

# Six Steps to Arc-Flash Nirvana

In the electrical industry the phrase “arc flash” is generating a lot of interest. Many managers and supervisors are asking “Why?” More to the point, many are saying, “I don’t see how this affects me or my people. We have never had an arc-flash incident.” If this is true, then what is all the fuss about?

## Statistically Speaking

At the 11th Annual IEEE-IAS Electrical Safety Workshop, Cawley and Homce of the Center for Disease Control (CDC)/National Institute of Safety and Health (NIOSH) presented statistics showing that during the period from 1992 through 2001 there were 44,363 electrically-related injuries. The number of nonfatal electrical shock injuries was 27,262, and 17,101 injuries were caused by electric arc-flash burn. Figure 1 is one of the slides presented during that presentation. In statistics presented at



by James R. White  
Shermco Industries

the 3rd International Conference on Electrical Injury in 1998, the Electric Power Research Institute estimated the direct costs of an electrical fatality at \$1.3 million dollars, with total direct and indirect costs reaching between four and ten million dollars.

Serious electrical injuries can be even more devastating to the people involved as well as to the bottom line. Floyd estimated the total of direct and indirect costs of a major electrical accident at \$17.4 million in 2003 dollars. Using the above estimates of costs related to an electrical injury or death, the sum can have a very serious effect on a company’s ability to function. There are also the additional costs for trained personnel to be away from the job recovering from an electrical accident: lost production, increases in workman’s compensation and insurance rates, possible OSHA fines, legal fees — the list

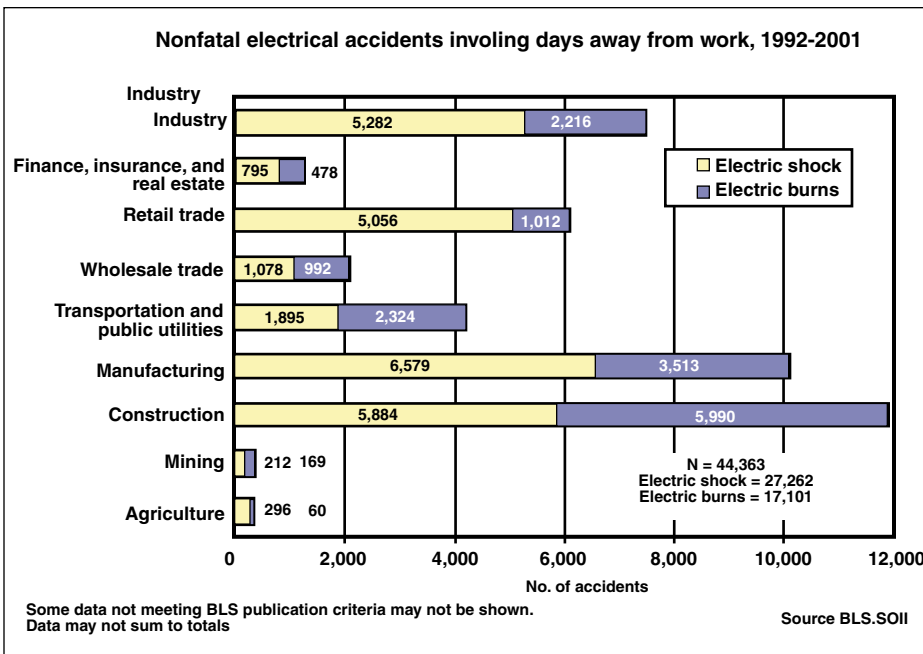


Figure 1

goes on and on. This does not take into account the pain, suffering and emotional costs which cannot be measured.

Another fact brought out by the CDC/NIOSH study is that electrical burn injuries cause a longer stay away from the job site. (See Figure 2.) Note that, even though burns accounted for only 38 percent of the total injuries, they caused a disproportionate number of days lost from work.

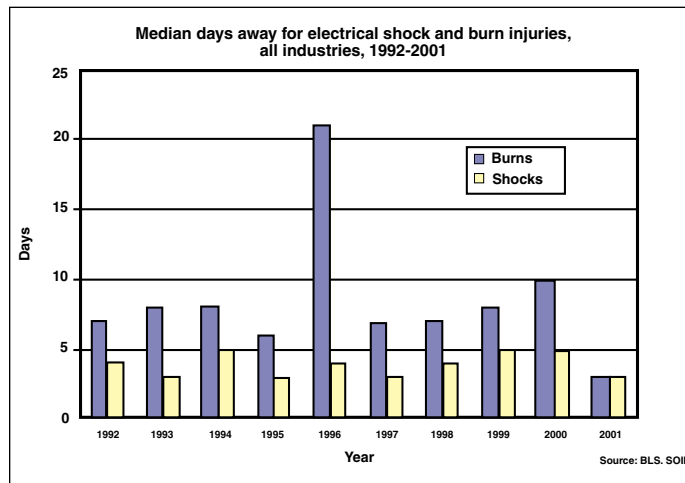


Figure 2

If we try to match the figures given in the CDC/NIOSH study with those in the Bureau of Labor Statistics (BLS) website, we will find that we cannot. Many of the numbers quoted by the CDC/NIOSH study are not available to the general public, so the numbers used do not match up with numbers posted on the BLS website.

The BLS site is somewhat limited in the data sorting it can do, whereas CDC/NIOSH has access to the complete database. Other important facts in that study:

- In the electrical construction industry, 80 percent of electrical injury victims are electrical workers, not laborers or helpers.
- Small companies (fewer than 10 employees) had a disproportionate number of electrical injuries. Figure 3 illustrates company size vs. percent injury.
- Most injuries occur more than six hours into the work shift.

By spending a small amount of time to research this data on the BLS website, management can begin to determine how their company matches up with general industry as a whole and with others in the same industry. Rates per 10,000 workers are also available on the site and may be easier to compare.

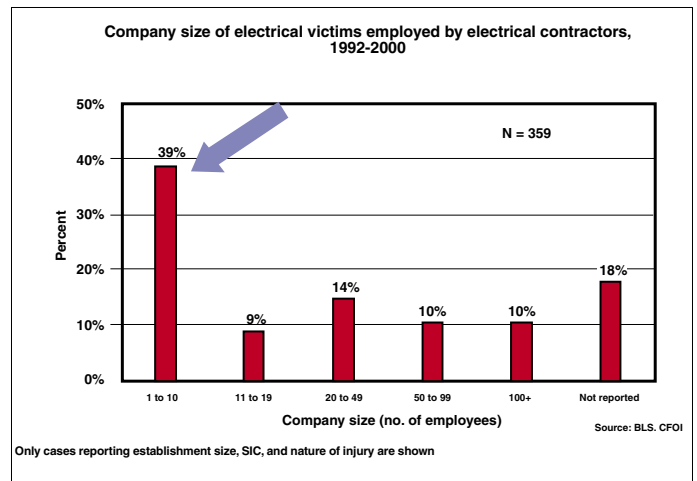


Figure 3

### Step 1: Determine the Flash Protection Boundary and Personal Protective Equipment

Now that the need has been established, what does a company need to do? In the area of arc-flash protection, the first thing is to determine if a danger exists. NFPA 70E, "Standard for Electrical Safety in the Workplace," states in Article 130.3, "A flash hazard analysis shall be done in order to protect personnel from the possibility of being injured by an arc flash. The analysis shall determine the Flash Protection Boundary (FPB) and the personal protective equipment [PPE] that people within the Flash Protection Boundary shall use." So, Step 1 on the list is to determine if the work being done is within the FPB.

The FPB can be calculated using the equations given in 70E or by using one of many available software programs, both freeware and commercial. Cooper-Bussmann has a calculator imbedded in its website that will do the job and is free, although calculations must be performed on the website.

In many cases, especially where the available short-circuit current is 10,000 amperes or less, the FPB may only be a few inches. Some examples of low-energy FPBs (all using 9,600-ampere available short-circuit current and protected by a molded-case circuit breaker) are shown as follows:

- 480 volts — three-phase 7.1 inches
- 277 volts — single-phase 4.1 inches
- 208 volts — three-phase 4.7 inches
- 120 volts — single-phase 2.7 inches

In these instances, correct PPE would be voltage-rated gloves and protectors, safety glasses or goggles, 12 ounces per square yard cotton or flame retardant clothing, and safety shoes. The key in these examples is that the available short-circuit current is less than 10,000 amperes. If a circuit is fed by an AWG 12 or less wire and is supplied by a general-purpose circuit breaker

or fuse (10,000-ampere interrupting rating), it would match the above figures. If the short-circuit available current is higher, the FPB will increase as well. More PPE would be required to match the hazard.

### Step 2: Gather the Information

The next step is to gather the information needed to perform the calculations. Several pieces of information are required, including:

- Available short-circuit current at the point of fault
- Nominal voltage
- Maximum total clearing time of the protective devices
- Working distance
- Type of ground system being used
- Type of protective device (including model numbers and settings)

This is the same information that is derived from the short-circuit analysis and coordination study. It is important that this information is correct and up-to-date or subsequent steps will be pointless.

### Step 3: Perform an Arc-Flash Study

This third step calculates the incident energy that would be received by the worker at the point of contact. The IEEE Guide 1584-2002 can be used to determine the FPB, the incident energy at working

distance, and the PPE required. It is used as a plug-in for many of the available engineering software packages on the market.

The incident energy provided by the spreadsheet calculator will be given in calories per square centimeter and needs to be reviewed to determine if adequate PPE is available and must be documented.

Figure 4 shows a screenshot of the SKM software package used by Shermco Industries when performing arc-flash studies. The FPB, working distance, and incident energy are all detailed. Also given is the NFPA Hazard Risk Category (HRC) required for the worker. If the incident energy is too great, it is flagged and highlighted on the spreadsheet.

One of the issues that arises when performing these calculations is that of the working distance. IEEE 1584 provides recommended working distance for use in its calculations, but in real life people are not so precise. A change of just a few inches can make a tremendous difference in the incident energy received by the worker. Often, increasing the distance by six inches from the component or part to the worker reduces the incident energy 30 percent or more. This cannot be applied in many situations but can be for tasks such as racking circuit breakers in and out of their cubicle. Longer racking handles or remote racking devices can be used to decrease incident energy to a tolerable level.

Bus Name	Protective Device	Bus kV	Bus Bolted Fault (kA)	Prot Dev Bolted Fault (kA)	Prot Dev Arcing Fault (kA)	Trip/Delay Time (sec.)	Breaker Opening Time (sec.)	Ground	Equip Type	Gap	Arc Flash Boundary (in)	Working Distance (in)	Incident Energy (cal/cm2)	Required Protective FR Clothing Class
11USS13.8kV LD	11USS HVFU	13.8	18.08	17.91	17.21	0.01	0	No	SWG	153	9	36	0.30	Class 0
11USS13.8kV LN	SR750 11USS	13.8	18.08	17.91	17.21	0.016	0.083	No	SWG	153	92	36	2.97	Class 1
12USS13.8kV LD	12USS HVFU	13.8	22.79	21.55	17.53	0.08	0	No	SWG	153	80	36	2.60	Class 1 (*3)
12USS13.8kV LN	SR750 12USS	13.8	22.79	21.55	20.63	0.02	0.083	No	SWG	153	122	36	3.91	Class 1
13USS 103B LD	13USS 103B	0.48	60.56	57.65	26.87	0.05	0	No	SWG	32	56	24	4.20	Class 2
13USS 103C LD	13USS 103C	0.48	60.56	57.65	26.87	0.05	0	No	SWG	32	56	24	4.20	Class 2
13USS 103D LD	13USS 103D	0.48	60.56	57.65	26.87	0.05	0	No	SWG	32	56	24	4.20	Class 2
13USS 104B LD	13USS 104B	0.48	60.56	57.65	26.87	0.05	0	No	SWG	32	56	24	4.20	Class 2
13USS 104C LD	13USS 104C	0.48	60.56	57.65	26.87	0.05	0	No	SWG	32	56	24	4.20	Class 2
13USS 13.8kVLD	13USS HVFU	13.8	19.25	18.86	18.1	0.01	0	No	SWG	153	9	36	0.32	Class 0
13USS 13.8kVLN	SR750 13USS	13.8	19.25	18.86	18.1	0.016	0.083	No	SWG	153	97	36	3.15	Class 1
13USS 480V BUS	13USS MAIN	0.48	60.56	45.99	18.22	0.652	0	No	SWG	32	246	24	36.8	Class 4 (*3)
13USS MAIN LN	13USS HVFU	0.48	60.56	45.99	21.44	2	0	No	SWG	32	583	24	131	Dangerous!!!

Figure 4

#### Step 4: Choose the Correct PPE

Correct PPE selection is critical to protecting the worker. After performing the incident energy calculations, the derived calories per square centimeter must be compared with the PPE being considered. Prior to the year 2000, there were no markings on flash protective equipment to show its arc rating. After that date the NFPA 70E required that PPE used as arc-flash protection be marked with the arc rating in calories per square centimeter on the label. Unfortunately, 70E did not specify that the face shield material be rated for the same heat as the rest of the PPE, and some low-dollar providers of PPE sold substandard face shields. This was resolved in the 2004 revision of 70E which requires that the face shield provide the same arc rating as the rest of the flash protection.

According to NFPA 70E, incident energy received by the worker must be reduced to no more than 1.2 cal/cm<sup>2</sup>. As an example, holding one's finger over a match for one second produces an incident energy of 1.0 cal/cm<sup>2</sup>, while 1.2 cal/cm<sup>2</sup> is considered to be the amount of heat required to produce onset of a second-degree burn on unprotected skin. Even though the worker wears arc-flash protective equipment, he can still receive burns if the heat is high enough. The heat passing through the PPE can be high enough to melt the elastic in undergarments. A good rule-of-thumb is to use PPE with an arc rating equal to or greater than the calculated incident energy.

#### Step 5: Mark the Equipment

The 2002 revision of NFPA 70, commonly known as the *National Electrical Code*, requires that new equipment be field-marked to warn of the hazards if the cover is removed. This is stated in Article 110.16:

“Flash Protection. Switchboards, panelboards, and motor control centers in other than dwelling occupancies, that are likely to require examination, adjustment, servicing, or maintenance while energized, shall be field marked to warn qualified persons of potential electric arc-flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.

FPN No. 1: NFPA 70E-2000, Electrical Safety Requirements for Employee Workplaces, provides assistance in determining severity of potential exposure, planning safe work practices, and selecting personal protective equipment.

FPN No. 2: ANSI Z535.4-1998, Product Safety Signs and Labels, provides guidelines for the design of safety signs and labels for application to products.”

This applies to all equipment installed after January, 2002. Why should any company worry about labeling? OSHA has a multiemployer worksite policy (CPL2-0.124) that makes it clear that the equipment owner is just as responsible for contractor safety as the contractor is. If a company allows the contractor on its job site, that company has approved the contractor's safety procedures and policies. Because of this, the smart move for any company is to be proactive, especially where known hazards exist. Employees as well as contracted workers can not always be counted on to know the methods and reasons of arc-flash protection. Many workers lack the training and knowledge needed to choose the right PPE accurately. Labeling the equipment ensures that those who work on power system equipment will be aware of the shock and arc-flash hazard involved and the required flash protective equipment. An example label is shown in Figure 5.

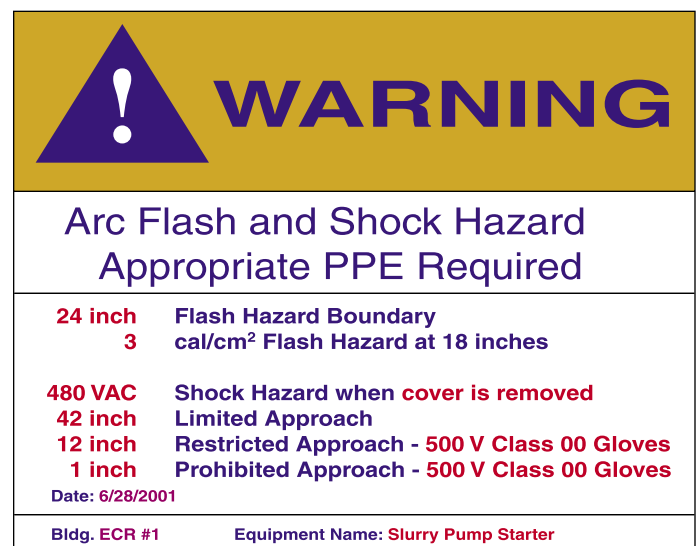


Figure 5

#### Step 6: Train the Workers

OSHA and NFPA 70E require that workers be qualified in order to work on or near energized electrical systems. “Qualified” is defined in 29CFR1910.399 as “one who is familiar with the construction and operation of the equipment and the hazards involved.” Further, 29CFR1910.331(a) states, “The provisions of 1910.331 through 1910.335 cover electrical safety-related work practices for both qualified persons (those who have training in avoiding the electrical hazards of working on or near exposed energized parts) and unqualified persons (those with little or no such training) working on, near, or with the following installations:” [a list of facilities is then given]. This statement requires that qualified workers also be trained in how to avoid the hazards. 29CFR1910.269 has similar requirements for those working on systems rated above 600 volts.

In order for the arc-flash study to be effective, workers must be trained in what the labels mean and how to apply the information on them. One of the first things OSHA does during a site inspection or an accident investigation is to review the training records for that company. Lack of training is often cited as a reason for large fines that come soon afterward. Who needs training? Almost everyone needs training. Unqualified workers must be trained on the hazards of electricity and how to avoid them. Qualified workers must meet the above requirements and other specific requirements given in 29CFR1910.332 and -.269.

Many companies providing on-the-job (OJT) training do a poor job of documenting that training. OSHA will accept OJT, but if a company doesn't document it, it may as well never have happened. Documentation includes date, name of attendee, and topic covered as well as initials or signature of attendee verifying he actually took the OJT.

## NFPA 70E

NFPA 70E has been mentioned a number of times in this paper. It is important for companies to have a copy of this document. In 1979, OSHA asked the NFPA to develop a consensus standard they could use to write the regulations. OSHA has two nonvoting members on the 70E Committee to ensure it stays consistent with the regulations. In fact, NFPA is conducting seminars for OSHA Compliance Officers on how to use 70E when writing citations. OSHA has used 70E as justification for these citations in court, and the court has upheld that practice.

One of the best features of 70E is the set of tables labeled "Table 130.7." These tables are helpful in choosing what PPE would be required for standard tasks performed by electrical workers. Figure 6 shows a partial view of Table 130.7(C)(9)(a), "Hazard/Risk

Table 130.7(C)(9)(a) Continued

Task (Assumes Equipment Is Energized, and Work Is Done Within the Flash Protection Boundary)	Hazard/ Risk Category	V-rated Gloves	V-rated Tools
<b>600 V Class Switchgear (with power circuit breakers or fused switches) — Notes 5 and 6</b>			
CB or fused switch operation with enclosure doors closed	0	N	N
Reading a panel meter while operating a meter switch	0	N	N
CB or fused switch operation with enclosure doors open	1	N	N
Work on energized parts, including voltage testing	2*	Y	Y
Work on control circuits with energized parts 120 V or below, exposed	0	Y	Y
Work on control circuits with energized parts >120 V, exposed	2*	Y	Y
Insertion or removal (racking ) of CBs from cubicles, doors open	3	N	N
Insertion or removal (racking) of CBs from cubicles, doors closed	2	N	N
Application of safety grounds, after voltage test	2*	Y	N
Removal of bolted covers (to expose bare, energized parts)	3	N	N
Opening hinged covers (to expose bare, energized parts)	2	N	N

Figure 6

Table 130.7(C)(10) Protective Clothing and Personal Protective Equipment (PPE) Matrix

Protective Clothing and Equipment	Protective Systems for Hazard/Risk Category						
	Hazard/Risk Category Number	-1 (Note 3)	0	1	2	3	4
<b>Non-melting (according to ASTM F 1506-00) or Untreated Natural Fiber</b>							
a. T-shirt (short-sleeve)	X				X	X	X
b. Shirt (long-sleeve)		X					
c. Pants (long)	X	X	X	X	X	X	X
			(Note 4)	(Note 6)			
<b>FR Clothing (Note 1)</b>							
a. Long-sleeve shirt			X	X	X	X	X
					(Note 9)		
b. Pants			X	X	X	X	X
			(Note 4)	(Note 6)	(Note 9)		
c. Coverall			(Note 5)	(Note 7)	X	(Note 9)	(Note 5)
					(Note 9)		
d. Jacket, parka, or rainwear			AN	AN	AN	AN	AN
<b>FR Protective Equipment</b>							
a. Flash suit jacket (multilayer)							X
b. Flash suit pants (multilayer)							X
<b>c. Head protection</b>							
1. Hard hat			X	X	X	X	X
2. FR hard hat liner					AR	AR	AR
<b>d. Eye protection</b>							
1. Safety glasses	X	X	X	AL	AL	AL	AL
2. Safety goggles				AL	AL	AL	AL
<b>e. Face and head area protection</b>							
1. Arc-rated face shield, or flash suit hood				X			
				(Note 8)			
2. Flash suit hood					X	X	X
3. Hearing protection (ear canal inserts)				X	X	X	X
				(Note 8)			
<b>f. Hand protection</b>							
Leather gloves (Note 2)			AN	X	X	X	X
<b>g. Foot protection</b>							
Leather work shoes			AN	X	X	X	X

Figure 7

Category Classifications.” Each general type of equipment is grouped and common tasks are listed. Each task is assigned a Hazard/Risk Category number (HRC) from HRC0 to HRC4, with HRC4 being the highest. For example, “insertion or removal (racking) of CBs from cubicles, doors closed” (on 600V Switchgear) shows an HRC 2, while the same action with open doors rates an HRC3. It is critical that the notes at the bottom of each table be reviewed and understood. The tables cannot be used outside of the stated limitations; otherwise, injury or death could result.

Table 130.7(C)(10) in Figure 8 shows a partial list of PPE required for the various HRCs. This would be used in conjunction with Table 130.7(C)(11), “Protective Clothing Characteristics” shown in Figure 9.

A change has been made to 70E Table 130.7(C)(9)(a), even though the standard has only been out since April of this year. Some of the notes at the bottom of the table have been revised as follows:


**Note Number                      Changes Made (In Italics)**

- 1 *Maximum of 25*-kiloampere short-circuit current available, 0.03 second (two-cycle) fault clearing time.
- 2 *Maximum of 65*-kiloampere short-circuit current available, 0.03 second (two-cycle) fault clearing time.
- 4 *Maximum of 42*-kiloampere (from 65-kiloampere) short-circuit current available, 0.33 second (20-cycle) fault clearing time.
- 5 *Maximum of 35*-kiloampere (from 65-kiloampere) short-circuit current available, up to *0.5* second (from 1.0 second) *(30-cycle)* (60-cycle) fault clearing time.

Corresponding changes were made within the table to reflect the changes in the notes.

**Summary**

An electrical accident can have far-reaching and severe negative aftereffects. As much as anything else, the litigation that will follow diverts needed resources and hurts morale. Most companies are already pressed for manpower and time. Adding the burden of an arc-flash study, coupled with the time and expertise involved in performing it, can be a daunting task. Many companies offer arc-flash studies and will handle everything from calculations to marking equipment to training.

One last thought on this topic: electrical equipment maintenance. All ratings and calculations are performed with the expectation that protective devices will function correctly, are correctly coordinated, and are set to that coordination study. Our experience has been that this often is not the case. In nearly every facility in which we work, there are breakers and switches that are too slow or nonfunctional due to lack of maintenance. This may increase the time of exposure to an arc from four to six cycles to one to three seconds, or even longer if the next upstream device is required to clear the fault. Under these circumstances, there is no protective equipment that could protect a worker. Adequate maintenance is as critical to safety as the selection of PPE. 

**References**

1. ANSI/NFPA 70, *National Electrical Code*, 2002.
2. ANSI/NFPA 70E, “Standard for Electrical Safety in the Workplace,” April, 2004.
3. Bureau of Labor Statistics website, [www.bls.gov](http://www.bls.gov).
4. Cawley, James, PE and Homce, Gerald T., “Occupational Electrical Injuries in the United States and Recommendations for Safety Research,” *Journal of*

Table 130.7(C)(11) Protective Clothing Characteristics

Typical Protective Clothing Systems		
Hazard/Risk Category	Clothing Description (Typical number of clothing layers is given in parentheses)	Required Minimum Arc Rating of PPE [J/cm <sup>2</sup> (cal/cm <sup>2</sup> )]
0	Non-melting, flammable materials (i.e., untreated cotton, wool, rayon, or silk, or blends of these materials) with a fabric weight at least 4.5 oz/yd <sup>2</sup> (1)	N/A
1	FR shirt and FR pants or FR coverall (1)	16.74 (4)
2	Cotton underwear — conventional short sleeve and brief/shorts, plus FR shirt and FR pants (1 or 2)	33.47 (8)
3	Cotton underwear plus FR shirt and FR pants plus FR coverall, or cotton underwear plus two FR coveralls (2 or 3)	104.6 (25)
4	Cotton underwear plus FR shirt and FR pants plus multilayer flash suit (3 or more)	167.36 (40)

Note: Arc rating is defined in Article 100 and can be either ATPV or E<sub>BT</sub>. ATPV is defined in ASTM F 1959-99 as 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. E<sub>BT</sub> is defined in ASTM F 1959-99 as the average of the five highest incident energy exposure values below the Stoll curve where the specimens do not exhibit breakopen. E<sub>BT</sub> is reported when ATPV cannot be measured due to FR fabric breakopen.

Figure 8

*Safety Research* 34, 2003, pp. 241—248, 11th Annual IEEE Electrical Safety Workshop.

5. Electric Power Research Institute, 3rd International Conference on Electrical Injury. 1998.
  6. Floyd , H. Landis, “Facts on Electrical Incident and Injury Costs,” 11th Annual IEEE Electrical Safety Workshop.
  7. IEEE 1584-2002, “Guide for Performing Arc-Flash Calculations.” October, 2002.
  8. OSHA 29CFR1910.331 - .335, Subpart S, “Electrical Safety-Related Work Practices.”
  9. OSHA 29CFR1910.269, Subpart R, “Electric Power Generation, Transmission and Distribution.”
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James R. White is currently the Training Director for Shermco Industries, a NETA Full Member company. Jim represents NETA on the NFPA’s 70E Committee as the Alternate and is a Level IV certified technician. Jim has spent the last twenty years directly involved in technical skills and safety training for electrical power system technicians.