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# A Guide for Designing and Implementing Arc Flash Mitigation

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## Abstract

Increasing awareness that the electric arc flash hazard is uniquely different from the long recognized electric shock hazard is largely attributed to the evolution and publicity associated with NFPA70E, *Standard for Electrical Safety in the Workplace*. NFPA70E addresses administrative and personal protective equipment hazard control measures, but does not provide guidance in engineering control measures of elimination and substitution. In order to design a comprehensive arc flash hazards mitigation program, the safety professional must look beyond NFPA70E and consider guidance in safety management systems standards such as ANSI Z10, *Occupational Health and Safety Management Systems*.

This paper provides a roadmap for safety 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
- The critical role of arc hazard assessments
- Elements for sustainable performance
- Measuring and monitoring quality and effectiveness.

## Introduction

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. This paper is intended to help safety professionals in managing this hazard through understanding and application of appropriate regulations and standards, implementing hazard assessments, evaluating mitigation options, reducing risks, and designing and implementing control measures to help assure an effective and sustainable program. It describes an approach that integrates the requirements for administrative controls and personal protective equipment in NFPA70E-2009 *Standard for Electrical Safety in the Workplace* with the proven safety management concepts and hazard control measures in ANSI Z10-2005, *Safety and Occupational Safety Management Systems*. This integration can help provide an effective and sustainable program to reduce or eliminate risk of injury from electric arcs.

The mitigation of electric arc flash hazards presents a difficult challenge for most safety professionals. The electric arc phenomenon is a complex hazard, and the mitigation standards and technology continue to evolve. Recognized standards offer different solutions, in particular with respect to the application of personal protective equipment. Some things are clear. OSHA regulations are very specific with regards to employers' responsibility to assess the workplace for hazards and enable employees to recognize and avoid these hazards, and implement mitigation and control measures to protect employees from these hazards. With regards to arc flash hazards, current language in OSHA regulations is not descriptive in arc hazard assessment and mitigation/control methods.

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 over 100 calories/cm$^2$. Bare skin can suffer a 2$^{nd}$ degree burn when exposed to thermal energy of 1.2 calories/cm$^2$ for one second duration. Depending on total skin area burned and the underlying health of the injured, even 2$^{nd}$ 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 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, NFPA70E, *Standard for Electrical Safety in the Workplace* provides the most comprehensive guidance for general industry to accomplish OSHA objectives relative to electrical hazards. In support of the requirements in NFPA70E, 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. Direct use of the standard requires a high degree of knowledge in power systems engineering. There are several commercially available arc hazard analysis software programs that make this task easier, but do not eliminate the need for the user to be knowledgeable in power system design.

## An Opportunity for Collaboration

As with any hazard in the workplace, a mitigation program can range from minimum compliance to one based on continuous improvement, utilizing state of the art technology and methods. While NFPA70E provides several options, especially with regards to the application of personal protective equipment, the 2009 edition also establishes an avenue for a comprehensive and effective mitigation program. Prior to the 2009 edition, article 110.7 included a fine print note stating, "Safety related work practices are just one component of an overall electrical safety program." This was an acknowledgement that a comprehensive electrical safety program should incorporate requirements from other standards or sources, in addition to the requirements in NFPA70E. 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 Safety and Health Management Systems, provides a framework for establishing a comprehensive electrical safety program as a component of an employer's occupational safety and health program."

It has been the author's experience that electrical safety management for many organizations shares a common characteristic that tends to limit the programs effectiveness and sustainability. The development and oversight of the electrical safety program is often delegated to electrical experts with little involvement from safety professionals. While the electricians, technicians and electrical engineers may be expert in electrical technology and work practices, they tend not to be expert in risk management and safety management systems, which is the expertise of safety professionals. This paper provides safety professionals an approach based on collaboration and synergy possible when the arc flash hazard mitigation program planning includes people expert in safety management systems, people expert in electrical technology and work practices, and management support to design and implement a mitigation program based on ongoing continuous improvement.

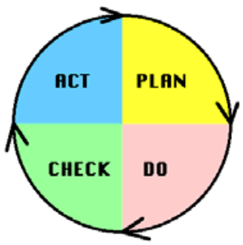
An excellent resource to help stimulate these discussions is available at no cost from the US National Institute for Occupational Safety and Health. In February 2007, with the intent to accelerate reduction in injuries and deaths from electric arc flash incidents, NIOSH released an educational and awareness tool, *Arc Flash Awareness*, designed to facilitate discussion and action on incident and injury prevention. The package includes a 25 minute video and leaders guide. The video 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

The leaders guide includes a summary of key points conveyed in the video and 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 from the NIOSH website at 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 is distributing the same materials, in a package including a DVD with printed leaders guide. This can be obtained for the nominal cost of duplication from ESFI at www.esfi.org.

## ANSI Z10 – 2005 Occupational Health and 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 published OHSAS 18001, *Occupational Safety and Health Management Standard*. A similar standard, *ILO Guidelines for Occupational Safety and Health Management Systems* was published by the International Labour Organization in 2001. More recently, ANSI Z10 *Occupational Safety and Health Management Systems*, and CSA Z1000, *Occupational Safety and Health Management* were first 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 as shown in Figure 1 is central to these safety management standards. These standards are also well harmonized on the comprehensive hazard control measures shown in Table 1. Further, they are harmonized in how these equally important measures are ranked in descending order of relative effectiveness in helping assure worker safety. Some companies have developed their own proprietary safety management standards that align with or go beyond industry standards. They may have been developed before the first industry consensus standards emerged.




**A model for continuous and sustainable quality improvement**

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

**Figure 1. Elements of the Deming Quality Improvement Model.**

Although this paper is making specific reference to ANSI Z10, the concepts relate to other widely recognized international standards, or proprietary safety management systems. Some of the safety management standards have rigorous third party certification process. ANSI 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 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 control measures are not included in NFPA70E. Recognizing this and understanding how to integrate the requirements of NFPA70E within the framework of safety management systems can help an organization maximize the return on its investment in improving its electrical safety program.

**Table 1. Control Measures to Reduce Arc Hazard Risks.**

| Hierarchy of Control Measures (from ANSI Z10-2005) | 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 480V 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; operating and maintenance procedures that reduce exposure and risk. |
| 6. Personal Protective Equipment | Clothing and equipment rated for arc flash exposures, selected to perform for predicted exposures |

## Other Relevant Standards

Table 2 lists some of the more prominent US regulations, codes and standards relevant to developing and implementing an arc flash hazards 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 the National Fire Protection Association (NFPA) and the Institute of Electrical and Electronics Engineers (IEEE) provide guidance on how to fulfill the workplace safety performance requirements. To support the technology evolution on personal protective clothing and equipment, the American Society for Testing and Materials (ASTM) has published test standards to quantify how well clothing materials and accessories perform when exposed to arc flash and flame. These ASTM standards have enabled flame resistant clothing manufactures 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, in capabilities of the workforce and age of facilities, among other variables.

## NFPA70E-2009 Standard for Electrical Safety in the Workplace

Widely considered one of the most prominent standards regarding workplace electrical safety in the US, NFPA70E *Standard for Electrical Safety in the Workplace,* currently focuses on control measures 4, 5, & 6 in Table 1, and does not effectively address the first three. As noted earlier, previous editions of NFPA70E have acknowledged this limitation with a Fine Print Note in Section 110.7. The 2009 edition added a second Fine Print Note, providing a reference to ANSI Z10.

The first three hazard control measures in Table 1 are not directly addressed in NFPA70E. The lack of attention on preventive measures is not unique to electrical safety, as evidenced by the National Institute for Occupational Safety and Health (NIOSH) Prevention *through Design* (PtD) initiative launched in 2007. One of the PtD strategies focuses on influencing regulations and consensus standards to develop additional emphasis and guidance on prevention measures to complement existing protective measures. The addition of the reference to ANSI Z10 in the 2009 edition of NFPA70E reflects this strategy.

**Table 2. US regulations, codes and standards relevant to developing an arc flash hazards mitigation program.**

| |
|---|
| **US 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** |
| NFPA70E 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 and Equipment Materials Performance Standards** |
| ASTM F-1506 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 F-1891 Standard Specification for Arc and Flame Resistant Rainwear |
| ASTM F-1958 Standard Test Method for Determining the Ignitability of Non-flame-Resistance Materials for Clothing by Electric Arc Exposure Method Using Mannequins |
| ASTM F-1959 Standard Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing |
| ASTM F-2178 Determining the Arc Rating of Face Protective Products |

## Hazard Control Measures in ANSI Z10

The safety professional does not need to be expert in the electrical technology aspects of these control measures. A critical role of the safety professional is serving as the conscience of the organization and asking the right questions to stimulate understanding and involvement of electrical experts in addressing each of these measures. The discussion below provides some 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.

## Elimination of the Hazard

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 when looking at designs of new facilities then for existing electrical installations. In either case, an organization that asks the question, “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 to a different location.

## 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 reduce arc flash exposures to their workers. The design of new installations and modifications to existing electrical systems should be analyzed for arc flash hazards, potential exposures and their severity identified, and options to reduce severity or frequency of exposures 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 direct thermal energy from an arc away from personnel interacting with the gear, 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 impacting arc flash exposure span a wide range of consideration. Engineering analysis to identify and quantify potential arc hazard exposures is one very important 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 and Other Communications

Labels and signage help to assure 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 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 assure common understanding by the people 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 NFPA70E, however some circumstances may call for additional procedures not described specifically in the standard.

Very critical to arc flash mitigation is the attention given to maintenance and reliability improvement programs for electrical equipment. It is important that workers responsible for operating and maintaining the electric power system be familiar with the effects of their work on the arc flash incident energy. For example, if there is a process upset, and they change out a fuse to a larger size (no fuse of the existing size was available quickly), then they need to understand that the arc flash energy of the equipment has been changed and may be higher. Protective devices including protective relays, circuit breakers, and switchgear must be maintained, inspected, and tested to help assure 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 volt 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. 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 re-energize, voltage testing is performed to verify electrical isolation, motor leads are disconnected and then reconnected, and fuses may be removed and reinstalled. Each one of these interactions has some risk for an arc flash incident. Electrical equipment and systems reliability improvement is an important component of an arc flash hazards mitigation program.

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 NFPA70E in Annex O, *Safety Related Design Requirements.*

## Personal Protective Equipment

The first five hazard control measures in Table 1 serve to help prevent exposure to an arc flash hazard. The last control measure, the application of personal protective equipment, 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 very short period of time. PPE may not prevent all serious injuries. The use of personal protective equipment, including flame resistant clothing, face shields, and other accessories, is a critical control measure of any arc flash hazards mitigation program. It should not be the only control measure. In order for the PPE to perform effectively, its arc thermal performance rating (ATPV) must meet or exceed the thermal energy transfer during the arc flash incident. The best way to predict the thermal energy transfer, or incident energy, is to have performed an arc flash hazard analysis. PPE clothing and accessories can then be selected on performance rating (i.e. Hazard Risk Category 1-4 from NFPA70E), and matched to the predicted energy exposure.

In selecting protective garments, it is important that they are from a reputable manufacturer and are labeled with the Arc Thermal Performance Rating (ATPV) or Hazard Risk Category (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 manufacture's recommendations in order to preserve the designed protection performance.

## Arc Hazard Analysis is Critical to All Control Measures

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 of the options provided in NFPA70E, in Article 130, 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 can also 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 their electrical system meets these requirements, and an electrical system study may be required to ensure these requirements in the notes are met.

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 necessary for effectively addressing the comprehensive hazard control measures in Table 1. The table-based approach in NFPA70E can help the user set up a PPE plan that gives a measure of protection to workers. But the table approach does not open up opportunities to identify, reduce and possibly eliminate hazard exposure and risk. To reduce or eliminate the hazard, a more detailed study and assessment of the electrical system and worker tasks is required.

A table-based approach can help the user set up a PPE plan that gives an improved measure of safety. It can also enable employers to provide protection to workers pending the completion of an arc hazard assessment. But the table approach does not open up opportunities to identify, reduce and possibly eliminate hazard exposure and risk. There is some risk that the assumptions on which the tables are based can result in over or under thermal protection performance of the PPE. While over protection can result in the potential of unnecessary heat stress to the worker, under protection 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. An approach that is based on a detailed arc hazard assessment is one that can help enable the opportunity to 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 assure personal protective equipment 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 you 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 Z10. Here are some considerations that can help the safety professional assess the program.

1. How solid is management commitment to the program? Is this commitment visible to the people at risk of injury and to the resources needed to design and implement the program?
2. Did the program design and development involve a collaboration of people with expertise in safety management and electrical technology? How do you feel about the effectiveness of this collaboration?
3. How well were all six hazard control measures from ANSI Z10 addressed?
4. Did the 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 above?

## Conclusion

An effective arc flash hazards mitigation and protection program is more than buying flame resistant garments and making them available for personnel to wear. An effective program involves management commitment to design and implement a comprehensive set of proven control measures, consistent with occupational safety and health management systems standards, such as ANSI Z10. An effective program should include, but is not limited to:

- 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 that help assure electrical equipment is kept in proper condition to help assure 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 assure personnel are informed of identified hazards
- Administrative/management controls to help assure 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
- Flame resistant personal protective garments and accessories that are engineered and manufactured to recognized industry standards; the PPE is selected based on engineering analysis to determine predicted thermal incident energy, to help assure PPE rated performance meets or exceeds the exposure potential; and personnel at risk know when, where, what and how to wear PPE appropriate for the task and exposure
- Management commitment and support to establish goals, set priorities, allocate resources, establish accountability, and reward success

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