on a five year study of a U.S. public utility, he estimated that each reported case had an average direct cost US$49,823, with inestimable indirect expenses. These numbers are useful to help define the scope of potential savings if electrical incidents are reduced. More significantly, the numbers are useful to explaining that, while training, practice innovation, personal protection programs, and other safety interventions are expensive, there is also a cost to doing work unsafely around electricity. There are no "savings" if electrical operations are managed without implementation of new standards, technologies, education, and record keeping. Rather, the expenses are distributed through accounts less readily monitored by electrical safety leaders and safety professionals, including equipment repairs and maintenance, outages, process interruptions, medical and disability payments, and litigation for fatalities and property losses.

Conclusion

This article outlines significant changes and developments impacting further improvement in the prevention of electrical incidents and their consequences. The reality is that it will take time to synthesize and transfer these advancements in standards and technology into real and broad reduction in exposure and consequences of electrical hazards. Further progress is not possible without the strategic involvement of safety and electrical safety professionals, who are best positioned in the general techniques of hazard analysis and risk assessment to significantly impact and accelerate changes for improving electrical safety, serving as the "electrical safety conscience" to owners, managers, electrical experts, and the workers most at risk to electrical injuries. "Are we aware of current standards—What are they?" "Are we utilizing available technology — how do you know?" "How are we staying current in developments impacting electrical safety—Are we sure?" "Considering serious electrical accidents are relatively rare, how do we measure the quality of our electrical safety program?" are just a few examples of how to exercise that conscience.

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