# Take the guesswork out of arc-protective apparel

The clothing that a utility worker is wearing when accidentally exposed to an electric arc is an important factor in determining if he/she is injured, and how badly. But until recently, very little quantitative data were available to help choose the best clothing for workers under arc conditions. Adequate data are now available, giving safety managers a wide variety of options for meeting the apparel section of OSHA's 1994 standard, 29 CFR 1910.269(l)(6)(ii- iii), covering power generation, transmission, and distribution.

A lack of data pushes utility management toward one of two errors: Either they claim that their industry is different and their service so vital that they have to face the hazards, or they take the overly conservative approach and treat all scenarios as the worst case. In the case of electrical arcs, the worst-case scenario for many utilities can overpower even flame resistant garments.

A much better approach is the continuous-improvement model. This involves continually looking at the problem from different perspectives (Fig 1). First, assess your scenarios and find out the consequences of each. Second, alert engineers and line workers to those scenarios and provide them with training on the consequences of electrical arcs. Third, locate the problem areas and include them in line-worker training. Fourth, consider different engineering perspectives to reduce the exposure (such as different breakers or circuit designs). Fifth, consider different work practices that reduce the intensity of arcs-breakers can be set for faster operation; reclosing devices can be set to one-shot, etc.

## How to assess clothing

The first thing you need to know is the thermal energy to which a worker could be exposed. Electric-arc thermal energy is determined by the following parameters:

- Current, amps (phase-to-ground or phase-to-phase).
- Duration of the arc, cycles.
- Length of arc.
- Distance from the arc.
- Source voltage-which only affects the maximum length of the arc.

The most accurate and easiest method for assessing arcs is ARCPRO® software from Ontario Hydro Technologies (OHT), Toronto, ON, Canada. This software, unlike some shareware and freeware, is based on an actual arc physics model, verified by thousands of pieces of data from the OHT lab (Fig 2). The software predicts energy produced by an arc in $cal/cm^2$ using the above parameters. It predicts arc energies at distances in front or above the arc, using a Windows interface. However, it assumes that you have data on clothing. ARCPRO® may include some data on cotton clothing in the near future.

**1. Work location** should be assessed for available fault current and fault clearing time to determine how much protection is it needed

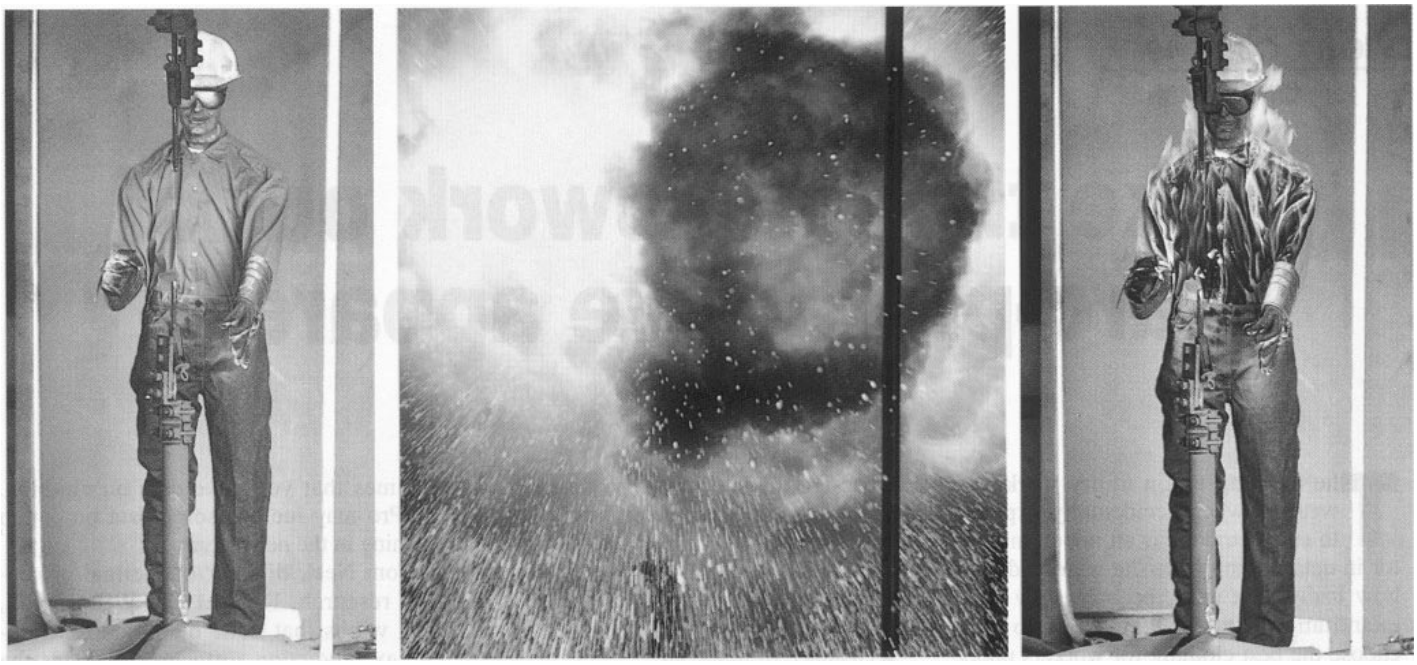
**By Hugh Hoagland,** *Utility Safety Consultant, Louisville Gas & Electric Co, Louisville, KY*

Tom Neal, director of thermal protection research, DuPont Co, Wilmington, DE, warns that none of the current arc energy prediction software calculates the effect of 3-phase arcs, or arcs in enclosed spaces, such as metal-clad switchgear. Clearly the injurious effects of an arc in such situations can be magnified many times.

Only when you know the potential arc exposures can you assess the protective value of clothing. Many utilities have found that much of their existing clothing performs well under 95% of work conditions (Fig 3) and have chosen to add a switching jacket/suit for high-fault-current situations. But this requires judgment and training. Workers must stop thinking in terms of transmission, distribution, or network systems, and start thinking in terms of arc potentials-low-amperage or high-amperage; short cycle time or long cycle time.

This may not be feasible for some utilities, but others have found the approach practical, especially if little of their system is high-amperage or has long clearing times. Many utilities have one substation with particularly high fault current, which affects a limited area with special power needs (that is, use of parallel buses). This area can be identified for special protection, while lighter clothing is allowed for normal distribution work. This approach avoids overprotection everywhere, which may increase other potential safety concerns, such as heat stress.

Be sure to include line workers in the decision-making process. Line workers are concerned about their safety and can add value to your clothing policy and selection. At Kentucky-based Louisville Gas & Electric Co (LG&E), many line workers have intuitively worn natural-fiber garments for years, which greatly lessens their risk of



**2. Arc testing sequence at Ontario Hydro's** high-current laboratory shows effect, of arc on a, mannequin wearing a 6 oz/yd2 cotton shirt and 14 oz/yd2 cotton jeans. The arc is 15 kA, 3000 V available, 12-in. electrode gap, 10-cycle duration. Centerline of the arc is 15 in. away from the mannequin surface

injury.

**Clothing performance** in terms of worker protection is determined by the following factors:

- Ease of ignition
- Degree and ease of flame spread
- Heat produced during burning
- Rate of heat transfer
- Ease of extinguishing the flame
- Other effects, such as melting

**Non-flame-resistant synthetic fabrics,** especially when worn externally, are extremely dangerous for workers exposed to electric arc. Specifically, blends of these fibers with cotton are much more easily ignited, more difficult to extinguish, and melt into the arc injury sustained by the worker. This greatly complicates treatment and increases the chance of infection during the healing process. Some utilities purchase wool-lined winter coveralls, which have none of the melting characteristics of the non-flame- resistant synthetic fabrics. Others depend on the heavy cotton shell of coverall/winter- wear to prevent the ignition of synthetic materials underneath. They keep test data to show that this complies with OSHA standard under their specific work conditions. Wool, in contrast to cotton, does not normally sustain a fire after the ignition source is removed. LG&E testing has shown no fires in wool garments held 12 in. away from a 16-kA, 10-cycle 12-in. gap arc. Manufacturers should consider offering wool-lined, insulated coveralls for electric utilities. However, wool face masks should not be used if they contain non-flame-resistant elastic around the face. Elastic tested in several facemasks burned and melted profusely when exposed to an electric arc. Another factor to consider when choosing clothing is the heat-transfer rate. Fig 4, adapted from the article "The Flammability of Different Textiles and Its Influence on the Severity of Skin Burns," *Annales Chirurgiae et Gynaecologiae* 69:240-243, 1980 by L Pakkala, shows price/heat-rate comparisons based on prices quoted to LG&E for flame-resistant garments and local retail prices on other garments.

**Blended flame-resistant fabrics** containing synthetic and natural fibers provide an alternative to the choice between expensive flame-resistant and non-flame resistant fabrics. Properly applied and assessed, these blends can afford the greatest protection at the least cost. Natural fibers afford excellent protection when they do not ignite and have the added benefits of lower cost and greater comfort. At the same time, it alleviates concern about heat stress that may be caused by some of the less breathable fabrics. Few utilities will be in compliance by using only natural fibers, but on the flip side, few utilities can fully protect workers with only minimum-compliance flame-resistant clothing. Blended fabrics are

### There's a glitch in the OSHA standard

Nothing raises the ire of employees or the blood pressure of safety managers and engineers more than the electric-arc-exposure apparel issue. Part of the problems is an error in the preamble to the 1994 OSHA 29 CFR 1910.269 standard covering power generation, transmission, and distribution. The standard states in part:

(ii) The employer shall train each employee who is exposed to the hazards of flames or electric arcs in the hazards involved.

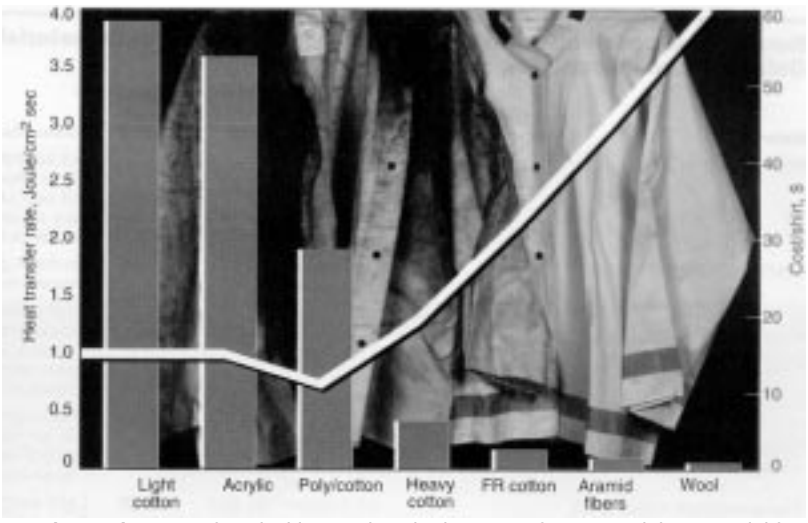
(iii) The employer shall ensure that each employee who is exposed to the hazards of flames or electric arcs does not wear clothing that, when exposed to flames or electric arcs, could increase the extent of injury that would be sustained by the employee,

NOTE: Clothing made from the following types of fabrics, either alone or in blends, is prohibited by this paragraph, unless the employer can demonstrate that the fabric has been treated to withstand the conditions that may be encountered or that the clothing is worn in such a manner as to eliminate the hazard involved: acetate, nylon, polyester, rayon.

These two small sections have caused much confusion in the electric-utility industry.

OSHA has repeatedly-as recently as in their victory in the Alabama Power v. OSHA case, affirmed that natural fibers do comply with the standard, if they will not ignite under the conditions faced by the worker. The confusion has come from OSHA's statement that: 11 oz/yd$^2$ fabric will not normally ignite under the 1989 tests performed by Duke Power Co. The test conditions are usually believed to be 3800 amp, 12-in. arc, for 10 cycles at a distance of 12 in. According to Duke Power representatives, the test was actually performed at 8000 amp, The 3800-amp figure was a technical error passed on to OSHA during committee hearings. Many others since then have tested and found that many 8.5-10 oz/yd$^2$ cotton shirts have a very low probability of ignition from a 10-kA arcs for 10 cycles. With more test data available every day, utilities can now find reasonable solutions to the apparel standard.

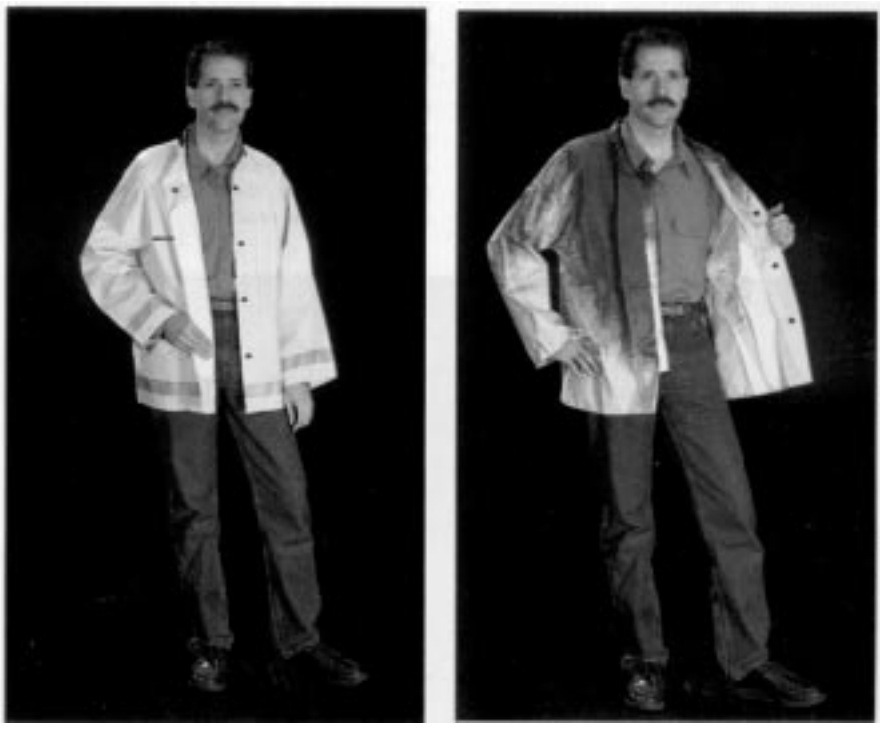
**3. Most rural distribution system** faults are below 8000 amps for 10 cycles. 100% cotton shirts may provide adequate protection




**4. Balance the cost** of work shirts against the heat transfer rate and the potential for serious burns from arc exposure

offered by Itex, Inc (BanWear®), Aurora, CO; and Springs Protective Fabrics (FireWear®), New York, NY. The addition of a tough synthetic fiber can add additional durability to a natural-fiber blend. A flame-resistant switching suit/jacket to protect natural fibers underneath from ignition can also provide an excellent way of meeting compliance.

**Washing** is an important factor to consider. You will hear claims of 300 washings for aramid fiber clothing, but under the abrasive conditions of linework, most flame-resistant fabrics have a life of 12-18 months. Clearly, this limited life must be considered in the fabric choice. Garments may last longer if home laundered rather than washed industrially, but you need to also consider the type of contamination that may get into the clothing. Note: flame-resistant fabrics should not be washed in chlorine bleach. This decreases the garment life substantially and can remove flame-retardant chemicals from cotton. Proper laundering of flame resistant fabrics must be part of the training program if you expect employees to wash their own flame-resistant garments. The good news is that many treated, flame-resistant fabrics available today generally do not wash out. Some flame- resistant, treated fabrics are guaranteed flame-resistant for the life of the garment. Aramid fabrics, manufactured by DuPont, Wilmington, DE (Nomex®, Kevlar®), and Hoechst-Celanese Corp (PBI®), Charlotte, NC, are inherently flame resistant and require no chemical treatment (Fig 5).



**5. LG&E's Hugh Hoagland** models a rain suit that was exposed to 30,000-amp arc for 10 cycles, 12 in. away. Test mannequin suffered more than Hoagland

### Take these steps to compliance

**1. Find the real arc hazard-**fault current availability, breaker clearing times, estimated are length potential (based on bus spacing and voltages), 3-phase-arc potential, and enclosures around the arc gap that can increase the exposure energy.

**2. Be creative.** Looking only for the worst case may not be the best course of action. Last summer, two New York utilities had lost-time injuries from heat stress because employees were required by company policy to wear a flame-resistant aramid-fiber coveralls, over their normal work clothes, year-round. The accident reports attributed the cause to excessive clothing. These utilities could have specified lightweight, flame-resistant garments, or an approved 8- 10-oz. cotton garment and avoided these lost-time injuries.

**3. Look for hot spots** where high-current and/or high-cycle-time faults are available. Provide proper protective clothing and train employees about these areas. Some substations, close to high-current users, may have twice the available fault current of other facilities and require extra protection. Networks and electrical systems in

**Results of arc-protection test conducted on different rainwear materials, conducted by LG&E at Ontario Hydro laboratories**

| Material | ATPV, cal/cm$^2$ | $E_{BTAS}$, cal/cm$^2$ | Suit Retail, $ | Comments |
|---|---|---|---|---|
| Nomex®/breathable urethane/ Nomex® Trilaminate 10 oz./yd$^2$ Yellow | 13 | 30 | 300-700 | Not as water proof. High afterflame at higher levels. Very expensive. Double duty as jacket and rainsuit |
| Neoprene®/Nomex® 10 oz./yd$^2$ Yellow | 9 | 40 | 180-300 | No melting, dripping, ignition, or flames. Overall, best switching material tested. |
| PVC/Nomex®-Kevlar® 8.5 oz./yd$^2$ Yellow & Fluorescent Orange | 8 & 17 | 31-38 | 80-200 | No melting, dripping, ignition. Overall, excellent switching material. Excellent tear resistance. |
| PVC/Nomex®-Kevlar® 7.5 oz./yd$^2$ Yellow & International Orange | 12 & 16 | 33-36 | 70-150 | No melting, dripping, ignition. Overall, excellent for weight. Lightweight. Tested material feels like leather. |
| PVC/Nomex® 10 oz./yd$^2$ Yellow, Fluorescent & International Orange | 5,7,& 13 | 30 | 50-120 | Most protective ATPV, but flames cascade over garment at higher exposure levels. Flames always self-extinguish. Lower tear strength than Neoprene-Nomex®, but more water repellent |
| FR Neoprene®/Nylon 10 oz./yd$^2$ Yellow | 12 | 29 Actually ignited at this level | 40-80 | This material has burned at 29.6 cal/cm$^2$ and is not recommended at higher arc currents. I consider all melting substrate rainwear hazardous in electric arcs. When FR is overridden they are a virtual fireball. |
| FR cotton-lined polyurethane/nylon 4.5 oz./yd$^2$ Each layer. Outer layer Yellow | 11 | 22 | 70-120 | Not recommended anymore due to several factors. Cotton layer tends to mildew if not allowed to dry properly. Cotton layer tends to wick. When the outer layer breaks open the nylon flys up on to mannequin. |

**Fluorescent Colors have much lower ATPV values in extensive testing**
**$E_{BTAS}$ is the level at which the material has not begun to break open. Table updated for reprint.**

powerplants are particularly hazardous and may require extra protection.

**4. Assess existing clothing** (include rainwear). Rethink your current policy or clothing program to see what will work. LG&E decided to replace lightweight cotton shirts and a jacket that had a synthetic lining in the hood. Under test conditions, it was found that the lining could onto the worker's face. Synthetic face masks for winter use were also discontinued.

**6. Under storm restoration** conditions a good rainsuit, with suitable undergarments, may provide protection from possible arcs, and from the weather

5. Train employees on arcs and clothing hazards. Getting employees to comply is part of the challenge and informed employees are more likely to comply their own. Thus the training program is a vital part of the process.

**Rainwear may provide compliance.**

LG&E considered purchasing switching jackets made of 7.5 oz/yd$^2$ Nomex® from a large clothing manufacturer. These jackets were designed to protect worker: in switching exposures, but under test conditions, they did not perform as well as quality rainwear, supplied by NASCO, Washington, IN, on each truck and uses that for the nominal switching applications that workers face. These apparel does double duties as rainsuits and providing assurance that workers are protected during storm restoration work (Fig. 6). The rainwear costs $50 less than the switching jackets.

Rainwear may not be the ideal for constant use because of its limited flexibility and inability to breathe. However, it serves well for short-term switching protection, especially for protection against enclosed arcs-known in the trade as "arc-in-a-box."

LG&E has since performed tests on seven rainsuit materials to determine the

arc thermal performance value (ATPV) and the heat attenuation factor (HAF) in accordance with the proposed ASTM test method (table) [Note: ASTM F-1891-98]. The ATPV is the are exposure-measured in cal/cm$^2$-at which a person, wearing only this garment, would normally not receive a second degree burn 50% of the time. Obviously, in the case of rainwear, the ATPV is not very meaningful because no one would work wearing nothing but a rainsuit. The HAF is the percentage of energy which is prevented from passing through the garment to the worker at the ATPV This percentage can be useful in predicting the level of energy that would reach the clothing under a rainsuit in the event of an electrical arc. Thus the HAF is a sort of efficiency measurement of a garment.

Suppose a garment has an HAF of 85% and an ATPV of 20 cal/cm$^2$. It would be reasonable to assume that this garment would protect a non-flame-resistant cotton workshirt underneath from ignition at an exposure of 20 cal/cm$^2$. Part of the definition of ATPV is that the garment cannot break through at that level. Another way to check this type of protection is to find the ignition threshold value for the workshirt, and the HAF for a rainsuit, and determine whether that workshirt could reasonably be worn under the rainsuit and be expected not to ignite. (The ignition threshold is the exposure level-in cal/cm$^2$-at which a garment does not ignite) For example, suppose the rainsuit above is to be assessed for an expected exposure of 30 cal/cm$^2$. If HAF is 85%, the energy passing through the rainsuit is only 4.5 cal/cm$^2$. This amount of energy would have a low probability of igniting a lightweight cotton workshirt. Thus a worker wearing this rainsuit with a lightweight cotton workshirt underneath Would be in compliance with the standard.

**Caution before using rainwear**

1. Never use even flame-resistant rainwear that is not rated for available arc conditions, unless there is no threat of exposure. Cheap, flame-resistant rainwear would not withstand an 8000-amp, 10-cycle electric arc. This rainwear is tested with the current "vertical flame test" (FTMS 191A-5903.1), which does not approximate arc performance well. Flame-resistant rainwear rated to pass this test may not perform well in an arc exposure.

2. Rainwear selected for use in switching applications should have information available on its Energy of Breakopen Above Stoll ($E_{BTAS}$). This is the energy that will not breakopen the material but will still burn a worker without additional protection under the rainwear.

3. The information in the table shows results of tests by LG&E at Ontario Hydro using an 8kA arc, 12-in. arc gap 12 in. away from material and clothing placed on mannequins or panels.

**What about protective equipment?**

The apparel section of standard (1910.269) does not apply to protective equipment, but much discussion has surrounded protective equipment, such as gloves, sleeves, safety glasses, and hard hats. Faceshields, though much contested, can provide added protection from molten metal in the event of an arc. Though there is no accepted industry practice, many electric utilities provide optional faceshields for certain operations, such as switching. LG&E has tested some face shields at levels up to 29 kA for 10 cycles, 12 in. away from the arc, without ignition or melting. This is not to say that faceshields never melt, but those attached to a hard hat have very little chance of melting to a worker's face and can reduce the amount of molten metal that hits the employee's face in the event of a frontal blast.

If used, faceshields should be field tested to determine the applicability to the job and arc-tested for the available exposure levels. Factors such as fogging, blocked or limited vision, and mobility should he considered in determining the usefulness of a faceshield. Faceshields must never be used as a substitute for safety glasses. Both LG&E testing and anecdotal evidence supports the continued use of approved safety glasses whenever exposures- to electrical arc is possible.

Class 2 rubber gloves and sleeves and safety straps show no substantial ignition during testing. In one test, a small fire was started in a nylon keeper on an old-style safety harness, but it did not ignite a cotton shirt on the test mannequin. This is good news, but you should check with the manufacturer for specific information on its materials and equipment.

**There's no hard and fast rule**

Standard apparel, used across the electric utility industry would probably not be the best way to comply with OSHA's standard (1910.269). Had this been the case, OSHA would have simply required standard clothing. But Arizona summers, Montana winters and Ohio Valley humidity require us to think through our clothing policies. To date, no simple answer has been found, even by companies with expensive clothing programs. Flame-resistant winter coveralls pose a major problem for the industry. Winter clothing must be warm and many winter coveralls offered to date have been short on warmth and substantially more expensive. Look for new solutions by next winter that will be much more cost-effective. Warmth, washability, and outer-shell strength must all be considered when choosing winter clothing. No manufacturer has adequately addressed the heat-stress issue in protective clothing systems for summer wear. But heat stress and thermal protection, must be balanced. OSHA has presented safety managers with a challenge. Minimum compliance can be accomplished by purchasing flame-resistant clothing, but this will not always protect against the most severe exposures. Engineering, work practices, and clothing assessment must be part of the solution. Reasonable solutions can be found by using a combination of flame resistant and untreated, natural-fiber products. Good information, team-based problem solving, and management action can save your utility headaches and heartache from the OSHA apparel standard.

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Hugh Hoagland is now R&D Director for NASCO Industries, Inc. and author of several papers and articles on the electric arc and its effect on clothing, rainwear, and personal protective equipment. Hugh is also a member of the following committees.
Co-Chair, ASTM F-18 Rainwear Taskforce
Secretary, ASTM F-18 Eye Protection Taskforce
Member F-18 Protective Clothing Testing Taskforce
Member F-23 Petrochemical Clothing Standard Taskforce
Principal Member NFPA Flash Fire Protective Garments Committee

To contact Hugh:
NASCO Industries, Inc.
3 NE 21st Street
Washington, IN 47501
"America's Largest Producer of Industrial Raingear"
Indiana Office: 800/767-4288 Ext. 20
Cell Phone: 502/641-7022
E-mail: hugh@nascoinc.com
Website http://www.nascoinc.com
Arc Hazard Assessment Support Page
http://www.nascoinc.com/archaz.htm