



Testing Times

The Top 10 Issues

During an Institute of Electrical and Electronics Engineers presentation, M. Capelli-Schellpfeffer, Ph.D., discussed the results of a 10-year study involving 120,000 employees at Electricite de France. On average, 125 electrical incidents occurred per year. Seventy-seven percent of these were electric arc-related, 21% resulted in permanent disabilities, and 2.4% were fatalities.

NFPA 70E-2012, Standard for Electrical Safety in the Workplace, requires that systems (electrical safety programs) are developed to address electrical safety. Electrical arc flash safety must be achieved through a program that addresses all aspects relating to engineering, behavior, PPE, auditing and systems.

This article examines arc-rated PPE by explaining the phenomenon of an arc, dos and don'ts of PPE, relevant standards and the importance of an electrical safety program. Arc-rated PPE is only one part of an electrical safety program, and end users should be cautious about the exclusive use of PPE to mitigate arc flash hazards.

ELECTRICAL ARC FLASH & EXISTING PPE

An electrical arc flash originates from a breakdown in the insulation medium creating a conductive plasma that can reach temperatures exceeding 36,032 °F. Heat propagates from the plasma in the form of a plasma spray and infrared radiation. Workers operating on electrical equipment posing an electrical arc flash hazard should be protected against such high temperatures.

At present, companies already provide hardhats, face shields, overalls, shoes and gloves, so why regulate clothing for electrical arc flash?

The intent of generic PPE was mechanical impact withstand, chemical and dust ingress protection and minimizing cuts and bruising among other workplace hazards.

Consider a face shield, which displays mechanical withstand capabilities when exposed to a 36,032 °F electrical arc flash. The face shield will melt, and the molten matter will ensure that the heat of the electrical arc remains attached to the skin of the worker long after the electrical flash has cleared.

Most over-the-counter overalls protect against small welding/cutting arcs and fires, which are not in the frame of reference of an electrical arc flash. This type of clothing will most often ignite, leaving workers with a poor chance of survival and severe burns.

To demonstrate this point, **ArcWear.com**, an arc flash testing specialist, compared the performance of common workplace overalls when exposed to an electric arc. Figure 1 shows the test rig with three samples consisting of an aramid, polyester-cotton combination and cotton.

When the arc was initiated, all three clothing types ignited. After arc extinction, the aramid stopped burning.

The polyester-cotton burned and dripped, while the cotton only burned without dripping. This study presented an important finding, which was able to explain why 80% of all fatal and disabling injuries result from the ignition of clothing.

UNDERSTANDING BURNS & PPE

An electrical arc flash results in energy propagation. The available energy varies according to the system fault level (kA), construction of the electrical apparatus, fault clearing time and other protection characteristics. The incident energy received by the worker depends on the distance between the worker, the arc energy and directionality.

Energy is measured in calories, although joules are also widely used. When referring to arc energies, we are more concerned with energy densities, hence the unit of measure of the available arc energy and the incident arc energy is cal/cm² (or J/cm² or kW.s/cm²).

If the incident energy from an electrical arc flash is completely dissipated by the PPE, then no further energy can be transmitted to the worker's body. This is the ideal case. In reality, heat transmission to the worker's body occurs (measured in terms of a Stoll curve differential).

Human tissue can dissipate a measure of heat before the onset of second-degree



Figure 1 Test Rig Comparing the Performance of Common Industrial PPE



Figure 2 Post-Arc Exposure, the Cotton PPE Burns While the Polyester-Cotton Burns & Drips



burns. In the early 1960s, Alice Stoll conducted studies on humans (academics and sailors) and animals. A predetermined amount of energy was exposed to skin for a certain period of time, which gave rise to the definition of a second-degree burn (also termed a blister burn). This is the point at which the epidermis burns and separates from the dermis (Figure 3).

In terms of thermal energy, second-degree burns will occur at energies on human skin exceeding 1.2 cal/cm^2 .

In other words, PPE should then dissipate or reflect enough energy so that the residual energy transmitted to the worker never exceeds 1.2 cal/cm^2 . Stoll's work provided a measure for human tissue burns as a function of heat flux, time and change in temperature.

Third-degree burns often result in permanent disability and death, but so can second-degree burns if they cover a large portion of the body. Ignition of clothing is usually the main culprit. In the case of a third-degree

burn, the epidermis and dermis are completely destroyed. Complete destruction of capillaries, nerve and muscle makes recovery highly improbable. Photo 1 (p. 20), taken Dec. 3, 2009, shows a burn victim with extensive third-degree burns.

Photo 2 (p. 20), an unrelated case, shows equipment failure, which provided an arc energy of 50 cal/cm^2 during an arc blast incident. The incident energy is believed to be around 20 cal/cm^2 according to arc-rated clothing expert Hugh Hoagland from ArcWear.com. The worker used a 90 cal/cm^2 flash suit jacket and non-arc-rated trousers as shown in Photo 3 (p. 21).

The brunt of the arc flash was over his right hand with little energy over the trouser. The worker did not suffer any effects on the right hand but experienced sunburn-type effects on the right leg covered by the non-arc-rated trouser. If the trouser had ignited, the effect would have been catastrophic.

Also note that the beekeeper's hood and gloves are noncompliant with International Electrotechnical Commission (IEC) and ASTM standards.

STANDARDS FOR ARC-RATED PPE

Understanding that a need for arc rated PPE exists is not sufficient. With a hoard of noncompliant PPE on the market, the end user must be aware of the international testing standards to specify such as a minimum acceptance criterion for procurement.

A specification outlines the minimum requirements of fabric before these can be assigned the "arc rated" title.

Specifications contain many test requirements and outline the pass/fail criteria. Test requirements are discussed in separate standards known as test methods. The test method states how the test should be performed and does not contain a pass/fail criteria. This explanation and the applicable standards are summarized in Table 1 (p. 20) and Figure 4 (p. 21).

Although many pass/fail criteria are in the specifications, two requirements are discussed to illustrate the relationship between a specification and a test method. ASTM F1506 requires that single-layered fabrics not display more than 5 seconds afterflame when tested using ASTM F1959 test method. ASTM F1959 is the electrical arc flash exposure test.

Single-layered fabric that burns for more than 5 seconds cannot be arc-rated.

INCLUSIONS & EXCLUSIONS

Most standards regulate arc-rated PPE for thermal protection only and do not address electrical shock, projectiles, shockwaves, hot oil release or other hazards of an electrical arc.

Figure 3 Cross-Section View of Human Skin





Photo 1: Electrical worker after an electrical arc flash incident. The worker was not protected by arc-rated PPE and only survived for a few days.



Photo 2: Electrical arc flash incident on 11 kV system.

The exclusion regularly questioned is the protection against contaminants, namely hot oil release. Hot oil release has resulted in fatalities previously and is a valid concern. Tests have shown that oil increases the ignitability of almost any garment. It is also accepted that little can be done to protect workers who are engulfed in flaming hot oil.

Tests show that arc-rated PPE doused with oil burned at the points of contamination. Most standards require that under such conditions, special precautions are taken, such as remote operation and de-energised work, among others. A self-contained breathing apparatus should be considered when hot oil release cannot be fully mitigated.

This will address the hazard of toxic smoke and hot air inhalation. The employer should assess each application uniquely and ensure that workers are not exposed to hot oil release.

CLOTHING & EQUIPMENT

Arc-rated protective equipment should protect a user who is completely engulfed in an electrical arc. PPE

consists of all items, including head, face, neck and chin protection, eye protection, hearing protection, body protection, hand and arm protection and foot and leg protection.

A beekeeper’s hood, long-sleeved shirt, innerwear or underwear, full-length trousers, coverall, jacket and rainwear are categorized as personal protective clothing (PPC). Arc-rated PPE refers to face shields, balaclavas, hardhats, hearing protection, fall arresting equipment, gloves and shoes. Welding aprons and flame-retardant coats are not considered arc-rated PPC.

1) Head protection. Head protection can be achieved by using a beekeeper’s hood, face shield, goggles or balaclava. The design requirements of the visor on the face shield and the hood are regulated by EN 166, Personal eye protection—Specifications and ANSI Z87.1, Occupational and Educational Personal Eye and Face Protection Devices.

The test to determine the arc rating of head protection should be according to ASTM F 2178-02, Standard Test Method for Determining the Arc Rating of Face Protective Products.

2) Hand protection. The general approach to hand protection is the use of the leather welding glove. Although this glove offers protection, its arc rating is rarely known. The debate regarding finger dexterity is often a contentious issue. Many countries have enforced the use of arc-rated gloves while others leave it to the end user. It is recommended that a dielectric natural rubber glove be used under a leather overprotector. The rubber offers electrical protection while the leather protects the rubber and adds arc flash protection.

A standard test method for determining the arc rating of gloves is currently in draft format in the U.S.

3) Miscellaneous PPE. Shoes, socks and hearing protection are usually not directly exposed to the arc. If exposed to an electric arc, fairly good arc ratings were attained from standard issue workwear. Leather shoes performed well when exposed to 50 cal/cm² while yellow hearing protection inserts withstood 25 cal/cm². These PPE items should be manufactured to the relevant

Table 1 Relationship Between Test Specifications & Test Methods

Detector	ASTM	IEC
Specification	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	IEC 61482-2, Live working – Protective clothing against the thermal hazards of an electric arc – Part 2: Requirements
Test method	ASTM F 1959, Standard test method for determining the arc rating of materials for clothing	IEC 61482-1-1, Live working – Protective clothing against the thermal hazards of an electric arc – Part 1-1: Test methods – Method 1: Determination of the arc rating (ATPV or EBT50) of flame resistant materials for clothing

South African National Standard and may be arc-tested to the relevant American standard test method.

Fall arrestors were not discussed in detail during the working committee meetings and hence excluded. However, with the recent focus on fall protection in terms of fatality prevention, a renewed focus is required. ASTM F887, Standard for Personal Climbing Equipment, provides electrical arc testing guidelines for fall protection equipment.

4) Clothing. Electrical arc flash hazards are present at low-voltage, medium-voltage, high-voltage and extra-high-voltage applications. Most industry, mines and small commercial installations consist of many electrical systems that offer a wide range of available arc energies.

A customized garment cannot be provided for each calculated incident energy level. Most companies have adopted a simple two-garment approach. The daily workwear will be used for frequent daily tasks where the incident arc energy is usually below 25 cal/cm². For higher incident energies, usually greater than 40 cal/cm², a full flash suit is used.

The use of melting fibers, such as polyester, nylon, acetate and spandex, is prohibited, irrespective of whether exposed to the arc or used as innerwear or underwear. Melting fibers will stick to skin if exposed to an arc.

This phenomenon will result in the melted fabric retaining heat on the skin and further damaging it. Some arc-rated materials contain low levels of these fibers, but these designs offer the user certain benefits. These are acceptable if tested against the standards cited here.

In the event a garment is exposed to an arc, all items of PPC exposed to an electric arc should be permanently withdrawn from service. It is advisable that the minimum number of laundering cycles be specified, before the arc rating of the garment decreases from its original rating.

The laundering cycles should comply with the manufacturer's laundering requirements. Once the number of laundering cycles has been attained, or if the laundering decreases the original arc rating of the garment, such garments should also be withdrawn from service. In general, fabric softeners and bleach should not be used when laundering arc-rated clothing.

Testing requirements of arc-rated clothing are governed by the ASTM or IEC standard. At present the majority of arc testing is conducted at the Kinectrics High Current Laboratory in Toronto, Ontario, Canada. Work is underway to expand testing in Europe and South Africa.

CONCLUSION

Protective equipment and clothing manufacturers must take the lead and ensure that products have undergone the requisite testing and

acceptance criteria before entering the market. End users should adopt a proactive approach by understanding the testing and acceptance criteria as required by relevant standards.

Major harm occurs when non-arc-rated clothing and equipment ignites. These incidents are responsible for more than 80% of all fatal and disabling injuries.

PPE is only one aspect of an electrical safety program. Industry should roll out electrical safety programs consisting of specialized electrical safety training, auditing, engineering and behavioral-based systems and engineering studies to determine arc flash parameters. ☺

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Photo 3: Electrical worker exposed to 50 cal/cm² arc blast.

Figure 4 Relationship Between Test Specifications & Test Methods

