Dress for Success

When it comes to personal protective equipment (PPE), there's no such thing as business casual.

NFPA 70E has given a whole new meaning to the phrase "dress for success." No, this is not about which shirt or tie to wear for a job interview. In this case, success means that if the very rare but potentially deadly arc-flash occurs, your chance of surviving with either no injury or only minor injury is greatly increased.

One slip of a screwdriver and an electric power system can act like a bomb releasing a tremendous amount of thermal energy, producing a blinding flash and pressure that sends molten metal and other debris hurling towards you at a frightening speed. In an instant, life could be changed forever.

If you have worked in the electrical industry long enough, you will either know someone who was severely injured or killed, or know someone who knows someone that was. This can be a very dangerous business.

OSHA and NFPA continue to work on making this business less dangerous by requiring that live work is kept to a minimum and only performed by qualified people wearing appropriate personal protective equipment (PPE). Although PPE will not make you "bullet proof" against an arc-flash, it will help minimize the injury that could result.

Burns and Other Gruesome Details

PPE is designed to provide a thermal barrier between the extreme heat of an arc-flash and a person's skin. Depending on how much heat the skin receives and how long it lasts, a person can experience anything from pain and redness to total destruction of the tissue.

Research dating back to the 1960s by Alice Stoll led to the development of the "Stoll Curve," which is essentially a plot of thermal energy and time predicted to cause a pain sensation or a second degree burn in human tissue. It is still used today in many tests for predicting thermal protective performance of materials for flame-resistant (FR) clothing.

The severity of a burn is defined by three categories:

- First Degree Burn—Redness of the skin surface affecting only the epidermis (outer layer of skin).

- Second Degree Burn—Blisters on the skin and superficial destruction of the epidermis.

- Third Degree Burn—Complete destruction of both the epidermis and dermis (both outer and inner layers of the skin), which can be life threatening and require skin grafts.

How Bad Is It?

Incident energy, is the term used to define the severity of an arc-flash. Measured in calories per square centimeter (cal/cm^2), it is the amount of thermal energy from the arc that reaches a surface such as a person's skin. 1.2 cal/cm^2 is considered to be the energy required to produce the onset of a second degree burn, so this number is used as the benchmark for protection. When the screwdriver slips and an arc-flash occurs, the incident energy can be large enough to cause severe burn injury and even death. However, providing a thermal barrier to limit this to no more than 1.2 cal/cm^2 at the person's skin is the goal of arc-flash PPE. It is important to keep in mind that this is where the onset of a second degree burn can occur, so there is still a possibility of being injured while being protected!

PPE selection for arc-flash protection is actually quite simple. It must be able to withstand the incident energy that a person could experience during an arc-flash and also provide enough of a thermal barrier to protect them against severe burns. This sounds easy enough but how do you know how much incident energy could exist for an arc-flash that has not yet happened? Also, how do you determine how much energy the PPE can withstand?

If you ever stand close to a large bonfire or fireplace that is too hot for comfort, you usually back up a few feet until it feels a little cooler. This same "backing up" principal applies to arc-flash protection. NFPA 70E defines this "back up distance" as the *Flash Protection Boundary*, which is the minimum distance that a person needs to be from a potential arc-flash source so the incident energy would be no more than 1.2 cal/cm^2. People without PPE need to be standing outside this boundary when live work is being performed, or else run the risk of severe burns in the event of an arc-flash. There are several methods that can be used to determine this boundary but remember, the further you are from an arc-flash, the less injury you would likely experience.

If live work is going to take place within the Flash Protection Boundary, NFPA 70E 130.3(B) requires that a detailed flash hazard analysis must be performed to determine how much incident energy a person could ultimately experience. Like so many other unknowns in electrical power systems, we cannot determine this with a "field test" (i.e. create an arc and see what happens). In

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addition to being a very bad idea, the results could be deadly and this type of test should only be performed by qualified persons in a controlled laboratory environment.

Instead, all we can do is predict the amount of incident energy by using very elaborate calculations, which could involve using exponents and logarithms. Determining how much short circuit current would flow in the arc, as well as how long it would last, are major components in the calculations. Other variables such as the gap distance of the arc, voltage, whether or not the system is grounded, are also important factors. Since these calculations can be very complex (and also to keep your sanity), commercially available computer programs are used rather than doing this manually with a calculator.

Many companies do not have the manpower, expertise or budget to undertake a detailed arc-flash study. As a simpler alternative, *NFPA 70E* Table 130.7(C)(9)(a) *Hazard/Risk Category Classifications* provides a rating system based on performing specific tasks such as voltage testing, racking in a circuit breaker, or inserting a motor control center bucket. Depending on the task, a Hazard/Risk Category number is assigned, rating the task from 0 to 4. The higher the number the more protection is required. Once the rating has been determined, a separate chart, *NFPA 70E* Table 130.7(C)(10) *Protective Clothing and Personal Protective Equipment (PPE) Matrix*, lists the PPE requirements for each category. Even though these tables are meant to simplify the process, they are still based on short circuit currents and device clearing times that are defined in the footnotes of the table. *NFPA 70E* Table 130.7(C)(11) *Protective Clothing Characteristics*, (Figure 1), provides a summary of typical protective clothing systems required for the various Hazard Risk Categories.

What Makes Clothing Flame-Resistant?

If you are wearing normal non-flame resistant clothing when an arc-flash occurs, it might initially block some of the heat, similar to grabbing a hot pan with a kitchen towel. However, depending on the amount of incident energy, the clothing would likely ignite and continue to burn long after the arc-flash has ended, much like using that kitchen towel to grab a burning piece of charcoal. One of the leading causes of increased burn injury is from clothing that continues to burn, which is one of the reasons the phrase “stop, drop and roll” was created.

FR clothing can actually burn or char during an arc-flash, but it is designed to stop burning as soon as the arc-flash ends. FR clothing is available with different protection capabilities, which NFPA 70E defines as the *Arc Rating*. This is the maximum incident energy in cal/cm2 before the clothing either breaks open or there is sufficient heat transfer through the material so that the wearer receives the onset of a second-degree burn. Breakopen occurs when the FR fabric begins to develop holes, or breaks open, directly exposing the skin to heat and flame.

Many standards exist that are used for the testing and specification of PPE and the American Society for Testing and Materials (ASTM) is the main source. To determine whether a fabric is flame-resistant, the Vertical Flammability Test, defined by ASTM D6413, is the most commonly used test. It is used to evaluate

Figure 1—Typical Protective Clothing Systems

Hazard Risk Category	**Clothing Description** (Typical number of clothing layers is given in parentheses)	**Required Minimum Arc Rating of PPE cal/cm^2**
0	Non-melting flammable materials (i.e. untreated cotton, wool, rayon, or silk, or blends of these materials) with fabric weight at least 4.5 oz/yd^2	N/A
1	FR shirt and FR pants or FR coverall (1)	4
2	Cotton underwear—conventional short sleeve and brief/shorts, plus FR shirt and FR pants (1 or 2)	8
3	Cotton underwear plus FR shirt and FR pants plus FR coverall, or cotton underwear plus two FR coveralls (2 or 3)	25
4	Cotton underwear plus FR shirt and FR pants plus multilayer flash suite (3 or more)	40

whether a fabric will ignite and continue to burn after it is exposed to a source of ignition. Details such as the size of the test sample, the number of trials, and the type of flame are all defined by this standard. Although it does not establish the actual pass/fail criteria, i.e. what are acceptable limits, the standard is used to measure the following data:

- **After Flame** (Seconds)—The time the fabric continues to burn after the flame source is removed.
- **Char Length** (Inches)—The length of fabric that was damaged by the flame that will easily tear under standard weight.
- **After Glow** (Seconds)—The length of time the fabric continues to glow after the flame extinguishes.

The measured data is then compared to the pass/fail criteria defined by ASTM F1506 *Standard Performance Specification for Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards*. The criteria include the following requirements:

- The After Flame must be 2.0 seconds or less.
- The Char Length must be no greater than 6 inches.
- Thread and bindings used in the garment cannot add to the severity of injuries to the wearer during an arc-flash and related thermal exposure.

In addition, the following information must be included on the garment label:

- Arc Rating
- Garment meets the requirements of ASTM F1506
- Manufacturer's name
- Garment care and handling instructions
- Tracking identification code system
- Size and other associated standard labeling.

Determining the ATPV Rating

The definition of Arc Thermal Performance Value (ATPV) is the incident energy on a fabric or material that results in sufficient heat transfer through the fabric or material to cause the onset of a second degree burn based on the Stoll curve. As an example, a person working where the maximum incident energy could be 8 cal/cm^2 must wear clothing with a minimum ATPV value of 8 cal/cm^2. The clothing would provide a sufficient thermal barrier to limit the energy at the skin surface to no more than 1.2 cal/cm^2, or the onset of a second degree burn.

Determining the ATPV requires simulating real world conditions based on ASTM F1959 *Standard Test Method for Determining the Arc Thermal Performance Value of Materials for Clothing*. The test is conducted by placing a fabric sample on a test panel that contains heat sensors. The fabric is then subjected to a known quantity of incident energy simulating the dangerous event. The heat sensors measure the temperature rise on the test panel, simulating the skin surface, to determine if a second degree burn would occur based on burn prediction models.

PPE manufacturers continue to push the envelope and today's PPE can have an ATPV rating of 100 cal/cm^2 or more. Care must be given, however, in the logic used for selecting the higher ratings. Although higher ratings provide much better thermal protection, NFPA 70E prohibits live work on systems where the incident energy is above 40 cal/cm^2. At higher energy levels, explosive forces become a serious concern. Results of staged arc-flash tests have shown that a higher power arc-flash can produce forces well into the thousands of pounds, which is enough to collapse lungs, crush skulls and launch a person into a concrete wall. Suddenly, thermal protection becomes only part of the problem and severe trauma injuries now enter into the deadly equation.

Bundle Up

Those of us who live in colder climates recall every winter when the temperature plummets toward 0 degrees F or even colder. Suddenly the phrase "dress in layers" becomes frequently used. The same layering philosophy that helps keep the extreme cold from reaching the skin can also help keep the extreme heat out during an arc-flash. Since an insulating air gap is formed between layers, two layers of lighter FR fabric can provide better thermal protection than one layer of heavy material. Doing the math, 2 layers of 6 cal/cm^2 clothing would not provide an ATPV rating of 12 cal/cm^2 of protection—it would provide a much higher rating.

Hand Protection

Arc-flash studies and PPE tables are based on protecting the face and chest area of the worker, usually based on a working distance of 18 inches from the arc source; however this distance could vary depending on the equipment and voltage. Attaching voltage probes, tightening a loose connection, or other similar tasks, would require that the hands be much closer than the rest of the body and they would receive significantly more energy. The Flash Protection Boundary requires "backing up" and increasing the distance to the arc so there will be less incident energy exposure. However, as you move closer to the arc, the incident energy exposure increases dramatically and varies as the inverse of the square of the distance from the arc source. For a person's body located 18 inches away from a possible arc source let's say the incident energy exposure was determined to be 8 cal/cm^2. If the hands are closer than 18 inches, perhaps half of that distance, or 9 inches, the energy level would increase by a factor of four to 32 cal/cm^2. If the distance is cut in two, the energy quadruples!

A person's hands create a special arc-flash protection problem. NFPA 70E requires that parts of the body, such as the hands, that are closer to a possible arc source than the working distance (18 inches in our example) need additional protection. In addition to wearing voltage rated gloves when there is a danger of electric shock, leather protectors must also be worn, which can provide some degree of arc-flash protection. For situations with higher energy exposure, arc-flash gloves are available with ATPV ratings as high as 100 cal/cm^2.

Eye, Face and Neck Protection

A blinding flash of light often occurs during an arc-flash, which can cause eye injury or even blindness. I have talked with many people over the years that have experienced an arc-flash and many of them describe the "blinding light" and how they could not see immediately afterwards. Some were blind anywhere from a few minutes to a half hour or more. Although they ultimately regained their sight, they did not know this at the time of the flash and did not know if they would ever see again. They were lucky because blindness is not always temporary.

Anytime there is a danger of an electric arc or flying debris, eye protection is required. It can range from safety glasses for lower levels of incident energy up to arc-rated face shields or arc-flash hoods. Up through Category 1, safety glasses are acceptable eye protection, however for Category 2, a face shield with a minimum arc rating of 8 cal/cm^2 must be worn. The face shield also must have additional wraparound guarding to protect the ears, neck and forehead in addition to the face. In some cases a double layer switching sock is required that completely covers the head and neck except for the eyes. For category 3 and 4 protection, a full flash hood with a suitable arc rating is required. ASTM F2178 *Standard Test Method for Determining the Arc Rating of Face Protective Product* defines the test method used to measure arc-rated products intended to protect the face of workers exposed to electrical arcs.

To reduce the possibility of eye injury from the blinding flash, face shields and flash hoods should have lenses that can filter out the harmful ultraviolet (UV) light. Advances in lens technology have enabled filtering light in the UV range while allowing normal visible light to pass through the lens. Older style face shields used extremely dark lenses that were often very difficult to see through, but today's lenses can transmit a greater amount of visible light. VLT or Visual Light Transmission is used as an indicator of how much visible light range will pass through the lens. The higher the VLT number, the more visible light will be transmitted.

Heads and Hearing Protection

During an arc-flash, copper can vaporize, expanding to approximately 67,000 times its original volume, creating an explosive force. For any hazard risk category above 0, non-conducting hard hats rated according to ANSI Z89.1 must be worn to protect against flying debris.

Normal conversation has a sound level of around 60 dB and gunfire is around 140 dB. For every 3 dB increase, the sound pressure doubles. Sound pressure recorded in the laboratory during staged arc-flash tests has been recorded in the 160 dB range! This would not only cause hearing damage but it could rupture the ear drum. Hearing protection is required for Hazard Risk Category 2 and higher.

To Understand the Future, Look at the Past

Manufacturers of PPE are stepping up to the challenge of making PPE lighter, cooler, stronger and more comfortable. In addition, PPE will be better able to withstand debris from the explosive forces. As these advances continue, there will be a time in the future when wearing PPE will be so simple and routine, we won't think twice about it.

Our understanding of electrical safety and safe work practices is continually evolving. Looking back at the past, it was a pretty common practice to use the "touch method" for testing to see if a panel was energized. This meant literally touching the bus bars to "feel" if they were energized (a very dangerous practice). Today we look back and think how crazy these people must have been to do such a thing. How times have changed!

In the future, it is very likely that the next generation of electrical workers will look back and think how crazy could people have been to work on live systems with no arc-flash protection!

Time has a way of putting things into perspective.