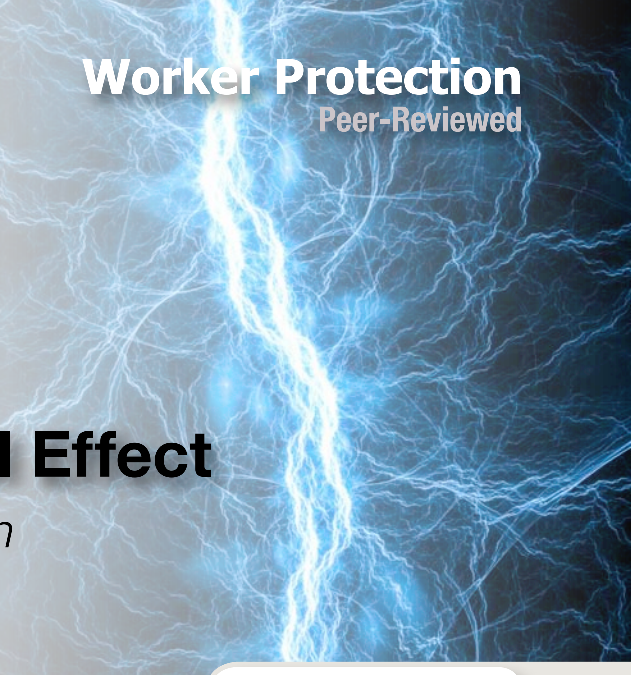


Electric Arc
Protecting Against Thermal Effect
Part 3: State of the Art & Standardization

By Mikhail Golovkov, Holger Schau and Gavin Burdge

IN BRIEF
- **This series of three articles provides a broad overview of today's state of the art for protecting electrical workers against electric arc thermal hazard.**
- **Part 3 discusses arc hazard assessment, limitations of arc rating and research on protective time current curves.**
- **It also identifies standardization misconceptions and associated challenges, and suggests improvements for the future.**

The downward trend of electrical fatalities is a reflection of several factors: ongoing replacement of ignitable materials in electric arc protective clothing that started about 20 years ago, wider awareness about electric arc hazards and improvement in workplace safety standardization. However, little or no change has taken place with arc hazard assessment methods, electric-arc-rated (AR) PPE test methods, and methods of proper AR PPE selection since their original adoption in the late 1990s and early 2000s. This is reflected in the stagnant rate of electric burn trauma with thousands of cases known from available statistics outlined in Part 2 of this series of articles.

Variability of AR numerical values depending on fault current has been known since 2004, but the standardized test method for AR fabric was frozen to only one 8 kA level of test arc current. The test methods have not evolved to include a range of test currents. The fault current occurring in a workplace arc event has an extremely low likelihood of matching the fault current used in the test method. Yet, a numerical value of arc rating is directly used for PPE selection by matching the PPE arc rating to some calculated or otherwise projected value. Reliable statistical support of proper electric arc protection based on current methods of PPE selection is questionable. Nonetheless, new research on electric arc properties, material behavior and classification of arc types opens new opportunities to close existing gaps in electric arc protection.

Assessing Safe Work Conditions & Electric Arc Protection: Perceptions & Challenges

Electrical safety is based on several types of standards: safety rules, hazard assessment, PPE requirements and PPE test methods. AR PPE is often called the last line

Mikhail Golovkov is an independent consultant DBA ArcFlash-CRT specializing in electric arc testing, performing commercial and research arc testing. Prior to this, he was a test contractor and manager for ArcWear.com, and senior test engineer with KEMA-Powertest, which extended his expertise into high-current testing. Golovkov was a high-voltage test equipment designer and test engineer for the Moscow utility Mosenergo. He organized and performed high-voltage diagnostic testing on Russian nuclear power plants and North American utilities. Golovkov holds four Russian patents on high-voltage test equipment and test methods. He holds an M.S. in Electrical Engineering from Moscow Power Engineering Institute, Moscow, Russia, and is a senior member of Institute of Electrical and Electronics Engineers and a member of ASTM F18, which develops standards related to arc-flash test methods.

Holger Schau, Dr.-Ing. habil., Ph.D., is professor and head of the Department of Electrical Power Supply Systems at Ilmenau Technical University. Prior to this, he was a lecturer at the German Leipzig University of Technology, and special project manager for electrical medium and high plants for Starkstrom-Anlagenbau Leipzig-Halle Co. He holds a Dr.-Ing. habil. (Ph.D. in Engineering) from Germany's Ilmenau Technical University. He serves on several electrical safety standard-setting organizations. He is project team leader for IEC 61482-1-2, Technical Committee (TC) 78 (arc box test method), the European equivalent to ASTM F1506 for testing protective clothing of electrical workers from arc thermal hazards. He is member of the European Committee for Electrotechnical Standardization (CENELEC) for live work protective clothing. Schau also works on several technical committees for Verband der Elektrotechnik, Elektronik und Informationstechnik (VDE), the European Association for Electrical, Electronic and Information Technologies, including the German Electrotechnical Committee Standard DKE UK 214.3 (requirements for live electrical work).

Gavin Burdge, CSP, CIH, is a safety and industrial hygiene freelance writer with a industrial hygiene and workplace safety background. He worked as an electrical safety specialist under contract with the U.S. Department of Defense Electrical Safety Working Group. Prior to that he was a senior occupational safety and health analyst with the Naval Safety Center as a consultant to the U.S. Navy Pentagon Safety Liaison Office. He worked in Georgetown University Safety Office and later as a corporate industrial hygienist for a large hazardous waste management firm. Burdge holds an M.S. in Environmental and Occupational Health from West Virginia University. He is a professional member of ASSE's Central Pennsylvania Chapter and is a member of the Society's Industrial Hygiene Practice Specialty.

CAPPAN/ISTOCK/GETTY IMAGES PLUS

TABLE 1

PPE Selection Requirements

NFPA 70E general approach	NESC general approach
"The entire arc flash suit, including the hood's face shield, shall have an arc rating that is suitable for the arc flash exposure."	"The employer shall require employees to wear clothing or a clothing system that has an effective arc rating not less than the anticipated level of arc energy."

of defense against electric arc hazards. This notion is only meaningful if risk assessment and preparation for PPE selection and maintenance are completed according to a company's safety program. The safety program (if one exists) is the document that specifies electrical workplace standards requirements, safe work practices, hazard assessment and PPE requirements.

However, for an electrician who is performing the task with live circuits or component parts, the last line of defense becomes the first line of defense. Nothing else exists between the worker and the electric arc if something unpredicted happens after all recognized hazards and identified steps for safe work have been completed. The key for survival now is properly designed PPE that is tested to a comprehensive test method and adequately selected to the type of potential arc.

Standardization Misconceptions & Consequences

One misconception is that an AR garment standard specification in the North American market exists. Product standards exist in North America that establish requirements for AR face protective PPE (ASTM F2178), AR rainwear (ASTM F1891) and AR fall protection (ASTM F887). However, no standards exist for AR clothing.

ASTM 1506 is promoted on the market as a garment standard. However, this standard specification only applies to flame-resistant (FR) fabric. The full title is Standard Performance Specification for Flame Resistant and Arc Rated Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards. Few cursory garment requirements were written in ASTM 1506. This means that the label on every AR garment contains information regarding textile specification instead of garment specification, which gives a false impression that ASTM 1506 is the garment standard.

With no standardized rules for AR garment construction, garment design may provide inadequate protection. One such example is the addition of vents under each arm and vertical vents along the back for added comfort, thus, introducing cuts and holes in the design. This defies arc-protective properties and leaves open the possibility for either easy ignition of a non-FR underlayer or skin burn, which makes the garment dangerous during an electric arc exposure.

A second misconception is about the arc rating numerical value. Arc rating of PPE is obtained from electric arc testing according to ASTM F1959, F2621, F2675, F2178, F1891 or IEC 61482-1-1 test methods. According to these standards, which use the open-air arc configuration, arc testing is conducted only at one 8 kA (8,000 A) test current level. Different sets of test parameters or different types of arcs return different rating values. As defined in ASTM standards, arc rating is a variable value. In the field, the arcing current is almost never 8 kA. The ASTM F1959 warns about the arc rating variability by including the clause, "Different exposure conditions may produce different results." But the standard stops halfway with the word *may* instead of the more accurate word *will*. Informative explanation or warning of the arc rating variability is currently under ASTM F18 committee consideration.

A third misconception is about the electric arc risk assessment and matching it with adequate protection or PPE arc rating. Table 1 translates the general PPE matching clauses in NFPA 70E and IEEE NESC C-2 standards into calculations for anticipated thermal energy level. The arc ratings selected for PPE requirements are greater than or equal to the calculated value, or are task related.

The calculated incident energy of a potential electric arc exposure is determined using either the IEEE 1584 formulas or ARCPRO software. Several other equations and formulas are available but they are rarely used. IEEE 1584 formulas are the most widely used, as they are built into the major engineering study software suites for electrical systems and networks.

The IEEE 1584 empirical formulas are based on a low-voltage three-phase arc-in-a-box testing with three vertically arranged electrodes. The testing is limited to 600 V with the variable test current and a small arc gap. Formulas were simply prorated into the higher voltages and longer arc gaps. No IEEE testing for arc rating is done for the open air or ejected types of arcs. The empirical ARCPRO equations are based on single-phase medium-voltage open-air test results.

Matching the arc rating to the calculated potential incident energy exposure value that is required by the safety standards can be erroneously interpreted because:

- PPE arc testing is done with open air arc configuration, while IEEE 1584 calculations are based on arc-in-a-box.
- There is variability of the numerical arc rating value depending on fault current.
- There is variability of the arc protective properties for the FR material for different types of arc.
- There is low accuracy and relatability of prorated projections above 600 V calculations.
- No arc rating or calculations are available for the injected arc.

Matching variable numbers obtained from testing to one type of arc with the number calculated using formulas based on another type of arc is a limitation that leads to an inadequate first line of defense.

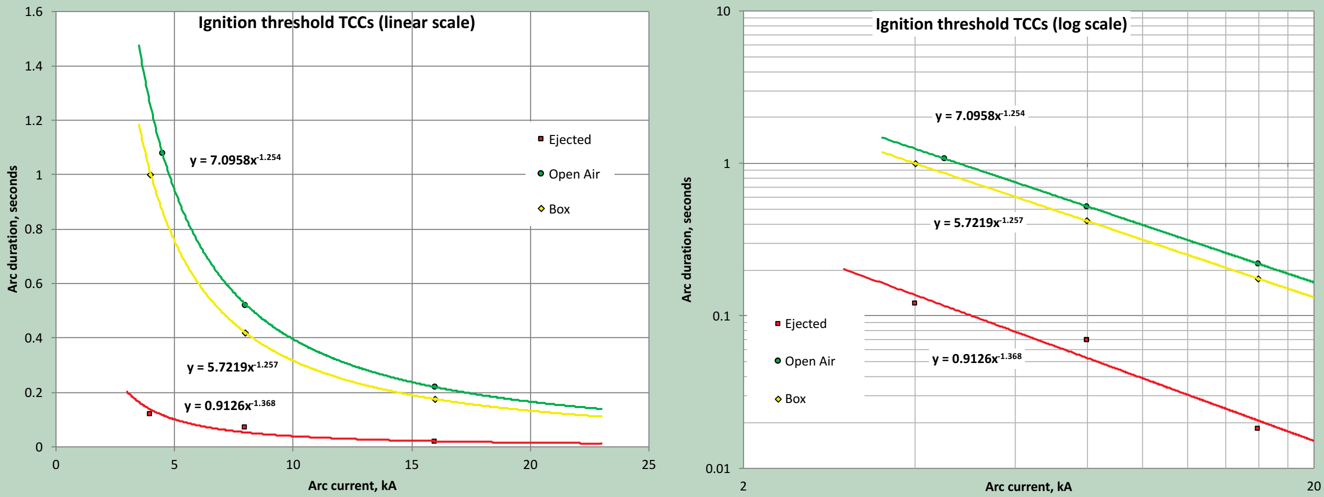
Protective Properties of the AR Material Against Different Types of Arc & for Different Arc Current Magnitudes

Previous Research Testing With Different Types of Arc

The fact that protection properties of AR fabric vary depending on either radiant or convective ther-

FIGURE 1

Non-FR Cotton T-Shirt Test Results & Ignition Time Current Curves



a) Linear scale

b) Logarithmic scale

Ignition threshold was reached		
ejected arc	< 7-10 times faster in ejected arc	open air or arc in a box

c) Arc type dependency

Ignition threshold was reached		
16 kA test current	< At least 5 times faster at 16 kA	2 kA test current

d) Test current dependency

Note. *Adapted from Effect of Arc Electrode Geometry and Distance on Cotton Shirt Ignition, by M. Golovkov, E. Hoagland, H. Schau, et al., 2015,* IEEE Transactions on Industry Applications, 51*(1), 36-45.*

mal energy dissipation has been known for years. For example, AR fabric can lose 50% of its ASTM F1959 open air arc rating when also tested using an arc-in-a-box configuration. Fabric exposures to a predominantly radiant thermal energy are evaluated using the ASTM F1959 open air test method. Neal and Lang (2008) researched fabric exposures to a high share of the convective energy. The same arc test current of 8 kA and the same distance to the arc of 12 in. were used in the box testing, repeating the standard test parameters of the ASTM F1959 test method. However, regardless of the similarity of test parameters, Neal and Lang (2008) illustrated reduction of arc thermal protective value (ATPV) or PPE protective properties against convective heat of arc-in-a-box. In other words, they demonstrated variability of ATPV depending on the electric arc type.

Earlier ASTM research on the ATPV test method found that changes of the test current magnitude correlate with changes in protective properties (ATPV) of AR fabrics (ASTM F18.65, 2004/2005). Presumably, the lower measured ATPV at the lower than 8 kA test current can be explained by the increase of the convective component share in heat dissipation. The increase in measured rating at the higher test current is caused by the increased radiant component in heat dissipation.

Golovkov and Schau's (2016) research on test methods demonstrates the variability of the AR fabric arc rating. Existing standardized arc-test methods are excellent tools for relative comparison among different materials and layers of materials. However, arc rating expressed as a value in cal/cm^2 cannot be absolutized as a universal protection value for all field conditions, for all arc types or for all fault currents.

Differences in thermal energy between different types of electric arcs were also demonstrated by research testing. A non-AR-treated cotton T-shirt was comparatively tested for ignition in open-air arc, arc-in-a-box and ejected arc demonstrating ignition threshold differences (Figure 1).

Uniform test parameters across different arc type test apparatuses were: the arc gap length of 12 in. (except low-voltage arc-in-a-box); distance between arcing electrodes and test T-shirt of 18 in. (distance most commonly used in IEEE 1584).

Ignition threshold was determined in each arc type test setup where cotton T-shirts were exposed to a range of arcs with test currents between 4 kA to 16 kA. Ignition threshold time was determined as the shortest duration of an arc with cotton T-shirt ignition. Ignition time current curves (ITCC) was plotted for each arc type (Figure 1).

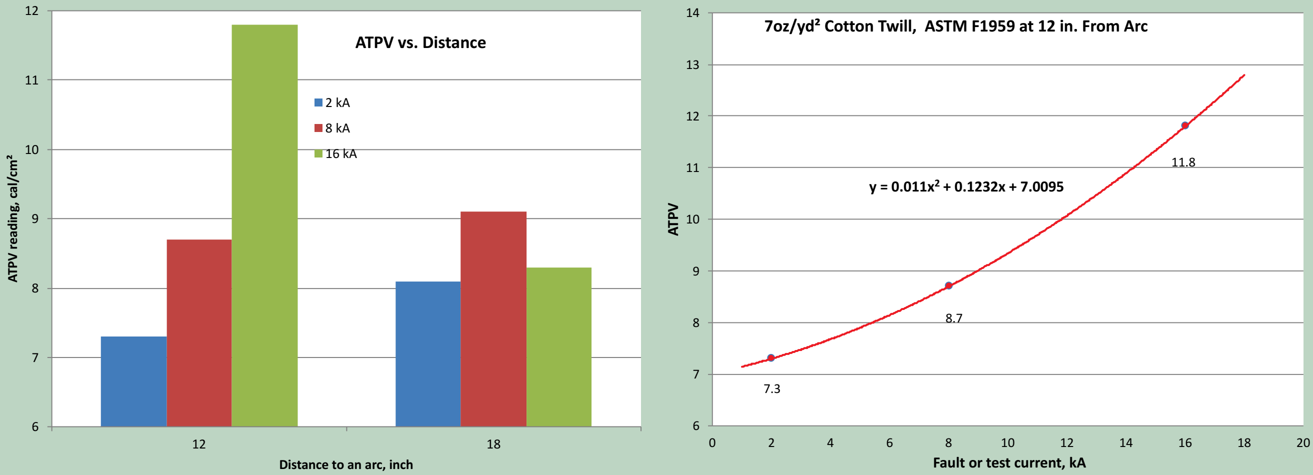
ITCCs were plotted together for direct comparison of severity among different arc types. The ejected arc demonstrated the lowest ignition thresholds across the full spectrum of arc current while the open air and arc in a box demonstrated similar ignition thresholds.

Recent Projects

In addition, Golovkov and Schau (2016) show that arc rating numerical values are also dependent

FIGURE 2

Variability of Arc Rating



a) Dependency on the distance to the arc **b) Dependency on the fault current**

Note. *Adapted from Effect of Arc Electrode Geometry and Distance on FR Fabric Protection Properties Against Second Degree Skin Burn (Conference paper ESW2016-15), by M. Golovkov and H. Schau, 2016, IEEE Electrical Safety Workshop, Jacksonville FL.*

on the distance from the arcing electrodes. The example in Figure 2 illustrates variability of the arc rating of the FR-treated 7 oz/yd^2 cotton fabric.

Obviously, using AR materials for clothing and other PPE makes a difference in protection against electric arc thermal effects and saving lives in electric arc incidents. However, to improve the reliability of AR clothing protection requires a method that is better than a single-number approach in describing electric arc protective properties. A three-dimensional approach for evaluation (i.e., type of arc, fault current, distance from arc) of AR fabric is a path to improved reliability.

Proposed Approach for the Evaluation of the Protective Properties

Golovkov and Schau (2016) tested a different way to evaluate the AR fabric protection where arc rating expressed in cal/cm^2 was not used as a measure of the fabric electric arc protection properties. Instead, the protection time of the fabric using the Stoll criterion for determining the second-degree burn was used. In other words, the maximum arc time duration when thermal energy transferred through the material did not cause the second-degree skin burn. The ASTM F1959 test panel instrumented with calorimetric sensors covered by the test fabric and data processing techniques were used.

The test protocol included determination of the protection times over the range of test currents and plotting protective time-current curves (PTCC) for the 7 oz/yd^2 FR-treated cotton fabric. The testing was repeated for the three arc types: open-air arc, arc-in-a-box and ejected arc (Figure 3).

PTCCs open the possibility for electrical workers to determine the protection time for their clothing they wear using a simple calculator when in the field. The potential arc type is easily assessed visually from equipment and workplace surroundings. Fault current and fault clearing time can be provided from a single line diagram or from a label placed on the equipment. Safe or unsafe conditions can be established by comparing the PPE protective time for the current determined from PTCC and the fault clearing time. The condition is safe if the PPE protective time is longer than the clearing time.

Problems With Electric Incident Reporting & Data Retrieving

BLS Coding System

Two common sources of data for workplace injuries and fatalities are Bureau of Labor Statistics' (BLS) Survey of Occupational Injuries and Illnesses and Census of Fatal Occupational Injuries. After 2010, electrical cases were identified by: 1) contact with electric current unspecified; 2) contact with electric current from machine, tool, appliance or light fixture; 3) contact with wiring, transformers or other components; 4) contact with overhead power lines; 4) contact with underground, buried power lines; 5) struck by lightning; and 6) contact with electric current not elsewhere classified.

Studies that provided information for electrical workplace injuries and fatalities categorized the incident causes into BLS's then classification codes. These codes were used by Cawley and Holmce (2003) considering 1992-1998 occupational electrical injuries in the U.S. where "electric shock caused 99% of fatal and 62% of nonfatal electrical accidents." New changes to BLS electrical injury resulted in "direct" or "indirect" exposure to electricity and these changes eliminated the codes based on electrical energy contact making impossible comparisons with older research as shown in Table 2 (p. 48).

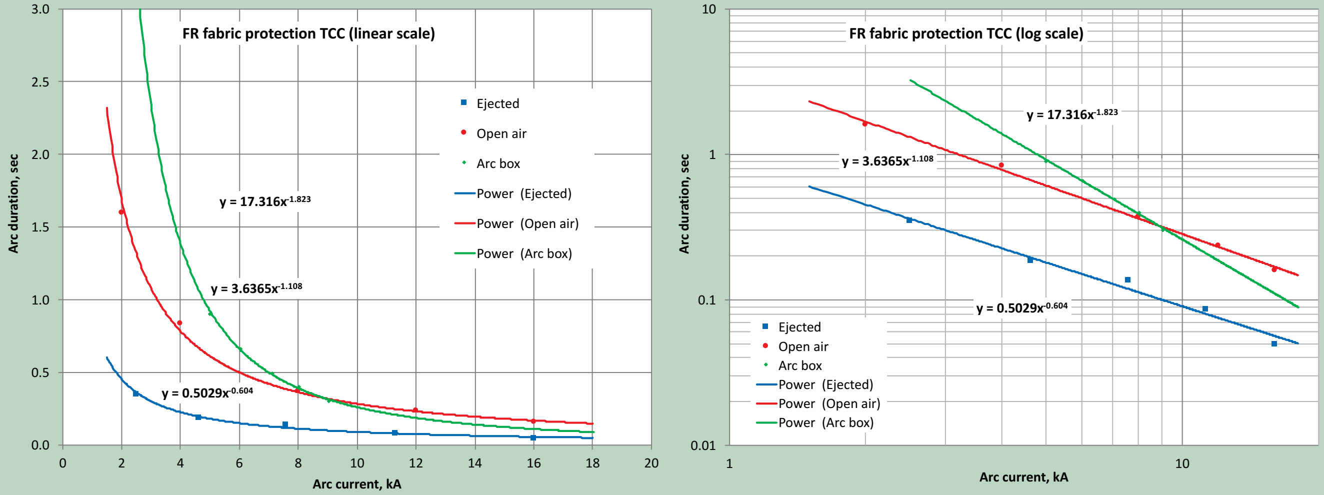
New BLS Coding

The new BLS code for direct exposure to electricity applies to cases in which the injury or illness resulted from direct contact with electricity, including lightning. Contact may be made directly from the power source to the person, such as touching a live wire or being struck by an electrical arc. Items that are intentionally electrified, such as electric fences, are considered direct exposure to electricity.

Another new BLS code is where electrical contact may occur indirectly, such as when a conductive material touches a source of electricity or when electricity is transmitted to an injured worker through a wet surface. Indirect exposure typically occurs when an object is unintentionally electrified.

FIGURE 3

FR Cotton Fabric Arc Protective Time Current Curves



a) Linear scale **b) Logarithmic scale**

Stoll criterion of second degree burn was reached		
ejected arc	< 3-5 times faster in ejected arc	open air or arc in a box

c) Arc type dependency

Stoll criterion of second degree burn was reached		
16 kA test current	< 7-10 times faster at 16 kA	the 2 kA test current

d) Test current dependency

Note. *Adapted from Effect of Arc Electrode Geometry and Distance on FR Fabric Protection Properties Against Second Degree Skin Burn (Conference paper ESW2016-15), by M. Golovkov and H. Schau, 2016, IEEE Electrical Safety Workshop, Jacksonville FL.*

Electric arc injuries or fatalities are included in the code for direct exposure to electricity. Differentiating fatalities or injuries between electrocution from direct electrical system contact and electric arc flash is not possible. Therefore, several limitations exist for obtaining electric arc statistics from BLS.

Burns are not itemized to indicate whether these workplace burns were caused by electricity, chemicals, hot objects or fire. The BLS burn classification includes the corrosive action of chemicals, chemical compounds and fumes. The codes for electrical injuries depend on whether the contact is direct or indirect. An example of direct exposure is contacting power lines during routine utility maintenance or work on electrical systems and components; an example of indirect contact is equipment or conductors contacting high power lines. Also, where a fall from height is caused by contacting electrical current, such as a fall off a ladder during light fixture maintenance, the case is coded as a fall.

In instances where an electric shock initiates a chain of events that results in an impact injury, the appropriate impact event code is selected. For example, if an electric shock knocks a worker from a ladder fracturing his leg, the event is not coded in contact with electric current or as an electrocution, but in Division 4, falls, slips, trips (BLS, 2012).

Conclusions: Challenges & Suggestions

Incident Energy Calculations

A revision of IEEE 1584 is currently in progress. Many more tests have been conducted at low and medium voltage. Five electrode configurations are clamed in new model: VCB, vertical electrodes in a cubic box; VCBB, vertical electrodes with barrier in a cubic box; HCB, horizontal electrodes in a cubic box; VOA, vertical electrodes in open air; and HOA, horizontal electrodes in open air. However, all of these configurations are actually the same three-phase parallel electrodes configuration. Placing the same electrodes inside or outside a box with or without barrier or orienting electrodes vertically or horizontally does not change the arc type. The new model still does not reflect open, moving and ejected arc types.

Standardization

ASTM F18 changed F1506 into a garment standard in 2016. If a name change is approved, the next challenge is the development of comprehensive set of requirements for AR garment construction.

Testing

Variability of the single open arc rating upon fault current must be addressed. A suggested path forward is to replace one-dimensional arc rating to two-dimensional PTCC. ASTM has a taskforce for including the ejected-arc test method. The first draft along with ejected arc configuration also proposes testing at different arc current levels and PTCC.

Electrical Safety & PPE Selection

Examples of different types of potential electric arc include overhead lines, open air medium- and high-voltage substations, enclosed medium-voltage substation equipment, low-voltage enclosed distribution and MCC equipment. Electric arc safe-

TABLE 2

Comparisons of the Old & Revised BLS Codes

Older BLS coding system		New BLS coding	
3100	Contact with electric current unspecified	5110	Direct exposure to electricity, unspecified
3110	Contact with electric current from machine, tool, appliance or light fixture	5111	Direct exposure to electricity, 220 V or less
3120	Contact with wiring, transformers or other components	5112	Direct exposure to electricity, greater than 220 V
3130	Contact with overhead power lines	5120	Indirect exposure to electricity, unspecified
3140	Contact with underground, buried power lines	5121	Indirect exposure to electricity, 220 V or less
3150	Struck by lightning	5122	Indirect exposure to electricity, greater than 220 V
3190	Contact with electric current not elsewhere classified		

ty rules can be more accurately adjusted according to the potential type of arc. PPE selection and testing should be targeted to a specific workplace such as utility transmission and distribution lines, utility substations or industrial low-voltage networks.

Electric Arc Incident Reporting & Statistics

BLS does not have a classification code for electric arc fatalities (BLS, 2012). Generally, electric burn data and arc incident descriptions are hard to retrieve. Partially, lack of arc incident data may be explained by failure to adequately recognize and report on arc injury events. No government regulation currently exists on identifying and reporting electric arc incidents, circumstances and sequence of events. Companies often keep the data confidential. This seems to be a lose-lose situation for both employer and employee when progress in electrical safety is in focus. **PS**

PS EXTRA

Parts 1 and 2 of this three-part article series appeared in the July and August 2017 issues. Read them at www.asse.org/assets/1/7/F3Gol_0717z.pdf; and www.asse.org/assets/1/7/F3Gol_0817z.pdf respectively.

References

ASTM F18.65.O1 (2004/2005). Technical subcommittee testing task group report on arc testing analysis of the F1959 standard test method (Unpublished report).

ASTM International. (2012a). Standard practice for determining response characteristics and design integrity of arc rated finished products in an electric arc exposure (ASTM 2621-12). Retrieved from www.astm.org/Standards/F2621.htm

ASTM International. (2012b). Standard specification for arc and flame resistant rainwear (ASTM F1891-12). Retrieved from www.astm.org/Standards/F1891.htm

ASTM International. (2012c). Standard test method for determining the arc rating and standard specification for eye or face protective products (ASTM F2178-12). Retrieved from www.astm.org/Standards/F2178.htm

ASTM International. (2013). Standard test method for determining arc ratings of hand protective products developed and used for electrical arc flash protection (ASTM F2675/F2675M-13). Retrieved from www.astm.org/Standards/F2675.htm

ASTM International. (2014). Standard test method for determining the arc rating of materials for clothing (ASTM F1959/F1959M-14e1). Retrieved from www.astm.org/Standards/F1959.htm

ASTM International. (2015). Standard performance specification for flame resistant and arc rated textile materials for wearing apparel for use by electrical workers exposed to momentary electric arc and related thermal hazards (ASTM F1506-15). Retrieved from www.astm.org/Standards/F1506.htm

ASTM International. (2016). Standard specifications for personal climbing equipment (ASTM F887-16). Retrieved from www.astm.org/Standards/F887.htm

Bureau of Labor Statistics (BLS). (2012). *Occupational injury and illness classification manual,* version 2.01. Retrieved from www.bls.gov/iif/oiics_manual_2010.pdf

BLS. (2015, Dec.). The quest for meaningful and accurate occupational health and safety statistics. *Monthly Labor Review*. Retrieved from www.bls.gov/opub/mlr/2015/article/pdf/the-quest-for-meaningful-and-accurate-occupational-health-and-safety-statistics.pdf

Cawley, J.C. & Homce, G.T. (2003). Occupational electrical injuries in the United States, 1992-1998, and recommendations for safety research. *Journal of Safety Research*, *34*(3), 241-248.

International Electrotechnical Commission (IEC). (2009). 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 (IEC 61482-1-1:2009). Retrieved from https://webstore.iec.ch/publication/5497

Institute of Electrical and Electronics Engineers (IEEE). (2002). IEEE guide for performing arc flash hazard calculations (IEEE 1584-2002). Retrieved from https://standards.ieee.org/findstds/standard/1584-2002.html

IEEE. (2017). National electrical safety code (IEEE C2-2017). Retrieved from https://standards.ieee.org/findstds/standard/C2-2017.html

Golovkov, M., Hoagland, E., Schau, H., et al. (2015, Jan./Feb.). Effect of arc electrode geometry and distance on cotton shirt ignition. *IEEE Transactions on Industry Applications*, *51*(1), 36-45.

Golovkov, M. & Schau, H. (2016, March). Effect of arc electrode geometry and distance on FR fabric protection properties against second degree skin burn (Conference paper ESW2016-15). IEEE Electrical Safety Workshop, Jacksonville FL.

Neal, T. & Lang, M. (2008, March). The impact of arc flash test conditions on the arc rating of PPE (Conference paper ESW2008-05). IEEE Electrical Safety Workshop, Dallas, TX.

NFPA. (2015). Standard for electrical safety in the workplace (NFPA 70E). Retrieved from www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=70E