Arc Flash

Designing and implementing an effective mitigation program

By H. Landis Floyd II

OVER THE PAST 15 YEARS, the evolution in regulations, codes and standards, as well as basic understanding of the arc hazard has elevated the importance and priority of managing and mitigating this hazard in the workplace. To achieve this, SH&E professionals must understand and apply appropriate regulations and standards, conduct hazard assessments, evaluate mitigation options, reduce risks, and design and implement controls to help ensure an effective and sustainable program. This article describes an approach that integrates the requirements for administrative controls and PPE found in NFPA 70E-2009, Standard for Electrical Safety in the Workplace, with the proven safety management concepts and hazard controls in ANSI/AIHA Z10-2005, Occupational Health and Safety Management Systems. This integration can help provide an effective, sustainable program to reduce or eliminate risk of injury from electric arc.

Abstract: *Increasing awareness that electric arc flash hazard is uniquely different from electric shock hazard is largely attributed to the evolution and publicity associated with NFPA 70E, Standard for Electrical Safety in the Workplace. NFPA 70E addresses administrative and PPE controls, but provides no guidance regarding engineering controls such as elimination and substitution. To design a comprehensive program to mitigate arc flash hazards, SH&E professionals must look beyond NFPA 70E and consider guidance found in safety management systems standards such as ANSI/AIHA Z10, Occupational Health and Safety Management Systems.*

Electric Arc Flash Hazards

Mitigating electric arc flash hazards presents a difficult challenge to most SH&E professionals. Electric arcs are a complex hazard, and the mitigation standards and technology continue to evolve. Recognized standards offer different solutions, particularly with respect to the application of PPE.

Some things are clear. OSHA regulations are specific with regard to employers' responsibility to assess the workplace for hazards and enable employees to recognize and avoid these hazards, and to implement controls to protect employees from these hazards. However, current language in OSHA regulations is not descriptive with regard to arc hazard assessment and mitigation/control.

In an arc flash event, the incident energy (thermal energy transferred to a person's body) is measured in calories/cm^2. Typical exposures in industrial and commercial power systems can range from 0 to well above 100 calories/cm^2. Bare skin can suffer a second-degree burn when exposed to thermal energy of 1.2 calories/cm^2 for 1 second duration (NFPA 70E-2009). Depending on total skin area burned and the underlying health of the injured, even second-degree burns can be fatal.

Flammable clothing typically can ignite or melt if exposed to thermal energy greater than 4.5 calories/cm^2. Clothing ignition or molten synthetic materials on the skin can cause even more serious

Arcing faults in electrical equipment can create hazard exposures. This photograph illustrates burn through in the left side cover and venting of hot gases around door edges and ventilation ports on the front of the switchgear. (Photo courtesy of DuPont)

injuries than the direct exposure to bare skin since the duration of the burning or melting is many times longer than the arc event itself.

The goal of arc flash hazard mitigation is to prevent exposures greater than these values, and to protect against injury in those situations where the hazard cannot be reduced to these levels. Currently, NFPA 70E provides the most comprehensive guidance for general industry to accomplish OSHA objectives relative to electrical hazards.

In support of the requirements in NFPA 70E, Institute of Electrical and Electronics Engineers (IEEE) Standard 1584, Guide for Performing Arc-Flash Hazard Calculations, provides the technical basis and methods for analyzing electric power systems and quantifying thermal hazards from electric arcs. However, direct use of the standard requires a high degree of knowledge in power systems engi-

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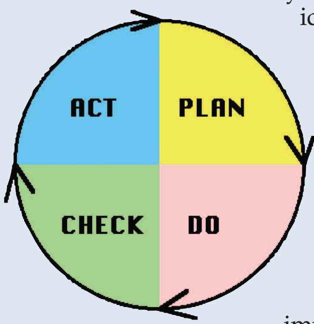
Figure 1

A Model for Continuous & Sustainable Quality Improvement



- **Plan:** Design or revise business process components to improve results, establish goals, identify resources, establish responsibilities and identify measures of success.
- **Do:** Implement the plan and measure its performance. This includes training, hazard assessments and work practices.
- **Check:** Assess the measurements and report the results to decision makers. This includes audits, skill and knowledge assessments, and incident investigations.
- **Act:** Decide on changes needed to improve the process. Review progress with management, reevaluate needs and gaps and reestablish management commitment.

Note. *Elements of the Deming quality improvement model. Adapted from ANSI/AIHA Z10-2005, Occupational Health and Safety Management Systems.*

neering. Although several arc hazard analysis software programs can make this task easier, using them does not eliminate the need for the user to be knowledgeable in power system design.

This article provides a road map for SH&E professionals to aid planning, design and implementation of a comprehensive and effective arc flash hazards mitigation program, from initial assessment to program audit. It addresses essential elements of planning and continuous improvement including:

- interim measures to help protect workers while designing a permanent program;
- relevant standards to consider when designing the program;
- critical role of arc hazard assessments;
- elements for sustainable performance;
- measuring and monitoring the program's overall quality and effectiveness.

An Opportunity for Collaboration

As with any workplace hazard, a mitigation program can range from minimum compliance to one based on continuous improvement, utilizing state-of-the-art technology and methods. While NFPA 70E provides several options, especially with regard to the application of PPE, the 2009 edition also establishes an avenue for a comprehensive and effective mitigation program. Prior to the 2009 edition, article 110.7 includes a fine print note, "Safety-related work practices are just one component of an overall electrical safety program." This acknowledges that a comprehensive electrical safety program should incorporate requirements from standards or sources other than NFPA 70E.

The 2009 edition provides direction on how to address the other components of an overall electrical safety program. A second fine print note was added, "ANSI/AIHA Z10-2005, American National Standard for Occupational Health and Safety Management Systems, provides a framework for establishing a comprehensive electrical safety program as a component of an employer's occupational safety and health program."

In the author's experience, electrical safety management in many organizations shares a common characteristic that tends to limit the program's effectiveness and sustainability. Program development and oversight are often delegated to electrical experts with little involvement from SH&E professionals. While electricians, technicians and electrical engineers may be experts in electrical technology and work practices, they tend not to be experts in risk management and safety management systems, which is the expertise of SH&E professionals.

Consider the collaboration and synergy possible when arc flash hazard mitigation program planning includes people expert in safety management systems, those expert in electrical technology and work practices, and management support to design and implement a program based on ongoing continuous improvement.

An excellent resource to help stimulate these discussions is available at no cost from NIOSH. In February 2007, hoping to accelerate reduction in injuries and deaths from electric arc flash incidents, NIOSH released an awareness tool, *Arc Flash Awareness.* Designed to facilitate discussion and action on incident and injury prevention, the program includes a 25-minute video and leader's guide.

NIOSH Arc Flash Awareness Video

This fact-based, noncommercial video program from NIOSH is available for download at no cost. The DVD and printed materials are available at a nominal cost to cover reproduction and shipping.

Content includes:

- discussion and demonstration of arc hazards found in the workplace;
- personal testimony from three survivors of severe arc flash injuries;
- the role of management and organizational resources in preventing incidents and injuries.

Watch the video at http://www.cdc.gov/niosh/docs/video/2007-116d.

The video discusses and demonstrates arc hazards found in the workplace; offers personal testimony from three survivors of severe arc flash injuries; and provides information on the role of management and organizational resources in preventing incidents and injuries. The leader's guide summarizes key points and includes questions for individual and group discussion, such as, "After viewing the video, which if any of your own work habits would you like to change?" and "What suggestions do you have for your company to help prevent arc flash incidents?"

Downloadable files for the video and printed materials are available at http://www.cdc.gov/niosh/mining/products/product152.htm. In support of the NIOSH initiative to reduce electric arc flash injuries, the Electrical Safety Foundation International (ESFI) distributes the same materials in a package including a DVD with printed leader's guide; this can be obtained for the nominal cost of duplication from ESFI at http://www.esfi.org.

Control Measures to Reduce Arc Hazard Risks

Following are hierarchy of control measures and application examples for arc flash hazards.

1) Elimination: System and facility designs that eliminate risk and exposure to arc hazards.

2) Substitution of less hazardous system or equipment: Current-limiting fuses and circuit breakers to limit magnitude of arc flash energy; high resistance grounding to limit frequency and magnitude of high energy arcs in 480 V power systems.

3) Engineering controls: IP20-compliant shrouding on terminal blocks and devices to minimize possibility of tool or metallic object initiating an arc flash event; remote switching to place personnel outside arc flash boundary.

4) Warnings: Labels as required by National Electrical Code article 110.116.

5) Administrative controls: Hazard assessments; preventive and predictive maintenance programs; and operating and maintenance procedures that reduce exposure and risk.

6) PPE: Clothing and equipment rated for arc flash exposures, selected to perform for predicted exposures.

Note. *Control measures adapted from ANSI/AIHA Z10-2005, Occupational Health and Safety Management Systems.*

ANSI/AIHA Z10-2005, Occupational Health & Safety Management Systems

Safety management systems standards provide the blueprint, or framework, to help enable effective, robust and sustainable programs for managing occupational safety and health risks. The first industry consensus standard addressing these needs appeared in 1995, with the revision of ISO 14001, Environmental Management Systems. In 1999, a collaboration of international safety organizations led to OHSAS 18001, Occupational Safety and Health Management Standard. A similar standard, ILO Guidelines for Occupational Safety and Health Management Systems, was published by International Labor Organization in 2001.

More recently, ANSI/AIHA Z10, Occupational Health and Safety Management Systems, and CSA Z1000, Occupational Safety and Health Management, were published in 2005 and 2006, respectively. These standards are well harmonized and are based on quality management principles attributed to W. Edwards Deming. The Deming plan-do-check-act quality improvement model (Figure 1) is central to these safety management standards.

These standards are also well harmonized on the comprehensive hazard control measures (sidebar, above). Further, they are harmonized in how these equally important measures are ranked in descending order of relative effectiveness in helping ensure worker safety. Some companies have developed their own proprietary safety management standards that align with or surpass industry standards. They may have been developed before the first industry consensus standards emerged.

Although this article specifically refers to ANSI/AIHA Z10, the concepts relate to other widely recognized international standards or proprietary safety management systems. Some safety management standards have rigorous third-party certification processes. ANSI/AIHA Z10 was developed specifically to provide a management framework, without the rigor of certification.

If a company or organization does not have an established safety management system as a framework to effectively manage the multitude of hazards and risks in its operations, ANSI/AIHA Z10 can be used to help plan and implement an effective electrical safety program, which includes arc flash hazards mitigation.

The continuous improvement management model and the comprehensive application of hazard controls are not included in NFPA 70E. Recognizing this and understanding how to integrate the requirements of NFPA 70E within the framework of safety management systems can help an organization maximize the return on its investment in improving its electrical safety program.

Other Relevant Standards

The "Regulations" sidebar (p. 36) lists some prominent U.S. regulations, codes and standards relevant to developing and implementing an arc flash hazard mitigation program. The OSHA regulations establish performance requirements, but generally contain little detail or specifics on how to achieve performance. The industry consensus standards from NFPA and IEEE provide guidance on how to fulfill workplace safety performance requirements.

To support the technology evolution in PPE, American Society for Testing and Materials has published test standards to quantify how well clothing materials and accessories perform when exposed to arc flash and flame. These standards have enabled flame-resistant clothing manufacturers to rate their products for arc flash applications. These standards are intended to be used by employers to design a safety program tailored to the unique work environment that may vary significantly depending on industry segment, workforce capabilities, facility age and similar variables.

NFPA 70E-2009, Standard for Electrical Safety in the Workplace

Widely considered one of the most prominent standards regarding workplace electrical safety in the U.S., NFPA 70E focuses on warnings, adminstrative controls and PPE, and does not effectively address elimination, substitution or engineering controls. As noted, previous editions of NFPA 70E have acknowledged this limitation and the 2009 edition even provides a reference to ANSI/AIHA Z10.

The lack of attention on preventive measures is not unique to electrical safety, as evidenced by NIOSH's Prevention Through Design (PTD) initiative launched in 2007. One PTD strategy focuses on influencing regulations and consensus standards to develop additional emphasis and guidance on preventive measures to complement existing protective measures. The addition of the reference to ANSI/AIHA Z10 in the 2009 edition of NFPA 70E reflects this strategy.

Hazard Control Measures in ANSI/AIHA Z10

The SH&E professional need not be an expert in the electrical technology aspects of these controls. The SH&E professional serves as the conscience of the organization. In this role, s/he must ask the right questions to stimulate understanding and involvement of electrical experts in addressing each measure. The following discussion provides several examples. This is not a complete list of how each control measure could be actualized, and they may vary by industry, age of facility and other considerations.

Hazard Elimination

With a high degree of certainty, one of the most effective ways to protect people from an arc flash exposure is to completely eliminate the arc hazard. This is easier to accomplish when looking at designs of new facilities than for existing electrical installations. In either case, an organization that asks, "Do we have any exposures that are unnecessary and could be eliminated?" may indeed find some opportunities.

An example is the discovery that a long-established employee break area, located in an electrical control room, was within the calculated arc flash boundary. While the individuals in the break area may not have interacted directly with the electrical equipment, the routine congregation of people within the arc flash boundary created an unnecessary risk. It was eliminated by relocating the break area.

Substitution of Less-Hazardous Equipment or Materials

With increased understanding of the need to reduce worker exposures to arc hazards, equipment manufacturers and system designers are bringing innovative solutions to market to help employers protect their workers. The design of new installations and modifications to existing systems should be analyzed for arc flash hazards; potential exposures and their severity should be identified; and options to reduce severity or frequency of exposures should be considered.

Design choices that tend to reduce the severity and/or frequency of exposure to arc hazards include high resistance grounding for industrial power systems; arc-resistant switchgear that directs thermal energy from an arc away from personnel interacting with the gear;

Regulations, Codes & Standards

U.S. regulations, codes and standards relevant to developing an arc flash hazards mitigation program:

U.S. Regulations

- OSHA General Duty Clause
- OSHA 1910.132, Personal Protective Equipment for General Industry
- OSHA 1910.269, Electric Power Generation, Transmission and Distribution
- OSHA 1910.335, Safeguards for Personnel Protection

Industry Consensus Standards

- NFPA 70E, Standard for Electrical Safety in the Workplace
- IEEE/ANSI C2, National Electrical Safety Code
- IEEE 902, Guide for Maintenance, Operation and Safety of Industrial and Commercial Power Systems
- IEEE 1584, Guide for Performing Arc Flash Hazard Calculations

Personal Protective Clothing & Equipment Materials Performance Standards

- ASTM F1506, Standard Performance Specification for Flame-Resistant Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards
- ASTM F1891, Standard Specification for Arc and Flame-Resistant Rainwear
- ASTM F1958, Standard Test Method for Determining the Ignitability of Non-Flame-Resistance Materials for Clothing by Electric Arc Exposure Method Using Mannequins
- ASTM F1959, Standard Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing
- ASTM F2178, Determining the Arc Rating of Face Protective Products

current-limiting protective devices that reduce the exposure by shortening the arc duration; and "smart" switchgear and motor control centers that can reduce exposures by changing how people interact with the equipment during troubleshooting and other maintenance tasks.

Engineering Controls to Reduce Exposure or Severity

Engineering controls that affect arc flash exposure span a wide range of considerations. Engineering analysis to identify and quantify potential arc hazard exposures is a critical engineering control measure in arc hazard mitigation. Remote switching and remote racking of power circuit breakers are examples of equipment options that allow personnel to work outside of the arc flash zone.

Warnings, Signs & Other Communications

Labels and signage help to ensure that personnel understand their proximity to potential hazards. Signs and labels may be temporary or permanent in nature depending on the work activity or duration of the potential hazard. The warning could be a sign on switchgear or a boundary marked on the plant floor. It could be a temporary barricade during certain work activity.

Because signage and labeling practices may not be consistent industry wide, contractors working in multiple facilities need to be aware of each facility's standards. One important consideration is consistency and uniformity, at least within the site operations, to help ensure common understanding among those potentially at risk. The 2009 edition of NFPA 70E expanded the requirements for permanent and temporary labeling. Temporary labeling is especially important for establishing the boundary of safe work zones.

Administrative Controls

Examples of administrative controls include training, qualification requirements, job procedures, work practices, planning tools, lockout practices and auditing systems. These administrative controls are well addressed in NFPA 70E. However, some circumstances may call for additional procedures not described specifically in the standard.

Critical to arc flash mitigation is the attention given to maintenance and reliability improvement programs for electrical equipment. Workers responsible for operating and maintaining the electric power system must be familiar with the effects of their work on the arc flash incident energy.

For example, if a process upset occurs and workers change out a fuse to a larger size (no fuse of the existing size was available quickly), then they need to understand that the equipment's arc flash energy has been changed and may be higher. Protective devices including protective relays, circuit breakers and switchgear must be maintained, inspected and tested to help ensure designed functionality when operating during an arc fault. Given that some of the highest frequency and severity of exposures to arc hazards involve interaction with 600 V class motor control centers, programs to increase mean time between failures of motors serve to reduce maintenance and operations personnel interaction with motor control centers.

An arc hazard analysis helps ensure that protective clothing is appropriately rated for the potential exposure. This two-layer system of flame-resistant garments was underrated for the actual incident energy from an arc flash incident. In this case, the thermal energy to the lower body exceeded the performance rating of the outer coverall on the right and exposed the inner garment on the left to thermal energy sufficient to cause disabling second- and third-degree burns to the lower body. (Photo courtesy of DuPont)

Consider these tasks that occur every time a motor fails mechanically or electrically. The motor starter disconnect switch is operated at least twice: to disconnect and eventually to reenergize; voltage testing is performed to verify electrical isolation; motor leads are disconnected, then reconnected; and fuses may be removed and reinstalled. Each interaction presents some risk for an arc flash incident. Electrical equipment and systems reliability improvement is an important component of arc flash hazards mitigation.

Essential to long-term goals to reduce and eliminate arc flash hazards is attention to the design of new facilities and systems. Capital project planning should include requirements to assess options in early design stages, with the goal to eliminate or reduce exposures and risk. Guidance for this was added to the 2009 edition of NFPA 70E in Annex O, Safety-Related Design Requirements.

PPE

The first five noted hazard control measures ("Control Measures" sidebar, p. 35) help prevent exposure to an arc flash hazard. The last control, application of PPE, serves to minimize injury to the worker if the other control measures have failed to prevent an incident. An arc flash event can involve a huge release of energy in a short period. PPE may not prevent all serious injuries.

Use of protective gear, including flame-resistant clothing, face shields and other accessories, is a critical control measure of any arc flash hazards mitigation program. However, it should not be the only control measure. For the PPE to perform effectively, its arc thermal performance rating (ATPV) must meet or exceed the thermal energy transfer that occurs during the arc flash incident. The best way to predict this transfer (or incident energy) is to have performed an arc flash hazard analysis. PPE clothing and accessories can then be selected based on performance rating [e.g., Hazard Risk Category (HRC) 1-4 from NFPA 70E] and matched to the predicted energy exposure.

Protective garments should be purchased from a

Arcing faults can eject parts and shrapnel from electrical equipment. In this case, shrapnel hit the worker's hardhat. The shrapnel punctured the hardhat, but the hat protected the person from injury. (Photo courtesy of DuPont)

reputable manufacturer and be labeled with the ATPV or HRC that meets or exceeds the potential incident energy exposure. The selection of fabric technology may depend on frequency of use, environmental conditions, worker feedback from wear trials, garment durability, and evaluation of total costs that considers initial purchase, garment life expectancy, and laundry and maintenance.

Personnel at risk should be educated on when, where and how to properly use PPE garments and accessories. PPE garments and accessories should be cleaned, inspected and maintained in accordance with manufacturer's recommendations in order to preserve the designed protection performance.

Arc Hazard Analysis: Critical to All Controls

A common question when developing an arc flash hazard protection program is, "Can you provide a simple chart to show what PPE to wear in various work tasks?" One option found in Article 130 of NFPA 70E is based on tables that provide lists of common tasks with appropriate arc flash protective equipment noted for each task. These tables can be useful, but they also can be misapplied. The explanatory footnotes accompanying the tables may be overlooked. These notes explain that the electrical system must have certain specifications for the tables to be applicable. The user must be sure that the electrical system in question meets these requirements, and an electrical system study may be required to ensure that this is the case.

The underlying limitation in using these tables is that it is in lieu of performing a detailed arc flash hazard analysis, which is the critical element in effectively addressing the comprehensive hazard control measures. The table-based approach in NFPA 70E can help the user set up a PPE plan that gives a measure of worker protection.

But the table approach does not open up opportunities to identify, reduce and possibly eliminate hazard exposure and risk. In addition, the table-based approach carries some risk that the assumptions on which the tables are based can result in over or under thermal protection performance of the PPE. While overprotection can expose workers to unnecessary heat stress, underprotection can result in injuries more serious than reasonably possible to prevent.

To reduce or eliminate the hazard, a more detailed study and assessment of the electrical system and worker tasks is required. A detailed arc hazard assessment helps identify where exposure potential exists; eliminate hazards completely through engineering design or administrative controls; reduce the frequency of potential arc flash events; reduce the magnitude of energy release; and better ensure that PPE is appropriately rated for exposures.

An arc flash hazard analysis is a complex engineering exercise. It generally requires engineering resources competent in power system design and analysis. The results of an arc hazard assessment help enable informed and factual decisions when designing and implementing a full range of control measures.

Measuring Success

How will one measure the success of the efforts to plan, design and implement an effective arc flash hazards mitigation program? One way is to critique the quality of applying the essential elements of safety management systems described in ANSI/AIHA Z10. These considerations can help the SH&E professional assess the program:

1) How solid is management commitment to the program? Is this commitment visible to those at risk of injury? Are sufficient resources provided to design and implement the program?

2) Did the program design and development involve a collaborative effort of people with expertise in safety management and electrical technology? How effective was this collaboration?

3) How well were all six hazard control measures from ANSI/AIHA Z10 addressed?

4) Did program implementation establish hazard knowledge and awareness at all levels in the organization? How does the program maintain this level of awareness?

5) Are there plans to periodically review with management the status and various assessments noted?

Conclusion

An effective arc flash hazard mitigation and protection program encompasses more than buying flame-resistant garments and making them available for employees. An effective program requires management commitment to design and implement a comprehensive set of proven controls, consistent with occupational safety and health management systems standards such as ANSI/AIHA Z10. An effective program should include:

- management commitment and support to establish goals, set priorities, allocate resources, establish accountability and reward success;
- project engineering practices that include analysis for opportunities to eliminate or reduce arc flash exposure through wise evaluation of engineering operations in equipment and systems design;
- maintenance programs to help ensure that electrical equipment is maintained in proper condition to help ensure that the safety features and functionality critical to prevention and/or mitigation of arc flash hazards maintains or exceeds design intent;
- warnings, labels, signs and other means to help ensure that personnel are informed of identified hazards;
- administrative/management controls to help ensure that personnel are trained and qualified for their roles and responsibilities; that proper tools and resources are available to perform work safely; and

that all elements of the program are audited periodically to monitor and control drift from designed expectations;

•adminstrative controls to ensure that selected flame-resistant personal protective garments and accessories are engineered and manufactured to recognized industry standards; that PPE selection is based on engineering analysis to determine predicted thermal incident energy, to help ensure that PPE rated performance meets or exceeds the exposure potential; and that personnel at risk know when, where, what and how to wear PPE appropriate for the task and exposure. ■

Protective clothing rated for thermal protection from arc flash hazards ranges from shirt and pants uniforms (as shown) to switching suits and head protection for higher thermal energy exposures. (Photo courtesy of DuPont)

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Two Case Histories: Two Outcomes

Comparison of two case histories helps illustrate the benefits of assessing an arc flash hazard mitigation program.

Case 1

The first incident involved six injuries, including two bystanders and four electricians who were wearing arc-resistant protective clothing rated for the task, but underrated for the amount of energy available at the work location. The task involved racking 480 V draw out circuit breakers on and off the substation bus. Full-body protection rated at 20 calories/cm^2 was being worn.

An unsecured metal plate used to cover an opening in the circuit breaker compartment door fell, contacted the exposed bus and created an arcing fault. Six people were transported to the hospital, including the four electricians and two supervisors who were observing the work activity from a distance. Burn injuries to two electricians prevented them from returning to work.

The investigation identified an unusual condition that had not been taken into consideration in the hazard analysis: a tie breaker was closed, which caused the available fault energy level to be greater than normal. In this case, it was estimated to be greater than 60 calories/cm^2.

Case 2

The second incident involved similar work activity, a similar arc flash and thermal energy, but significantly different injury outcome. In this case, the injury was limited to a first-aid case second-degree burn approximately ¼-in. in diameter on the tip of the electrician's nose.

This incident occurred 4 years after the first. In the interim, IEEE 1584, Guide for Performing Arc Flash Hazard Calculations, was published. This standard had been used to analyze arc hazard exposures in the workplace in which the second incident occurred. Based on the arc flash hazard study, the plant had performed detailed analysis of the electric power system, identified unusual conditions, implemented design changes to reduce energy levels, installed warning labels, modified work practices to limit the number of personnel within the arc flash boundary, provided training for supervisors and workers, and selected PPE based on the hazard analysis study.

The analysis had predicted the incident energy to be 50 calories/cm^2 and the selected protective clothing was rated for 100 calories/cm^2. The minor burn to the tip of the electrician's nose was due to the head protective hood and face shield being pressed against his nose due to the blast forces of the arc. The hood suspension connection to the electrician's hardhat was broken, allowing excessive movement of the hood and face shield.