



Failure to Wear Proper Personal Protective Equipment Results in Arc Flash Injury

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On April 14, 2006, at the Brookhaven National Laboratory (BNL), an electrical engineer was injured by an arc flash while closing a fused-disconnect switch in an electrical panel at the Relativistic Heavy Ion Collider (RHIC). The electrical engineer was not wearing appropriate clothing or the PPE required for this operation and received first- and second-degree burns to his face and body. The arc flash resulted from an overvoltage condition caused by a ground fault. (ORPS Report SC--BHSO-BNL-AGS-2006-0002)

On the day of the event, BNL experienced a reduction in electrical power when the regional electrical utility suffered a power dip. This power upset caused problems within the RHIC electrical systems that required troubleshooting. The electrical engineer was called in to help two electronic technicians troubleshoot a high-current ripple problem. Once the problem had been solved, they began restoring electrical power. The electrical engineer was closing four fused-disconnect switches on 480-volt panel PB-1 (Figure 1-1) while the electronic technicians were preparing a 13.8-kV circuit breaker for closure in a nearby panel. The electrical engineer closed switches 4A and 5A at the top of the panel and then closed switch 2A at the bottom of the panel. When he closed switch 3A, he heard a very loud noise and saw sparks and smoke coming from within the panel.

The arc flash created radiant heat energy and molten aluminum, most of which was contained within the panel or vented away from the electrical engineer. However, what was expelled from the front of the panel set his hair on fire and caused first-degree



Figure 1-1. Electrical panel PB-1 with switch 3A in the center with signs of arc flash (soot)

blown out, and adjacent wiring insulation was melted from the heat of the arc flash. The vent panels on the ends of the switches were seared and completely blown off, and the front covers were deformed (Figure 1-2).

A Type B Accident Investigation Board was established to investigate the cause of this accident. The Board believes the arc flash was caused by an overvoltage condition tied to a ground fault on an underground cable, which resulted in the initial arc between the grounded steel frame and phase B bus on the back of switch

burns on his face, scalp, and chest. He also received first- and second-degree burns on his hands and forearms and a corneal abrasion to his left eye because he was not wearing safety glasses. The electrical engineer's non-flame-resistant shirt and undershirt were slightly burned.

The two 400-amp switches (2A and 3A) were coated on the inside with a layer of black soot. The left end of both switches was partially



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Figure 1-2. Bowed cover on switch 3A

3A. This arc then caused phase-to-phase arcing within switch 3A and the failure of switch 2A. The Board concluded that the accident resulted from a number of deficiencies in the implementation of management systems and processes. The following are examples of these deficiencies.

- BNL failed to ensure that ground-fault monitoring detection was operable. This is important because the installed power supply is an ungrounded delta, which can be vulnerable to transients and overvoltages. Ground-fault relays were not included in a preventive maintenance program.
- BNL failed to implement National Fire Protection Association (NFPA) 70, *National Electrical Code* (NEC) 2005 for ground fault protection, which requires detectors for some specific applications of ungrounded electrical systems.

- BNL failed to implement formal work controls for working on ungrounded delta systems that could have a ground fault.
- BNL failed to implement NFPA 70E, *Standard for Electrical Safety in the Workplace*. Arc flash calculations for the building where the incident occurred were not completed. Had they been completed, PPE requirements based on arc flash calculations would have been posted on the electrical panel.
- BNL failed to ensure adequate implementation of the Collider-Accelerator Department Conduct of Operations Program. Pre-job briefings were not held; personnel did not stop work when they observed the electrical engineer not wearing proper PPE; and surveillances of ground-fault conditions were not formalized through approved procedures.

The details of the Board's investigation and Judgments of Need can be found in the Type B Accident Investigation Report, *Arc Flash at Brookhaven National Laboratory*, which is available at <http://www.eh.doe.gov/csa/reports/accidents/index.html>.

An important issue in this accident was the failure to wear appropriate PPE when approaching and operating the switches on the electrical panel. The danger of exposure to energized circuits when not wearing required PPE was underscored in a recent industry event at a Midwestern commercial nuclear power plant.

On August 26, 2006, an experienced electrician suffered serious flash burns to his hands, arms, face, and torso from a 480-volt arc flash. The arc flash occurred when the electrician decided to test a high-voltage detection device (hot stick) in a spare circuit breaker cubicle (Figure 1-3). His action caused a phase-to-phase short circuit and electrical arc. The electrician was sent to a regional burn center because of his injuries. He did not don the required PPE for accessing the circuit breaker cubicle



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Figure 1-3. The damaged spare 480-volt circuit breaker cubicle and hot stick on scorched floor

(i.e., NOMEX[®] suit, gloves, and face shield). His impromptu decision to test the hot stick was outside the scope of work and was not authorized. (NRC Event Number 42805)

Arc flash events have also occurred at other DOE facilities. The following occurred while personnel were knowingly working on energized equipment.

On December 10, 2005, at the Pantex Plant, an electrical

arc flash occurred while an electrician was installing a 12.47-kV fuse in an automatic transfer switch. Investigators believe the arc flash occurred because the fuse holder was misaligned, operated too slowly, or operated with insufficient force. The electrician was not injured because he was wearing a 40-calorie protective suit and using a 6-foot-long hot stick.

Although appropriate PPE was specified, the need to perform the work with the equipment energized was not questioned. A fundamental principle of NFPA 70E is that work on or near energized components must be justified based on safety or system capability and not on operational convenience.

As a corrective action, an Energized Work Permit was implemented that requires a description of need and justification whenever equipment cannot be de-energized. (ORPS Report NA-PS-BWXP-PANTEX-2005-0137)

On December 6, 2005, at the Fernald Environmental Management Project, an electrician received minor burns to the face when an arc flash occurred inside a 480-volt disconnect panel during voltage testing. A faulty multimeter caused a phase-to-phase short circuit. The electricians who were involved in this incident were not wearing flame-retardant clothing, Voltage-rated gloves, face and head protection, or hearing protection specified by NFPA for performing voltage checks. Investigators determined that Fluor Fernald failed to identify current electrical safety program requirements based on NFPA 70E and failed to integrate those requirements into work authorization documents. (ORPS Report EM-OH-FCP-FFI-FEMP-2005-0043)

On October 11, 2004, at the Stanford Linear Accelerator Center, a subcontractor journeyman electrician received serious burns from an electrical arc flash while installing a circuit breaker in an energized 480-volt electrical panel. The electrician's clothing caught fire resulting in burn injuries that required hospitalization. A DOE Type A Accident Investigation Board conducted a formal investigation of the accident and determined that workers did not wear the appropriate flame-resistant clothing and all required PPE. A pre-work hazards analysis was not performed, nor was there an approved electrical hot work permit. (ORPS Report SC-OAK-SU-SLAC-2004-0010; OE Summary 2005-01)

On May 10, 2004, at the Pantex Plant, a warranty service technician received minor flash burns to his eyes from an electrical arc after replacing a failed part in a new chiller system. He was not wearing any PPE and a lockout/tagout was not used. The technician did not incur permanent eye damage. (ORPS Report ALO-AO-BWXP-PANTEX-2004-0046; OES 2004-16)



NFPA 70E provides guidance in determining the severity of potential exposure to arc flash and selecting protective equipment. Equations for calculating incident energy and flash protection boundaries are provided in NFPA 70E and IEEE 1584-2002, *IEEE Guide for Performing Arc-Flash Hazard Calculations*.

NFPA 70E, section 130.3, *Flash Hazard Analysis*, states the following:

A flash hazard analysis shall be performed to protect personnel from arc flash injury. This analysis shall determine the Flash Protection Boundary and the necessary PPE to work within that boundary. The analysis shall determine the incident energy exposure to the worker (in calories/cm²) and shall be based on the working distance of the worker's face and chest areas from a potential arc source for the specific task. The default Flash Protection Boundary for systems rated at 600 volts or less shall be 4 feet. The following approach boundaries are identified in NFPA 70E.

- *Limited Approach Boundary* is the distance from an exposed energized part within which a shock hazard exists.
- *Restricted Approach Boundary* is the distance from an exposed energized part within which there is an increased risk of shock, due to electrical arc-over combined with inadvertent movement, for personnel working in close proximity to the energized part.
- *Prohibited Approach Boundary* is the distance from an exposed energized part within which work is considered the same as making contact with the energized part.

- *Flash Approach Boundary* is the distance from exposed energized parts within which a person could receive a second-degree burn if an electrical arc flash were to occur.

Only a qualified person should be permitted to work within the Limited Approach Boundary of exposed energized parts operating at 50 volts or more. They must be trained to distinguish exposed energized parts from other parts of electrical equipment, to determine nominal voltage of exposed energized parts, to know approach distances and corresponding voltages, and to determine the degree and extent of hazards and the PPE and job planning necessary to perform the task safely.

Section 110.16, *Flash Protection*, of National Electric Code, requires posting switchboards, motor control centers, panelboards, and industrial control panels with markings to

ELECTRICAL HAZARDS

- **Electrical Shock and Burns** – Contact with electrical energy can result in nerve and tissue damage, severe burns, and electrocution as current flows through the body.
- **Arc Flash Burns** – An arc flash can heat the air to temperatures as high as 35,000 °F, vaporizing metal and causing severe skin burns from direct heat exposure and by igniting clothing.
- **Arc Blast** – The heating of air and vaporization of metal creates a pressure wave that can damage hearing, cause a concussion, and produce other injuries from flying metal debris or worker falls.



warn personnel of arc-flash dangers. An example warning label is shown in Figure 1-4.

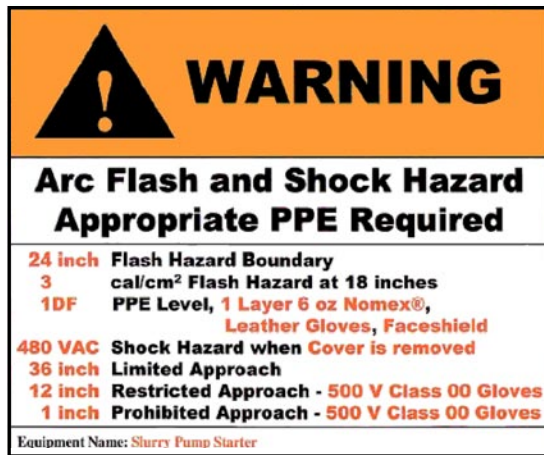


Figure 1-4. Example of arc flash warning label

safe work condition, unless the employer can demonstrate that de-energizing introduces additional or increased hazards or is not feasible because of equipment design or operational limitations.

These electrical arc-flash events underscore the importance of implementing the guidance in NFPA 70E for arc-flash protection. Electrical safety engineers should perform flash hazard analyses and ensure that these calculations are controlled. Information on approach distances and required PPE should be posted on electrical equipment. Facility managers should make sure that the need to work on energized circuits has been reviewed and justified and that the use of required PPE is strictly enforced.

In addition to flash hazard analysis, personnel training, and selection of PPE, justification to work on energized components should be performed. NFPA 70 E, section 130.1, *Justification for Work*, states that energized parts to which a worker might be exposed shall be put into an electrically

APPROPRIATE NFPA 70E DEFINITIONS

- **Flame-Resistant (FR)** — The property of a material whereby combustion is prevented, terminated, or inhibited following the application of a flaming or non-flaming source of ignition, with or without subsequent removal of the ignition source.
- **Flash Hazard Analysis** — A study investigating a worker's potential exposure to arc-flash energy, conducted for the purpose of injury prevention and the determination of safe work practices and the appropriate levels of PPE.
- **Flash Suit** — A complete system of FR clothing and equipment that covers the entire body, except for the hands and feet. This includes pants, jacket, and beekeeper-type hood fitted with face shield.
- **Qualified Person** — One who has the skills and knowledge related to the construction and operation of electrical equipment and installations and has received safety training on the hazards involved.

KEYWORDS: *Arc flash, injury, electrical safety, personal protective equipment, NFPA 70E, flame retardant, flash boundary*

ISM CORE FUNCTIONS: *Define the Scope of Work, Analyze the Hazards, Develop and Implement Hazard Controls, Perform Work within Controls*