Using Rainwear as Switching Jackets: A Reasonable Solution for Electric Arc Exposure

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***Abstract*—Louisville Gas & Electric, Louisville, KY, has tested numerous types of clothing for worker protection under electric arc exposure situations and discusses the test methods used, along with practical application of the arc thermal protective value and heat attenuation factor results which are being reported by manufacturers of arc-resistant clothing. This paper focuses on the newly discovered and documented feasibility of using flame-resistant (FR) rainwear in high fault current switching applications. This paper includes data and a comparison of several popular rainwear materials in their performance under electrical arc conditions. Some of these rainsuits have been shown by mannequin testing to withstand arcs up to 30 000 A, 15 cycles without sustained fire or ignition of clothing covered. Using rainwear as switching jackets could allow "double-duty" use of rainsuits in plants and on line trucks. Further, Neoprene/Nomex and some PVC/Nomex/Kevlar rainsuits have, in our testing, proven more protective than woven Nomex "switching jackets" costing substantially more.**

***Index Terms*—Arc protection, arc-resistant clothing, electric arc testing, flame-resistant clothing, rainwear, worker safety.**

I. Introduction

LONG before the introduction of 29 CFR 1910.269 (l) (6) (ii-iii), the electric utility industry was concerned about protecting workers from the hazards of electric arcs. Many companies have been on the forefront of this effort by requiring 100% natural fiber clothing or flame-resistant (FR) clothing for their workers. That arc/flame injuries may be greatly reduced by the wearing of these types of clothing is widely documented in the medical literature. Specifically, FR materials (i.e., treated fabrics like FR cottons) or inherently FR fabrics (i.e., aramid fibers), wool, silk, and to a limited extent, heavy weights of 100% cotton have been shown to have protective effects under electric arc conditions. This paper seeks to add to the discussion of methods to help prevent arc injuries from clothing by assessing some switching jacket materials and offering a reasonable method of providing cost-effective arc protection for workers exposed to electric arcs in switching applications.

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II. Definitions

1) Stoll Curve: This is a standard curve, based on heat and time, used by the American Society for Testing Materials (ASTM) to predict the onset of second-degree burn injury. Energies above the Stoll curve would normally produce a second-degree burn. Those below the Stoll curve would normally not produce a second-degree burn.

2) Calorimeter: This is an instrument which measures total heat. The calorimeter is calibrated to measure temperature rise in degrees Celsius, which is then converted into calories per square centimeter (cal/cm^2) reaching its surface.

3) Incident Exposure Energy (E_i)*:* This is the amount of energy (total heat, cal/cm^2) received at a surface, as a direct result of an electrical arc, as measured by the temperature rise on the copper calorimeters. For our test setup, incident exposure energy is the average of the two sensors placed on either side of a panel or mannequin.

4) "Pass-Through" Energy: This is the amount of energy (total heat, cal/cm^2) which passed through the material on the panel as measured by the temperature rise on copper calorimeters which are located behind the material on the panel. For our test setup, the "pass-through" energy is the average of the two sensors located behind the material covering a panel.

5) Arc Thermal Protective Value (ATPV): This is the E_i value where the garment is predicted to have a 50% probability of preventing a second-degree burn under the test conditions.

6) Energy Breakopen Threshold Above Stoll (EBTAS): This is the average of the five or more highest E_i above the second-degree burn curve in cal/cm^2 that did not break open the material.

7) Breakopen: ASTM F1959 defines it as a 1-in crack or .5-in^2 hole in the material after exposure to the electric arc.

8) Heat Attenuation Factor (HAF) or haf point: This is the percentage of total incident energy striking the panel which is prevented from reaching the panel sensors by a single layer or multilayer fabric specimen under the test conditions at the ATPV level. The *haf point* for any given panel is expressed by

$$\left[1 - \frac{\text{(Average ``Pass-Through'' Energy)}}{\text{(Average Incident Energy)}}\right] \times 100 = haf\,\text{point.}$$

The HAF (*all caps*) is calculated by plotting the *haf points* (all lower case) from each panel and determining through linear regression analysis the point at which the ATPV passes through that line. Thus, the HAF is a prediction of the percentage of total incident energy which is prevented from reaching the panel sensors at the point at which the garment (or multilayer fabric system) prevents a second-degree burn.

III. Test Purpose

The objective of this test method is to determine the HAF and ATPV for specific materials used in clothing for electrical workers. The ATPV provides the end user the E_i in cal/cm^2 at which the particular clothing would protect the individual's skin from a second-degree burn. Add a nonigniting layer to any system and the ATPV could rise substantially, because that system would be more protective. Breakthrough affects the protective value of any clothing system. Some FR materials are more susceptible to breakthrough than others, and when any material has breakthrough it is less effective in preventing the material underneath from ignition. Caution is necessary in applying data because the E_i level at which a particular material displays breakthrough could be only slightly above the ATPV for some fabrics.

The clothing tested for HAF and ATPV were rainsuit materials. These materials would not be worn without clothing underneath. Thus, the ATPV alone has little meaning except to compare one rainsuit with another (and this is not a totally accurate means of comparison). The HAF is, on the other hand, very valuable in helping utilities choose garments to wear underneath the rainsuits tested. The HAF predicts the "efficiency" of a garment in preventing energy from reaching the layer beneath it. 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-FR cotton work shirt underneath from ignition at the 20 cal/cm^2 point, since part of the definition of the ATPV is that the garment cannot have breakthrough at that level. One could also take a table of ignition threshold values (the threshold of cal/cm^2 at which a garment does not ignite) for a particular work shirt and the HAF for a rainsuit to help determine whether that work shirt could reasonably be worn under the rainsuit and be expected to not ignite.

For example, we could take the rainsuit above and assess its use at an expected exposure of 30 cal/cm^2. Using the HAF (85% prevented from passing through) we would find that the energy passing through that rainsuit at that E_i (30 cal/cm^2) is only 4.5 cal/cm^2 or 15% of the energy to which the worker would be exposed. This amount of energy would not ignite a lightweight cotton work shirt, thus a worker wearing this rainsuit and a lightweight cotton work shirt would most likely not receive a second-degree burn on the covered areas of his/her body. Another major factor to consider is whether the rainsuit performs differently at that higher level. Ignition threshold testing, or at least tests performed at the arc energies expected, is vital to determine if the garment will break through, causing the garment to ignite the clothing worn under it. These pieces of information being in place, we can assess the use of garments for high-amperage switching applications or other high-level exposures. Certainly, removal of the hazard is the best solution to prevent injuries from electric arcs, but if a worker is exposed, properly chosen rainsuits with proper garments worn underneath would not add to the extent of injury and would prevent substantial amounts of energy from reaching the covered parts of the worker.

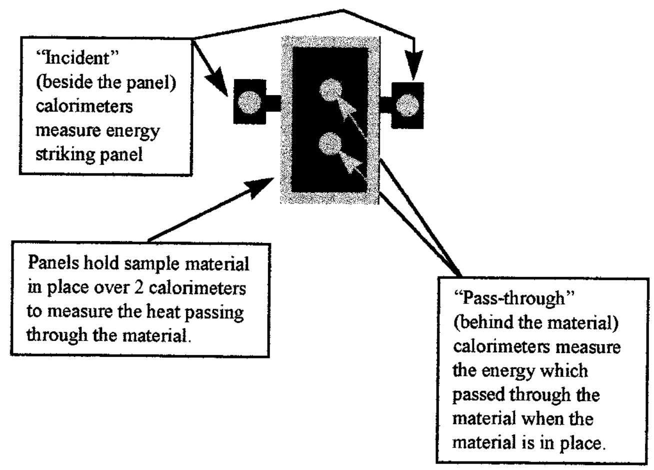

Fig. 1. OHT panel (front view).

IV. Test Method

The clothing, following ASTM method PS58 (now F1891-99a and F1959-99), was placed on a panel 12 in away from the arc source. The arc length was 12 in and the test material size was 12 in $\times$ 26 in. The panels contained two calorimeters which were located under the clothing and two calorimeters which were on either side of the clothing. The two side calorimeters were used to measure the E_i in cal/cm^2. The two calorimeters underneath the clothing measured the total heat which passed through the garment. The percentage of heat prevented from passing through to the garment was the *haf* point for that panel in the test. These individual *haf* points are plotted to find the HAF which measures the percentage of heat kept from striking the panel at the ATPV (see Figs. 1 and 2).

Each material was tested using 24 panels (eight separate arcs). Each material was ensured to have at least 20% of the shots exceeding the Stoll curve (above the predicted second degree burn curve) and at least 20% below the Stoll curve (averaging the energy reaching the two calorimeters behind each panel). The averaged points were then plotted using statistical software to perform a linear regression analysis of the point at which the E_i passed through the Stoll curve and the 95% confidence limits of that calculation. This calculation determined the ATPV.

Then, the percentage of energy which was prevented from reaching the panel (i.e., the *haf* points) was plotted as a function of the E_i (95% confidence limits were reported for this calculation, also) and linear regression analysis was performed to find the HAF which is defined as the point at which the *haf* points cross the ATPV.

V. Test Setup

The test setup is illustrated in Figs. 1 and 2. This is the ASTM F1959 setup still used today at Kinetics (formerly Ontario Hydro), Toronto, ON, Canada.

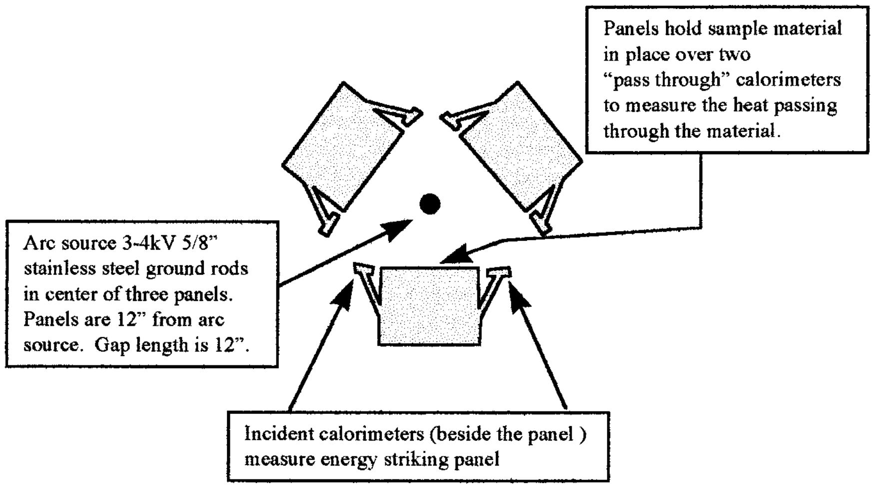

Fig. 2. OHT panel testing (top view). Note that two of the panels are replaced with mannequins for Mannequin testing. The third panel is removed for Mannequin testing to facilitate dressing the mannequins. Mannequin testing performed over 16 kA uses copper ground rods for practicality purposes.

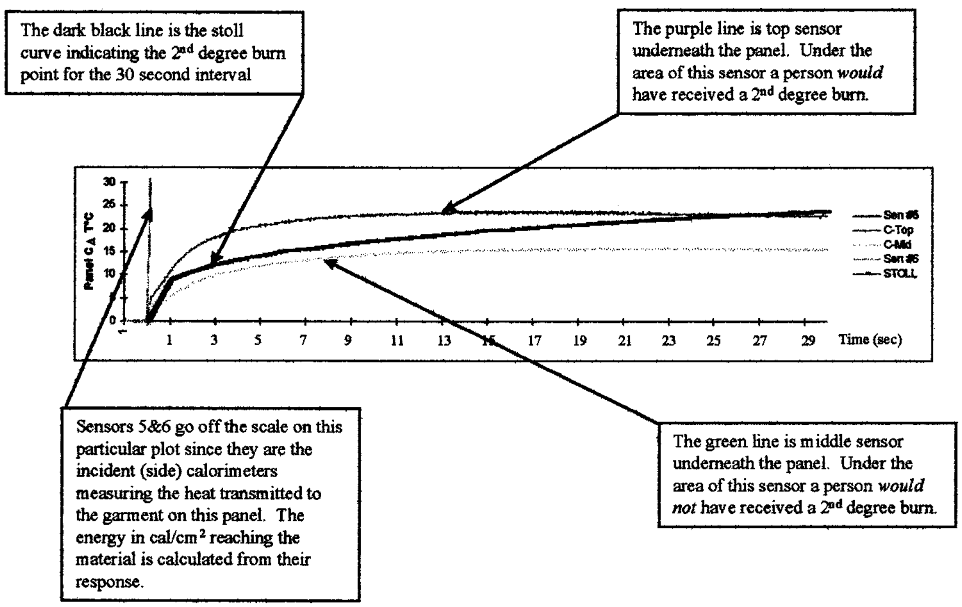

Fig. 3. Example of a single panel (three are used for each shot) from a single arc (eight were used for each material to find the HAF and ATPV). By averaging the $DeltaT$ for this particular panel, we would find that, at more than one point, the energy average would pass above the stoll curve. Thus, this panel would be considered as one of the panels above the stoll curve and this panel would give us one *haf point* to use in calculations for the HAF of this material.

Fig. 3 is the actual response from one panel during a test at Kinetrics.

The HAF and ATPV were plotted using the information gained from the individual shots (see Figs. 4 and 5) and reported in Table I.

It should be noted that the lower 95% confidence limit gives 95% confidence that the individual would receive a second-degree burn 50% of the time wearing this clothing. In the case of rainwear testing, this is less important since workers would be wearing other clothing underneath. Note that many materials perform better at higher amperages since the exposure time is less. These examples were developed before this discovery and prompted our request to change the new ASTM standard for rainwear and clothing in 1998. The new standard performs testing only at 8 kA.

VI. Testing Results and Interpretation

Unless there is an ignition, the HAF is fairly stable. Therefore, the rainwear we tested is very protective up to (and some past) the ATPV, since at the ATPV there is, by definition, no breakthrough or ignition. The HAF and ATPV can help you choose garments to be worn beneath another garment by providing the percentage of "pass-through" energy and a level at which there is no breakthrough. It should again be noted that some garments may break through at levels slightly above the ATPV and further arc testing is necessary to evaluate garments for thermal protection at levels substantially above the ATPV. Levels 2–5 cal/cm^2 above the ATPV should be fine for most garments without additional testing and, in some cases, we have found that these rainwear materials did not have breakthrough, even at 15 cal/cm^2

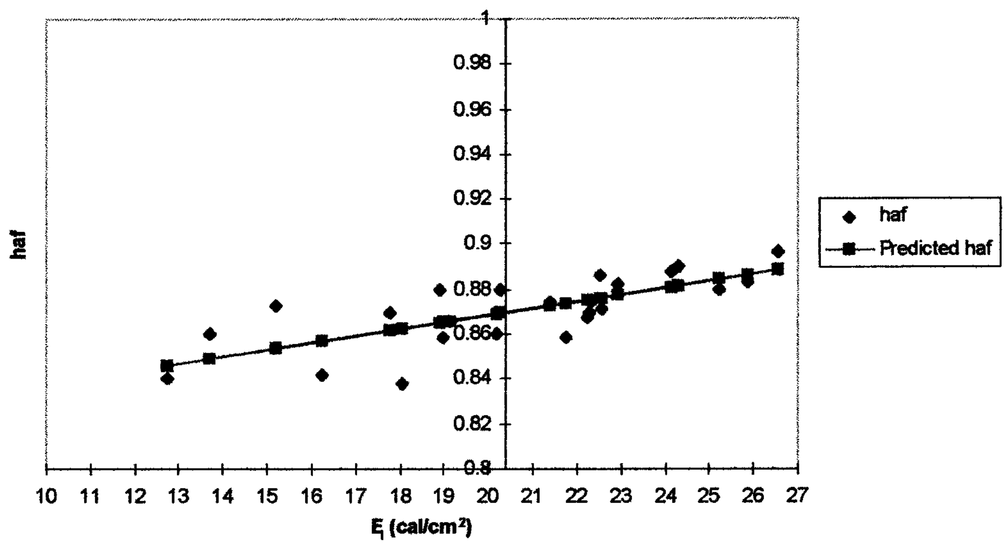

Fig. 4. The HAF occurs at the ATPV in this plot of the individual *haf* points. HAF is the percentage of energy that did not pass through the fabric.

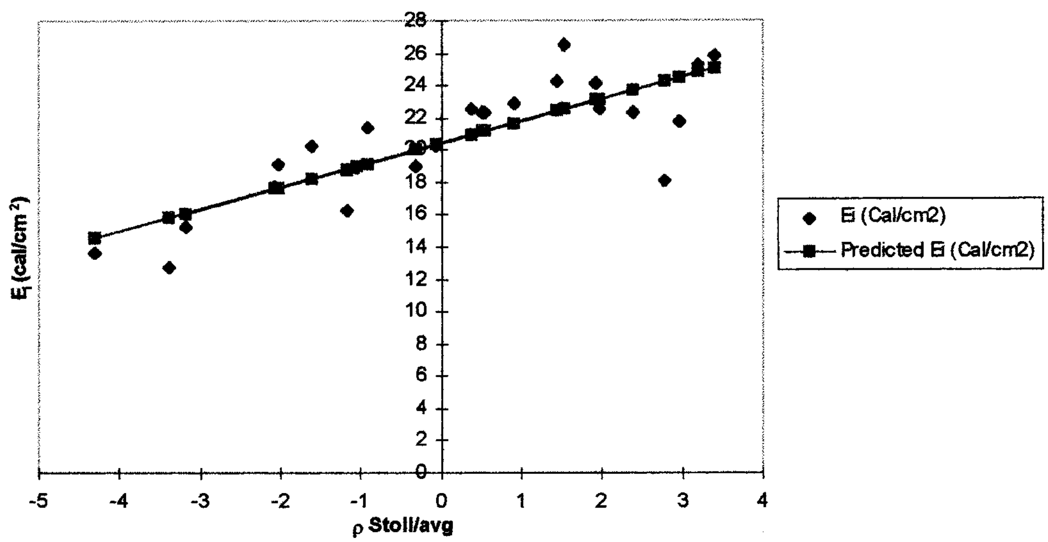

Fig. 5. ATPV is at Stoll = 0. Thus, the ATPV is the onset of second-degree burn injury.

TABLE I
9.5-oz/yd^2 PVC/Nomex Rainwear Material (12-kA Data in Full Results; Table Done at 8 kA in Accordance with ASTM PS58 Standard)

		Lower 95% Confidence Limits	*Upper 95% Confidence Limits*
Arc Thermal Protective Value (ATPV)	20.4 cal/cm^2	19.5 cal/cm^2	21.4 cal/cm^2
Heat Attenuation Factor (HAF)	87.0%	86.5%	87.4%

above their ATPV. More specifics are available in Table II. The new proposed rainwear standard from ASTM should require a test at twice the ATPV to indicate material response at that level.

The original rainwear testing by Louisville Gas & Electric, Louisville, KY, was conducted at the OPT High Current Laboratory at 12 000 A (±600 A) with arc durations from 4 to 16 cycles. Other testing had previously been completed measuring higher amperage exposures. Except as noted, the data in this paper have been updated to reflect new ASTM standard requirements for testing all materials at 8 kA (±500 A). When the original testing was compared to testing done at different amperages, it was discovered that most materials perform differently at different amperage exposures, thus, ASTM set 8 kA as the testing amperage for this method.

1) Our results, to date, show a PVC/Nomex/Kevlar to have the highest ATPV and HAF (see Table II for specifics),

TABLE II
ARC TESTING RESULTS

Material	ATPV, cal/cm^2	HAF, %	E_{BTAS}, cal/cm^2	Approx. Retail Cost, $	Comments
Nomex®/Breathable Urethane/Nomex® 10 oz/yd^2	15	19	30	200	Durable water treatments on outer shell and may need retreatments. Afterflame >2 s at higher levels.
Neoprene/Nomex® 10 oz/yd^2	9.7	71	34	100-250	Chars on the outside. No melting or dripping. No ignition or afterflame.
PVC/Nomex® 9.5 oz./yd^2 Fluorescent Orange (FO) International Orange(IO), Yellow (Y)	IO=14 Y=7.1 FO=4.9	IO=83 Y=65 FO=56	IO=30 Y=30 FO=30	55-80	Afterflame at higher levels for up to 7 s . Coating weight makes large differences. Lower tear strength.
PVC/Kevlar®/Nomex® 8 oz./yd^2 Fluorescent Orange (FO) & Lime-Yellow (FL), International Orange(IO), Yellow (Y)	IO=16 Y=12 FO=7.7 FL=7.8	IO=84 Y=79 FO=68 FL=69	IO=33 Y=36 FO=40 FL=36	75-140	Lightweight Fair tear strength.
PVC/Kevlar®/Nomex® 8 oz./yd^2 Yellow rainwear over 4.5 oz/yd^2 Nomex® shirt material (Royal Blue)	40	94	N/A	N/A	This shows the power of just two layers of clothing in a real switching outfit.
PVC/Kevlar®/Nomex® 8.5 oz./yd^2 Fluorescent Orange rainwear over 4.5 oz/yd^2 Nomex® shirt material (Royal Blue)	29	91	N/A	N/A	Same as above with Fluorescent Orange color
PVC/Kevlar®/Nomex® 8.5 oz./yd^2 Fluorescent Orange (FO) & Lime-Yellow (FL), International Orange(IO), Yellow (Y)	Y=16 FO=7.7	Y=86 FO=69	Y=40 FO=31	75-140	Lightweight Good PVC formulation Excellent tear strength.
Double coated Neoprene/Nylon 10 oz/yd^2	14	82	<26	50-60	Ignited at 29.6 cal/cm^2 *(14 oz/yd^2 Neoprene/Nylon has withstood 30 cal/cm^2. Expect ignition at higher level).*
4.5 oz./yd^2 FR-cotton lined polyurethane/nylon	11	85	19 *	45-60	Lightweight Flaming droplets from nylon

* Outer layer broke open and melted before this level.

closely followed by PVC/Nomex (9.5 oz/yd^2). At some higher levels ($\sim$27 cal/cm^2), the PVC/Nomex (9.5 oz/yd^2) afterflamed on the outer shell longer than 5 s (current ASTM acceptable time allowed for rainsuit materials to afterflame at 2$\times$ their ATPV), but did self-extinguish and the underside was still intact although there was some evidence of softening/melting on the outside. In further testing, we have noticed that, at the higher levels, the afterflame is less than at moderate levels. It should be noted that PVC formulations differ drastically. Another PVC/Nomex which is fluorescent orange has a much lower ATPV of 5–6 cal/cm^2. All fluorescent colors have been shown to have lower ATPV values due to color effect, FR chemical systems, and differences in PVC/plasticizer combinations.

2) The least ignitable material tested was a 10-oz/yd^2 Neoprene/Nomex which never sustained a flame longer than 2 s in 30 cal/cm^2 arc (measured at 30 000 A/15 cycles) or in higher arcs for the EBTAS.
3) A 14-oz/yd^2 Neoprene/Nylon garment also withstood the 30 cal/cm^2. Some consider this weight of fabric to be fairly heavy for rainwear, but it should not be used in switching applications due to the danger of the melting substrate. The 10-oz/yd^2 Neoprene/Nylon ignited (and

did not self-extinguish) at the 30 cal/cm^2 level and this indicates that the 14 oz/yd^2 would also ignite at some higher level and not self-extinguish. Due to this factor, these materials are not recommended for high-level switching jackets.

4) Alhough the FR-cotton-lined polyurethane/nylon did receive an ATPV, it did not withstand an arc of 27 cal/cm^2. This rainwear is no longer recommended for electric utility use due to the spray of melting droplets which has been observed at levels below its ATPV in further testing. The melting of the nylon makes the material unpredictable in the arc.

VII. Recommendations

1) Assess system for "hot spots."
   a) Assess your hazards (use software such as ARCPRO sold by OPT to translate those assessment parameters into cal/cm^2, then assess your clothing needs with available data). Necessary parameters for assessment include the following:
      i) available fault current (amperes);
      ii) breaker clearing times (cycles);
      iii) arc length potential (inches);
      iv) worker distance from arc (inches);
      v) physical constraints which add to potential hazard, such as "arc in a box."
   b) Assess possibilities of reengineering your system to reduce these hazards.
   c) Assess work methods to reduce hazards, including hot sticking, minimum approach distances, setting breakers to "one shot" during hot work, working grounded, and deenergized lines when possible.
   d) Remember to account for the restrictions of arc length due to physical constraints such as busbar distances and source voltage constraints.
2) Assess the need for "switching jackets" or "arc protective jackets" for all exposed workers and consider using rainwear for "double duty," both as switching jackets and rainwear. The rainwear we tested would be more protective against electrical arc than 7.5-oz/yd^2 Nomex "switching jackets" purchased for testing at a cost of $125 (U.S.) each.
3) Complete an end-user comparison of rainwear you choose for switching jackets and have a clothing committee recommend the applications in which to use the chosen rainwear. Keep in mind that you might use two types of rainwear (one less expensive for normal work when not exposed to electrical arc and the more expensive for high-amperage switching applications). You could have the switching rainwear custom designed with a Velcro face flap like the switching jackets currently marketed. These rainsuits should not be used to replace fire suits with supplied air, which are currently used in some substation fire situations. They are only good for electrical arc up to the levels tested.
4) Ensure adequate rainwear whether you choose to use it for switching or not for all line technicians' trucks and for all substation workers. Rainwear is said to meet the ASTM 1506 standard which is no longer acceptable since 1997 after a note was added to the standard forbidding the practice since that method was not intended to test rainwear.
5) Ensure adequate protection for workers involved in high-amperage switching. See NFPA 70-E 2000 version for job-specific recommendations.
6) Remove all non-FR and melting synthetic blends from your system, especially when they are used in an exposed layer.

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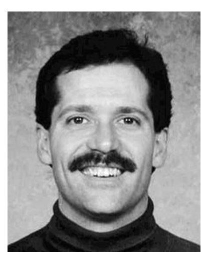

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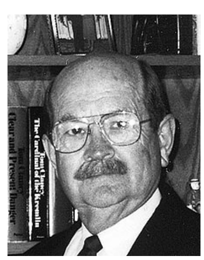

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