or any member of the line management of the organization.

- On the other hand, the *employee* is the electrician or other worker. A first or second line supervisor, then, has two roles. He or she might be a representative of the company, operating as an employer, in addition to being an employee.
- The term *owner* has still a different twist. Rather than a person, the owner is the entity that *owns* the equipment or facility. The owner has a role and responsibility that is somewhat different from either employer or employee.

In The Act, OSHA is chartered to establish requirements for *employers*. It has no jurisdiction to assign responsibilities to employees. Therefore, meeting requirements defined by OSHA is the responsibility of the employer (management of the company). It is the employer who must:

- provide for a safe workplace
- establish and implement a safety program
- establish an enforcement policy to ensure that employees follow established practices

In the case where a *contractor* is performing work on a site or facility owned by someone else, some inherent responsibilities must be assumed by the *owner*. Perhaps the most important of those responsibilities is to make sure that the contractor is fully apprised of all hazards existing that might impact the work.

National consensus standards are not similarly constrained. As a result, *NFPA 70E* also assigns responsibility. Responsibility assigned to the employer is the same as in 29 CFR 1910, Subpart S. The employer's responsibilities include the development and implementation of an electrical safety program, and the development of safety procedures and guidelines for an employee safety training program on proper implementation of those procedures.

NFPA 70E suggests that employees are responsible for implementing the program and procedures provided by the employer. The standard goes on to suggest that although responsibility of employer and employee are distinct and clear, the most effective process is to establish a close working relationship between employer and employee in which each has value for the other as they work together.

IX. Electrical Incident and Hazard Prevention

A. Not working on or near

According to OSHA 1910.333(a)(1) and *NFPA 70E* 130.1, workers shall not work on or near exposed live parts except for two demonstrable reasons:

1. De-energizing introduces additional or increased hazards (such as cutting ventilation to a hazardous location) or
2. Infeasible due to equipment design or operational limitations (such as when performing diagnostics and testing for startup or troubleshooting and this work can only be done when circuits are energized).

So, for circumstances other than the two exceptions, the circuits/equipment shall be put in **an electrically safe work condition** prior to commencing electrical work.

B. Electrically safe work condition

An *electrically safe work condition* is a concept first introduced in *NFPA 70E*. This term is now defined in *NFPA 70E* Definitions and the steps to put a circuit in an electrically safe work condition are detailed in 70E-120.1.

The concept embraces several ideas and suggests that six different steps must be taken before an electrical circuit is safe to approach or touch without PPE. Electricians and other workers tend to believe that a circuit is safe to approach or touch if it is de-energized. The fact that injuries continue rather frequently, based upon this belief, proves that additional steps are needed.

Some people also believe that if a lock and tag are placed on a labeled disconnecting means, the equipment is safe to work on. However, other issues must be considered. For example, labels can be marked incorrectly, equipment can be supplied from more than one source, or a temporary conductor could have been installed. It also is feasible that an unrelated energized circuit conductor could contact the conductor leading to the work area.

In other instances, workers outside the area or complicated systems can affect the work area. Often it is assumed that if the contact point is tested for absence of voltage, the point is safe for executing the task. But this only proves that no voltage is present at the time of the voltage test. Voltage could be absent due to a process interlock being open, or a second source of energy could simply be turned off for the moment. Avoiding incidents and injury requires training, planning, and preparation.

NFPA 70E 120.1 requires a process of six discrete and independent steps be executed prior to declaring the existence of an electrically safe work condition. Only after the following steps have been executed can work begin without possible exposure to an electrical hazard.

1. Determine all possible sources of energy. Review all reliable and up-to-date drawings, documentation, and identification tags and labels. Drawings must include *all* energy sources, including temporary and back up power sources.

2. After properly interrupting the load, open all disconnecting devices for the circuit. At this point, the equipment or circuit is simply de-energized.
3. Where possible, visually verify that all disconnecting devices, including drawout circuit breakers, are open. Also check that all disconnecting devices meet appropriate codes and standards.
4. Apply lockout/tagout devices in accordance with documented and established policy. An established policy is an enforced written procedure made available to all employees.
5. Use adequately rated voltage testers to verify the absence of voltage on each point where physical contact is expected. Employees are required to use only voltage testing equipment that is rated by a third party.
6. Where the possibility of induced voltage or stored energy exists, ground the phase conductors before touching them. Where it is reasonable to expect that the conductors could be re-energized due to accidental contact with another source of energy, install grounding devices rated for the available fault current.

Until these six steps have been adequately executed, some potential of exposure to an electrical hazard still exists.

Note: *While putting circuits/equipment in an electrically safe work condition, safe work practices appropriate for the circuit voltage and arc-flash energy level shall be used, including adequate personal protective equipment [70E-120.2(A)]. When a disconnect is opened, the circuit may be de-energized but the circuit is not yet considered to be in an electrically safe work condition until all the above steps of 70E-120.1 are successfully completed. For instance, voltage testing of each conductor, which is a necessary step while putting a circuit in an electrically safe work condition, requires adequate PPE. Essentially the same requirement is in OSHA 1910.333(b) which considers de-energized circuits as energized until all the appropriate steps have been completed successfully.*

C. Shock hazard and flash hazard analysis

If a worker is to work on or near exposed conductors that will not be in an electrically safe work condition, a shock hazard analysis and flash hazard analysis are required.

NFPA 70E 110.8(B)(1)

(a) Shock Hazard Analysis. A shock hazard analysis shall determine the voltage to which personnel will be exposed, boundary requirements, and the personal protective equipment necessary in order to minimize the possibility of electrical shock to personnel.

FPN: See 130.2 for the requirements of conducting a shock hazard analysis.

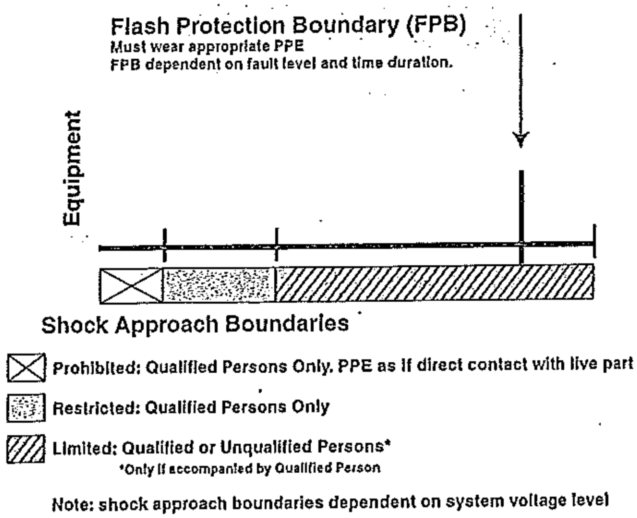
(b) Flash Hazard analysis. A flash hazard analysis shall be done in order to protect personnel from the possibility of being injured by an arc-flash.
The analysis shall determine the Flash Protection Boundary and the personal protective equipment that people within the Flash Protection Boundary shall use.

FPN: See 130.3 for the requirements of conducting a flash hazard analysis.

NFPA 70E has developed requirements to reduce the risk of injury to workers due to shock and arc-flash hazards. There are three shock approach boundaries in *NFPA 70E* Table 130.2(C) that are required to be observed. These shock approach boundaries are dependent upon the system voltage and are discussed in the next section.

As has been discussed, arc-fault currents can release tremendous amounts of energy. *NFPA 70E* requires that before a worker approaches exposed electric conductors or circuit parts that have not been placed in an electrically safe work condition; a flash hazard analysis must be performed. The flash hazard analysis must determine the flash protection boundary (FPB) and level of personal protective equipment (PPE) that the worker must wear. The flash protection boundary is the distance from the energized parts at which a worker could sustain a just curable burn (bare skin) as a result of an arcing fault. A worker entering the flash protection boundary must be qualified and must be wearing appropriate PPE. This will be covered in greater depth in the Flash Hazard Analysis Section.

The following figure depicts the flash protection boundary and the three shock approach boundaries that shall be observed per *NFPA 70E*. In an actual situation, before a worker is permitted to approach equipment with exposed parts that have not been placed in an electrically safe work condition, these boundaries must be determined. In addition, the worker must be wearing the required level of PPE, which can be determined by shock and flash hazard analysis. It is important to observe the shock approach boundaries together with the flash protection boundary; do not only observe the shock approach boundaries to the exclusion of the flash protection boundaries or visa-versa. This figure is an over-simplification. The *NFPA 70E* distance for each boundary is in all directions from the exposed parts, which creates a protection boundary sphere.



D. Approach boundaries for shock protection

Table IX(D) (based on Table 130.2(C) in *NFPA 70E*) provides approach distances to exposed energized electrical conductors. The table identifies boundaries for limited approach, restricted approach, and prohibited approach. The table establishes satisfactory distances between a qualified or unqualified person and conductors that have not been placed in an electrically safe work condition.

- The ***limited approach boundary*** (columns 2 and 3) is the limit of approach distance for unqualified persons to a live part. In concept, unqualified people are less capable of recognizing a shock and flash hazard. Therefore, these persons should remain at a safer distance from open, energized conductors. When there is a need for an unqualified person to cross the limited approach boundary to perform a minor task, or look at equipment, a qualified person shall advise him/her of the possible hazards and ensure the unqualified person is safeguarded. Under no circumstances shall an unqualified person be permitted to cross the restricted approach boundary.

The *exposed movable conductor* (column 2) is intended to mean that either the conductor might move (as in an overhead line) or the person might move (as in an articulating support platform). A fixed circuit part (column 3) refers to a task where the conductor is not expected to move, such as within a unit substation.

- The ***restricted approach boundary*** (column 4) is the closest distance for an *unqualified* person. Under no circumstances shall an unqualified person be permitted to cross the restricted approach boundary. To cross this boundary, a person must meet the following criteria:
  - Be a *qualified* person
  - Have an approved plan
  - Use PPE approved for the conditions
  - Position his or her body in a way that minimizes risk of inadvertent contact

In some instances, work outside the restricted approach boundary but within the person's reach may be classified as restricted work if, in the judgment of the personnel involved, conductive objects or ungrounded body parts could make unintentional contact or cross the prohibited approach boundary.

- The ***prohibited approach boundary*** (column 5) is the minimum approach distance to an exposed energized conductor or circuit part and is the closest point to prevent flashover. To cross this boundary and enter the prohibited space shall be considered the same as making contact with exposed energized conductors or circuit parts.

To cross the prohibited approach boundary, the qualified person must do the following:

- Have specified training to work on energized conductors or circuit parts
- Have a documented plan that justifies the need to work inside the prohibited approach boundary
- Perform a hazard risk analysis
- Have both the documented justification plan and the hazard risk analysis approved by the site manager
- Use PPE appropriate for working on exposed energized conductors or circuit parts and rated for the voltage and energy level involved

Table IX(D). Approach Boundaries to Live Parts for Shock Protection [*NFPA 70E*, Table 130.2(C)]

1	2	3	4	5
	Limited Approach Boundary[1]		Restricted Approach Boundary[1]	Prohibited Approach Boundary[1]
Nominal Voltage Range Phase-to-Phase	Exposed Movable Conducter	Exposed Fixed Circuit Part	Includes Inadvertent Movement Adder	
0 to 50	Not specified	Not specified	Not specified	Not specified
51 to 300	10 ft. 0 in.	3 ft. 6 in.	Avoid contact	Avoid contact
301 to 750	10 ft. 0 in.	3 ft. 6 in.	1 ft. 0 in.	0 ft. 1 in.
751 to 15 kV	10 ft. 0 in	5 ft. 0 in.	2 ft. 2 in.	0 ft. 7 in.
15.1 kV to 36 kV	10 ft. 0 in.	6 ft. 0 in.	2 ft. 7 in.	0 ft. 10 in.
36.1 kV to 46 kV	10 ft. 0 in.	8 ft. 0 in.	2 ft. 9 in.	1 ft. 5 in.
46.1 kV to 72.5 kV	10 ft. 0 in.	8 ft. 0 in.	3 ft. 3 in.	2 ft. 1 in.
72.6 kV to 121 kV	10 ft. 8 in.	8 ft. 0 in.	3 ft. 2 in.	2 ft. 8 in.
138 kV to 145 kV	11 ft. 0 in.	10 ft. 0 in.	3 ft. 7 in.	3 ft. 1 in.
161 kV to 169 kV	11 ft. 8 in.	11 ft. 8 in.	4 ft. 0 in.	3 ft. 6 in.
230 kV to 242 kV	13 ft. 0 in.	13 ft. 0 in.	5 ft. 3 in.	4 ft. 9 in.
345 kV to 362 kV	15 ft. 4 in.	15 ft. 4 in.	8 ft. 6 in.	8 ft. 0 in.
500 kV to 550 kV	19 ft. 0 in.	19 ft. 0 in.	11 ft. 3 in.	10 ft. 9 in.
765 kV to 800 kV	23 ft. 9 in.	23 ft. 9 in.	14 ft. 11 in.	14 ft. 5 in.

Notes:

[1] See Glossary in section XIII for definition of terms.

All dimensions are distance from live part to worker.

For SI Units: 1in = 25.4mm; 1ft = 0.3048m.

For flash protection boundary, see NFPA 70E; 130.3(A)(1).

Column No. 1: The voltage ranges group voltages that require similar approach distances based on the sum of the electrical withstand distance and an inadvertent movement factor. The value of the upper limit for a range is the maximum voltage for highest nominal voltage in the range based on ANSI C84.1-1995, Electric Power systems and equipment—Voltage Ratings (60Hz). For single-phase systems, select the range that is equal to the system's maximum phase-to-ground voltage times 1.732.

Column No. 2: The distances in this column are based upon OSHA's rule for unqualified persons to maintain a 10ft (3.05m) clearance for all voltages up to 50kV (voltage-to-ground), plus 0.4in (102mm) for each 1kV over 50kV.

Column No. 3: The distances are based on the following:

- 750V and lower, use NEC Table 110.26(a) Working Clearances, Condition 2 for 151-600V range.
- For voltages over 750V, but not over 145kV, use NEC Table 110.34(a) Working Space, Condition 2.
- For over 145kV, use OSHA's 10 foot (3.05m) rules as used in Column No. 2.

Column No. 4: The distances are based on adding to the flashover dimensions shown above the following inadvertent movement distance:

- 300V and less, avoid contact, based upon experience and precautions for household 120/240 systems.
- Over 300V and not over 750V, add 1 foot 0 inches inadvertent movement. These values have been found to be adequate over years of use in ANSIC2, National Electrical Safety Code, in the approach distances for communication workers.
- Over 72.5kV, add 1 foot 0 inches inadvertent movement.

These distances have been found to be adequate over years of use in the NESC in the approach distances for supply workers.

Column No. 5: The distances are based on the following:

- 300 and less, avoid contact.
- Over 300 but less that 750V, use clearances from NEC table 230.51(C).
- Between open conductors and surfaces, 600V not exposed to weather.
- Over 750V but not over 2.0kV, value selected that fits in with adjacent values.
- Over 2kV but not over 72.5kV, use NEC Table 490.24, "Minimum Clearance of Live Parts," outdoor phase-to-ground values.
- Over 72.5kV, add 0 foot 6 inches inadvertent movement.

These values have been found to be adequate over years of use where a hazard/risk analysis, either formal or informal, has been performed of a special work procedure that allows closer approach than that permitted by the restricted approach boundary distance.

E. Flash hazard analysis

A flash hazard analysis must be performed before work can be done on or near exposed circuits that have not been put in an electrically safe work condition.

> *NFPA 70E section 110.8(B)(1)(b):*
>
> *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 and the personal protective equipment that people within the Flash Protection Boundary shall use.*

> *NFPA 70E Flash Protection Boundary definition:*
>
> *An approach limit at a distance from exposed live parts within which a person could receive a second-degree burn if an electrical arc-flash were to occur.*

Because workers might need to work on or near equipment not in an electrically safe work condition, additional safety measures must be taken. Since electrical arcs can seriously burn workers, *NFPA 70E* has adopted procedures to provide safe working distances from a hazardous arc. Whenever work is to be done on or near exposed parts not in an electrically safe work condition within the flash protection boundary (FPB), the worker(s) must wear the proper PPE for the potential arc-flash hazard. Note: this includes testing for absence of voltage while putting a circuit in an electrical safe work condition.

The two variables that have the greatest impact on the amount of energy released during an arcing fault are the available bolted fault current, and the time it takes the overcurrent protective device to clear the fault. Different types of overcurrent protective devices can have opening times that vary greatly. Current-limiting devices will open in less than $\frac{1}{2}$ cycle in their current-limiting range, while devices that incorporate a short-time delay can take up to 30 cycles to open. If not properly maintained, circuit breakers could have unintentionally longer clearing times, resulting in higher hazard levels (for more information see Section X(M)).

Different methods are available for conducting a flash hazard analysis for systems 600V or less. No matter which method of flash hazard analysis is used, certain information is required for a proper assessment. In this publication, three methods are discussed for systems 600V or less:

1. Determine FPB and Hazard Risk Category/PPE Using Tables in *NFPA 70E*
2. Calculate FPB and Incident Energy Using *NFPA 70E* Formulae
3. NEW Determine FPB and Incident Energy Using IEEE 1584

Method 1: Determine FPB and Hazard Risk Category/PPE Using Tables in *NFPA 70E*
(See Example 1 on page 30)

FPB:

If the overcurrent protective device has a clearing time of 6 cycles or less and available fault current of 50kA or less (or any combination where the product of clearing time and available fault current does not exceed 300kA cycles or 5000A-seconds) *70E*-130.3(A)(1) allows a flash protection boundary of 4 feet to be used.

There are equations in *70E*-130.3(A)(1) that can be used to calculate the flash protection boundary. These equations shall be used when the clearing times and bolted fault currents are greater than 300kA cycles, or may be used as an alternative to the 4 feet FPB when under engineering supervision. They are based upon the work outlined in a technical paper by Ralph H. Lee, "The Other Electrical Hazard: Electrical Arc-blast Burns," in *IEEE Transactions on Industrial Applications*, Volume IA-18. No.3, May/June 1982. Either of the following formulae may be used for this calculation.

$$D_c = [2.65 \times MVA_{bf} \times t]^{1/2} \text{ (ft)}$$

or

$$D_c = [53 \times MVA \times t]^{1/2} \text{ (ft)}$$

Where:

- D_c = flash protection boundary in feet
- MVA_{bf} = bolted 3-phase fault MVA at point involved = 1.73 x voltage L-L x available short-circuit current x 10^{-6}
- MVA = MVA rating of transformer (For transformers with MVA ratings below 0.75 MVA, multiply the transformer MVA rating by 1.25)
- t = time of arc exposure in seconds

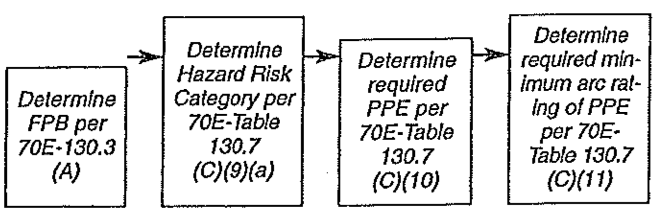
The first formula is more accurate, since it accounts for conductor impedance in the circuit. Note the two important circuit variables in each equation are available short-circuit current and time of arc exposure. MVA_{bf} is the bolted three-phase short-circuit available expressed in millions of volt-amps. The other critical variable is time. Energy released in an electrical arc escalates rapidly. The flash protection boundary therefore is dependent on the characteristics of the overcurrent protective device. An overcurrent device should be selected that limits the arc time duration and, if possible, limits the magnitude of the current. When the fault current is within the current-limiting range of current-limiting fuses, the arc-flash hazard is generally reduced. Current-limiting fuse equivalent RMS let-through data (where available) can be used in the flash distance formula. Where data is unavailable, the full available short circuit should be used.

PPE from tables: The flash hazard analysis must also determine the proper PPE. The PPE can be selected by using tables in *NFPA 70E*. It is important to note that several qualifiers to these tables must be satisfied to use the tables. The result is that the overcurrent protective device opening time, and available fault current, must be known in order to use the tables properly. This point is made in the following:

> *NFPA 70E section 130.7(C)(9)(a):*
>
> *For tasks not listed, or for power systems with greater than the assumed short circuit current capacity or with longer than the assumed fault clearing times, a flash hazard analysis is required in accordance with 130.3.*

70E-Table 130.7(C)(9)(a) *Hazard Risk Category Classifications* allows users to determine the hazard risk category for a specific work task simply by using this table. The table lists several types of electrical equipment and specific tasks to be performed. The user selects the equipment and task that will be performed and reads across the row to determine the hazard risk category and also whether voltage-rated gloves and/or voltage-rated tools are required. The hazard risk categories are 0, 1, 2, 3, and 4. If the task to be performed is not listed in the tables, or the table qualifiers are not met, the PPE shall be selected by calculating the incident energy (see methods 2 and 3, following).

Once the hazard risk category has been determined, 70E-Table 130.7(C)(10), Protective Clothing and Personal Protective Equipment (PPE) Matrix, can be used to select the required PPE. 70E-Table 130.7(C)(11), Protective Clothing Characteristics, is then used to determine the required minimum arc rating of the PPE. See Example 1 on page 30.



Method 2: Calculate FPB and Incident Energy Using *NFPA 70E* Formulae
(See Example 2 on page 31.)

FPB: The flash protection boundary is determined using one of the equations in Method 1 discussed previously.

PPE from calculations: With this method, the first step is to determine the thermal energy an arcing fault would release for the specific circumstances, and then determine the PPE. A calculation is made to determine the value for the arc-flash energy release. Typically, what is calculated is the incident energy, which is a thermal energy measurement (calories or joules) over an area (typically centimeter squared) at a distance the workers head and torso would be from the arc. Incident energy is measured in cal/cm² or joules/cm². The industry has generally accepted 18 inches as a typical working distance for calculating the incident energy on low voltage systems. However, it can be calculated at different distances if required. The equation to calculate the incident energy is found in *NFPA 70E* Annex D, D.6.2. The formula is taken from a paper by R.L. Doughty, T.E. Neal, and H.L. Floyd II, "Predicting Incident Energy to Better Manage the Electric Arc Hazard on 600V Power Distribution Systems," Record of Conference Papers, IEEE IAS 45th Annual Petroleum and Chemical Industry Conference, September 28-30, 1998.

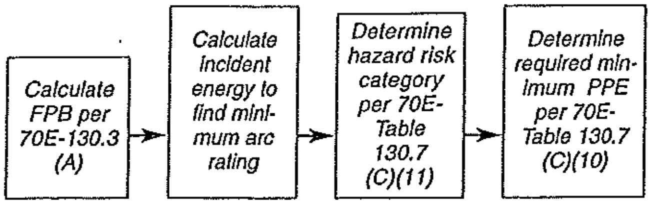
$$E_{MB} = 1038.7 D_B^{-1.4738} t_A [0.0093F^2 - 0.3453F + 5.9675]$$

Where:

E_{MB} = incident energy, cal/cm²
D_B = distance, inches (for distances ≥ 18 inches)
t_A = arc duration, in seconds
F = bolted fault, short-circuit current, kA (16-50kA)

Note: *The formula is applicable for a range of 16kA to 50kA short-circuit current.*

Just as with the flash protection boundary equation, the incident energy is also a function of the available fault current and the time it takes the overcurrent protective device to clear the fault. Equivalent RMS let-through data, (where available) can be used in the incident energy formula. Where data is unavailable, the full available short circuit should be used. This incident energy will determine the required minimum arc rating of the PPE. The calculated incident energy then can be used to determine the hazard risk category from 70E-Table 130.7(C)(11), and the actual PPE required is found in 70E-Table 130.7(C)(10).



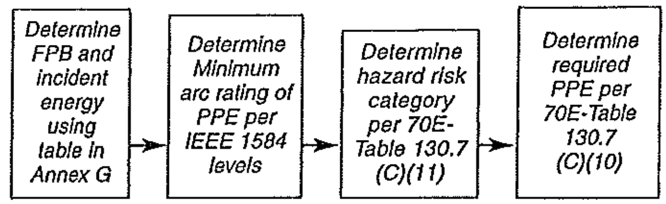
Method 3: Determine FPB and Incident Energy Using IEEE 1584
(See Example 3 on page 33.)

This is a newer method that is included in *NFPA 70E*, Annex D. It is IEEE 1584 *Guide for Performing Arc-flash Hazard Calculations.* IEEE 1584 used extensive testing and analysis to develop new formulae for doing a flash hazard analysis. IEEE 1584 has several calculation alternatives.

IEEE 1584 simplified method: IEEE developed formulae to calculate incident energy for current-limiting fuses and low-voltage circuit breakers. These equations allow the incident energy to be calculated directly from the available three-phase bolted fault current on a 480V system if the type and ampere rating of overcurrent protective device is known. This simplified method does not require the availability of time current curves for the devices. The **fuse formulae** are based on actual arc-flash test data using Cooper Bussmann LOW-PEAK® fuses. The circuit breaker formulae were developed by analyzing typical circuit breaker operation and calculated arcing currents. Because there are several equations dependent on the type, and size of the overcurrent protective device and range of fault currents, the equations are not reprinted here. These equations can be found in IEEE 1584 Sections 5.6 and 5.7 and in D.8.6 in *NFPA 70E*, Annex D.

For convenience, the incident energy and flash protection boundaries for LOW-PEAK® fuses and circuit breakers, based on IEEE 1584, have been presented in an easy-to-use tabular format in Annex G of this book. This table makes it simple to find the incident energy and flash protection boundary based on the available three-phase bolted fault current at 480V and the type of overcurrent protective device. This information is also available using an interactive online calculator at www.bussmann.com.

The notes in Annex G should be read before using the table in Annex G. The calculations in this table were created so that the PPE selected from the calculated incident energy would be adequate for 98% of arc-flash incidents. In up to 2 percent of incidents, the level of PPE may be one level too low. For IEEE 1584, the set of PPE arc ratings were chosen as 1.2, 8, 25, 40, and 100cal/cm². For incident energy results that fall between these values, PPE with the next higher standard arc rating must be used. For instance if the incident energy is calculated to be 11cal/cm², the PPE used must have a 25cal/cm² arc rating. PPE with intermediate arc ratings can be utilized per this method, but at the next lower arc rating. If intermediate arc ratings are not utilized at the next lower arc rating, there is a higher probability that the PPE will not be adequate for an arc-flash incident.



IEEE 1584 other methods: Using IEEE 1584, the arcing fault current is calculated based on the available bolted fault current and then the arcing current is used to determine the opening time of the overcurrent protective device. Using this opening time and the arcing current, the incident energy is calculated using formulae. IEEE 1584 uses the incident energy to calculate a flash protection boundary.

Summary on flash hazard analysis

Methods 1, 2, and 3 are acceptable ways to conduct the flash hazard analysis. With each method the available three-phase bolted fault current must be known. If the available bolted fault current is not known, it must be calculated before performing a flash hazard analysis. With methods 1 and 2, the opening time of the overcurrent protective device must be known. Although different analysis methods are likely to provide different results, the requirement is that *some* method be used to enable a worker to select arc rated PPE. An employer should select one method to assess the arc-flash hazard. The selection should be based on the overall work environment at the work site. The desired result of the analysis, regardless of which method is chosen, is that a worker must be able to select flame-resistant PPE. One factor directly associated with the selection is that workers must understand the procedure, and supervisors must be able to administer it. The most important issue is that workers wear PPE that has an adequate arc rating and that all exposed body parts within the flash protection boundary are covered by arc rated, flame-resistant material. The idea is to consider the following elements and then identify a safe working distance to avoid an arc-flash injury.

- Available three-phase bolted fault current
- Current that is "let-through" by the overcurrent device (if current-limiting)
- Length of time the fault current is permitted to flow

If the skin's surface is covered with clothing, the analysis objective changes. In this situation, the objective is to avoid ignition or breakopen of the clothing material. Should the apparel be ignited, the exposure time to a very high temperature is much greater. Clothing must not add to the degree of the injury.

The following example provides some insight into typical situations:

Example 1 Using Method 1 - FPB and Hazard/Risk Category/PPE Tables in *NFPA 70E*:

Use Method 1 to determine the flash protection boundary and required PPE to perform voltage testing on a 480V motor control center (MCC). The available three-phase bolted fault current is 18,000A. The opening time of the feeder overcurrent protective device upstream from the MCC is 1 cycle (0.0167 seconds).

The flash protection boundary must be established. The combination of available bolted fault current and the device clearing time is 18kA cycles (<300kA cycles); therefore 4.0 feet can be used as the flash protection boundary.

Next, find the correct heading in 70E-Table 130.7(C)(9)(a) (excerpts are printed below), which is 600V *Class Motor Control Centers (MCCs).* Notice the references to Notes 2 and 3. These notes must be checked to verify that the qualifications are met. If the qualifications are not met, the table cannot be used, and a calculation method shall be used. Note 2 states an assumed short-circuit current of 65kA, and an assumed fault clearing time of 0.03 seconds (2 cycles). Note 3 allows the Hazard/Risk Category to be reduced by one number if the available fault current is below 10kA. With 18,000A available and a 1-cycle clearing time, we are within the limits of the assumed short-circuit current and fault clearing time; therefore the table can be used, but the Hazard/Risk Category cannot be reduced.

Excerpts from Hazard Risk Category Classifications (*NFPA 70E* Table 130.7(C)(9)(a))

Task (Assumes Equipment is Energized, and Work is Done Within the Flash Protection Boundary)	Hazard/ Risk Category	V-rated Gloves	V-rated Tools
Panelboards rated 240V and below - Notes 1 and 3	—	—	—
• • •	• • •	• • •	• • •
600V Class Motor Control Centers (MCCs) — Notes 2 (except as indicated) and 3	—	—	—
• • •	• • •	• • •	• • •
CB or fused switch or starter 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 120V or below, exposed	0	Y	Y
• • •	• • •	• • •	• • •

Legend:

V-rated Gloves are gloves rated and tested for the maximum line-to-line voltage upon which work will be done.
V-rated Tools are tools rated and tested for the maximum line-to-line voltage upon which work will be done.
2* means that a double-layer switching hood and hearing protection are required for this task in addition to the other Hazard/Risk Category 2 requirements of Table 130.7(C)(10).
Y = yes (required)
N = no (not required)

Notes:

1. 25kA short circuit current available, 0.03 second (2 cycle) fault clearing time.
2. 65kA short circuit current available, 0.03 second (2 cycle) fault clearing time.
3. For <10kA short circuit current available, the Hazard/Risk Category required may be reduced by one number.
4. 65kA short circuit current available, 0.33 second (20 cycle) fault clearing time.
5. 65kA short circuit current available, up to 1.0 second (60 cycle) fault clearing time.
6. For <25kA short circuit current available, the Hazard/Risk Category required may be reduced by one number.

Once it is verified that the table can be used, the task is selected under the equipment heading. In this case, work on energized parts, including voltage testing. The Hazard/Risk Category for this task is 2*, and V-rated Gloves and Tools are required (denoted by 'Y' in those columns). The legend explains that 2* means that a double-layer switching hood and hearing protection are required for this task in addition to the other Hazard/Risk Category 2 requirements of 70E-Table 130.7(C)(10).

70E-Table 130.7(C)(10) Protective Clothing and Personal Protective Equipment (PPE) Matrix requires the following equipment for Category 2. This table also has a legend and Notes that should be referenced. (After this listing are the applicable notes.):

Non-melting (according to ASTM F 1506-00) or Untreated Natural Fiber

- T-shirt (short-sleeve)
- Pants (long) (Note 6)

FR Clothing (Note 1)

- Long-sleeve shirt
- Pants (Note 6) - Alternate is to use FR coveralls (minimum arc rating of 4) over non-melting or untreated natural fiber pants and T-shirt.

FR Protective Equipment

- Hard hat
- Safety glasses or safety goggles
- Flash suit hood (face shield is not allowed because of the 2* requirement from 70E-Table 130.7(C)(9)(a))
- Hearing protection (ear canal inserts) (Note 8)
- Leather gloves (Note 2)
- Leather work shoes

NFPA 70E Table 130.7(C)(10) Notes:

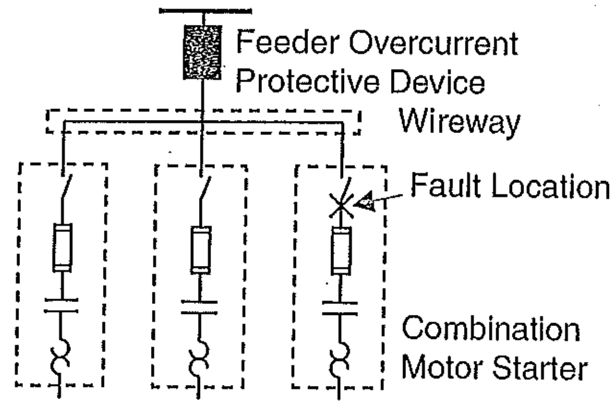
1. See Table 130.7(C)(11). Arc rating for a garment is expressed in cal/cm².
2. If voltage-rated gloves are required, the leather protectors worn external to the rubber gloves satisfy this requirement.
6. If the FR pants have a minimum arc rating of 8, long pants of non-melting or untreated natural fiber are not required beneath the FR pants.
7. Alternate is to use FR coveralls (minimum arc rating of 4) over non-melting or untreated natural fiber pants and T-shirt.
8. A faceshield with a minimum arc rating of 8, with wrap-around guarding to protect not only the face, but also the forehead, ears, and neck (or, alternatively, a flash suit hood), is required.

Finally, since the hazard/risk category is 2*, 70E-Table 130.7(C)(11) (see page 35) requires all PPE for this work task to have a minimum arc rating of 8cal/cm².

The minimum requirement is that qualified persons within 4.0 feet of exposed energized parts for this task shall wear an untreated cotton T-shirt, 8cal/cm² long-sleeve shirt, 8cal/cm² long pants, hard hat, safety glasses, 8cal/cm² flash hood, hearing protection, Class 00 insulating gloves and leather protectors. Substitutions are allowed in accordance with *NFPA 70E*. 1000V rated insulated tools are also required. Unqualified persons shall not enter the flash protection boundary.

Example 2 Using Method 2:

Calculate FBP and incident energy - *NFPA 70E* Formulae: Use Method 2 to determine the flash protection boundary and required PPE for the circuit from Tests 4 and 3 shown in Section VI. The available three-phase bolted fault current is 22,600A at 480V. Because it is possible to initiate a fault on the line side of the branch-circuit short-circuit device inside the combination motor starter, the device that is upstream must be used for the flash hazard analysis



Test 4: 640A Circuit Breaker Protecting a Feeder
The feeder overcurrent protective device from Test 4 was a 640A circuit breaker with short-time delay (STD); the fault current was permitted to follow for 6 cycles.

First calculate the flash protection boundary using 22,600A available bolted fault current, and 0.1 second device opening time (6 cycles):

$$D_c = [2.65 \times MVA_{bf} \times t]^{1/2} \text{ (ft)}$$

$$D_c = [2.65 \times 1.732 \times 480 \times 22{,}600 \times 10^{-6} \times 0.1]^{1/2} \text{ (ft)}$$

$$D_c = (4.98)^{1/2} \text{ (ft)}$$

$$D_c = 2.23 \text{ ft}^{\dagger} \text{ Flash Protection Boundary}$$

Next calculate the incident energy at 18 inches:

$E_{MB} = 1038.7D_B^{-1.4738}t_A\,[0.0093F^2 - 0.3453F + 5.9675]$ (cal/cm²)

$E_{MB} = 1038.7(18)^{-1.4738}(.1)\,[0.0093(22.6)^2 - 0.3453(22.6) + 5.9675]$ (cal/cm²)

$E_{MB} = 4.27$cal/cm²† Incident Energy at 18 inches

†If the circuit breaker has not been maintained properly, the incident energy and flash protection boundary may be much greater.

This is a Category 2 hazard level per 70E-Table 130.7(C)(11). 70E-Table 130.7(C)(10) Protective Clothing and Personal Protective Equipment (PPE) Matrix requires the following equipment for Category 2:

Non-melting (according to ASTM F 1506-00) or Untreated Natural Fiber

- T-shirt (short-sleeve)
- Pants (long) (Note 6)

FR Clothing (Note 1)

- Long-sleeve shirt
- Pants (Note 6) - Alternate is to use FR coveralls (minimum arc rating of 4) over non-melting or untreated natural fiber pants and T-shirt.

FR Protective Equipment

- Hard hat
- Safety glasses or safety goggles
- Arc-rated face shield, or flash suit hood (Note 8)
- Hearing protection (ear canal inserts) (Note 8)
- Leather gloves (Note 2)
- Leather work shoes

The minimum requirement is that qualified persons within 2.23 feet of exposed energized parts shall wear an untreated cotton T-shirt, 5cal/cm² long-sleeve shirt, 5cal/cm² long pants, hard hat, safety glasses, 5cal/cm² arc-rated face shield, hearing protection, Class 00 insulating gloves and leather protectors. Substitutions are allowed in accordance with *NFPA 70E* (see table notes in Example 1). 1000V rated insulated tools are also required. Unqualified persons shall not enter the flash protection boundary.

Test 3: KRP-C-601SP LOW-PEAK® Fuses Protecting a Feeder

The feeder overcurrent protective device from Test 3 was a KRP-C-601SP current-limiting fuse (Class L). For 22,600A available bolted fault current, the KRP-C-601SP will let-through 11,000A (to learn how to determine let-through, current consult The SPD - Electrical Protection Handbook available at www.bussmann.com). The KRP-C-601SP cleared the fault in ½ cycle (0.008 seconds). The flash protection boundary is:

$D_c = [2.65 \times MVA_{bf} \times t]^{1/2}$ (ft)

$D_c = [2.65 \times 1.732 \times 480 \times 11{,}000 \times 10^{-6} \times 0.008]^{1/2}$ (ft)

$D_c = (0.19)^{1/2}$ (ft)

$D_c = 0.44$ ft flash protection boundary

It is recommended to use a minimum flash protection boundary of 0.5 feet (6 inches).

Next calculate the incident energy at 18 inches:

$E_{MB} = 1038.7D_B^{-1.4738}t_A\,[0.0093F^2 - 0.3453F + 5.9675]$ (cal/cm²)

$E_{MB} = 1038.7(18)^{-1.4738}(.008)\,[0.0093(16)^2 - 0.3453(16) + 5.9675]$ (cal/cm²)

$E_{MB} = 0.33$ cal/cm² Incident Energy at 18 inches

Note: *Even though the let-through current is only 11kA, 16kA is entered because it is the minimum applicable fault current for the equation.*

The calculated incident energy is below the second-degree burn threshold of 1.2cal/cm². This is a Category 0 hazard level in 70E-Table 130.7(C)(11). 70E-Table 130.7(C)(10) Protective Clothing and Personal Protective Equipment (PPE) Matrix requires the following equipment for Category 0:

Non-melting (according to ASTM F 1506-00) or Untreated Natural Fiber

- Shirt (long-sleeve)
- Pants (long)

FR Protective Equipment

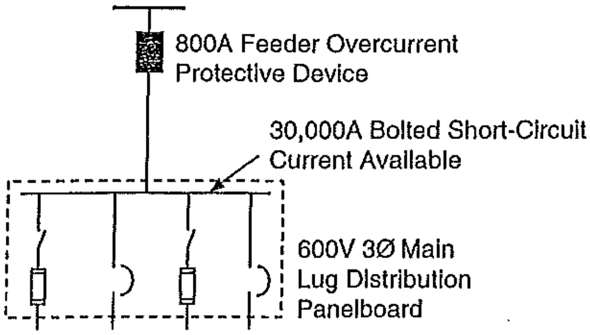
- Safety glasses

The minimum requirement is that qualified persons within 0.44 feet of exposed energized parts shall wear an untreated cotton long-sleeve shirt and long pants, and safety glasses. Class 00 insulating gloves and leather protectors, and 1000V rated insulated tools may also be required to protect the worker from a potential shock hazard. It is recommended to use 6 inches as a minimum flash protection boundary. The use of Class 00 insulating gloves and leather protectors while working on or near energized parts is recommended as the best way to protect the workers hands from arcing events.

This example illustrates the tremendous impact the type of overcurrent protective device can have on the hazard level for a given circuit. By limiting the magnitude of the available fault current and clearing the fault within ½ cycle, the LOW-PEAK® KRP-C-601SP current-limiting fuse (Class L) was able to significantly reduce the level of energy in this case.

Example 3 Using Method 3:

Determine FPB and Incident Energy - IEEE 1584: Use Method 3 to determine the flash protection boundary and incident energy on the following 480V circuit:



The available bolted fault current is 30,000A at the main lugs of the distribution panelboard. Calculate the flash protection boundary and incident energy for a LOW-PEAK® KRP-C-800SP current-limiting fuse (Class L) feeding the distribution panelboard, and also for an 800A low voltage power circuit breaker with short-time delay feeding the panelboard.

Use *Arc-flash Incident Energy Calculator* in Annex G (an excerpt from the table follows). Find the amps rating and type of overcurrent protective device in the header of the table. Select the available bolted fault current from the left column.

Excerpts From Arc-flash Incident Energy Calculator (Full table is found in Annex G)

Arc-flash Incident Energy Calculator

Fuses: Cooper Bussmann LOW-PEAK® KRP-C_SP (601-2000A), Circuit Breakers: Low Voltage Power Circuit Breakers (w/STD)

Incident Energy (I.E.) values are expressed in cal/cm². Flash Protection Boundary (FPB) values are expressed in inches.

Bolted Fault Current (kA)	601-800A				801-1200A				1201-1600A				1601-2000A			
	Fuse		LVPCB		Fuse		LVPCB		Fuse		LVPCB		Fuse		LVPCB	
	I.E.	FPB	I.E.	FPB	I.E.	FPB	I.E.	FPB	I.E.	FPB	I.E.	FPB	I.E.	FPB	I.E.	FPB
1	>100	>120	>100	>120	>100	>120	>100	>120	>100	>120	>100	>120	>100	>120	>100	>120
2	>100	>120	>100	>120	>100	>120	>100	>120	>100	>120	>100	>120	>100	>120	>100	>120
3	>100	>120	>100	>120	>100	>120	>100	>120	>100	>120	>100	>120	>100	>120	>100	>120
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
26	1.34	19	50.35	>120	7.52	63	50.35	>120	23.08	>120	>100	>120	28.92	>120	>100	>120
28	1.22	18	54.18	>120	6.28	55	54.18	>120	22.71	>120	>100	>120	28.67	>120	>100	>120
30	1.10	17	58.01	>120	5.16	48	58.01	>120	22.34	>120	>100	>120	28.41	>120	>100	>120
32	0.98	16	61.83	>120	4.15	42	61.83	>120	21.69	>120	61.83	>120	28.15	>120	>100	>120
34	0.86	14	65.66	>120	3.25	35	65.66	>120	18.59	116	65.66	>120	27.90	>120	>100	>120
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•

KRP-C-800SP Fuse
Incident Energy = 1.1cal/cm²
Flash Protection Boundary = 1ft 5in

800A LVPCB w/STD
Incident Energy = 58.01cal/cm²†
Flash Protection Boundary >10 ft†

†*If the circuit breaker has not been maintained properly, the incident energy and flash protection may be much greater*

For the KRP-C-800SP Fuse:
The calculated incident energy is below the second-degree burn threshold of 1.2cal/cm². This is a Category 0 hazard level in 70E-Table 130.7(C)(11). 70E-Table 130.7(C)(10) Protective Clothing and Personal Protective Equipment (PPE) Matrix requires the following equipment for Category 0:

Non-melting (according to ASTM F 1506-00) or Untreated Natural Fiber

- Shirt (long-sleeve)
- Pants (long)

FR Protective Equipment

- Safety glasses

The minimum requirement is that qualified persons within 1 foot 5 inches of exposed energized parts shall wear an untreated cotton long-sleeve shirt and long pants, and safety glasses. Class 00 insulating gloves and leather protectors, and 1000V insulated tools may also be required to protect the worker from a potential shock hazard. It is recommended to use Class 00 insulating gloves and leather protectors while working on or near energized parts as the best way to protect the workers hands from arcing events.

For the 800 A LVPCB w/STD:
While PPE manufacturers make flash suits with arc ratings up to 100cal/cm², *NFPA 70E* does not have a Hazard Risk Category for incident energies above 40cal/cm². Working on energized circuits with energy levels in excess of 40cal/cm² should be avoided by all means necessary. If energized work must be performed on these circuits, steps should be taken to reduce the hazard before the work is to be performed. For more information about designing safer systems, or upgrading existing systems see Section X.

Arcing fault currents in the long time characteristic of overcurrent protective devices

In many electrical fault analysis studies the focus is only on the circuits with the highest or worst case short-circuit currents. However, in flash hazard analysis, it is important to also investigate circuits where the arcing fault current may be a value that is less than a circuit breaker's instantaneous trip setting (resulting in an opening time of up to several seconds) or may be a value that takes a fuse several seconds to open. On lower-amps-rated circuits, this is not typically a problem for several reasons. However, on larger-amps-rated circuits (over 1200A) this can become more of an issue. For some higher amps rating overcurrent protective devices, the incident energy and flash protection boundaries are extremely large for some lower fault currents. Workers also must consider examining the flash protection boundary and incident energy for circuits with low levels of arcing current. Some lower-level arcing faults are not able to sustain themselves; however, there is not much recent research in this area. In those cases where a low-level arcing fault is sustained, extended clearing times can produce extremely high incident energy levels.

Other considerations

Consideration should also be given for how long a worker could be exposed to an arc, based upon the location of the worker.

> *IEEE 1584 Annex B*
>
> *If the time is longer than two seconds, consider how long a person is likely to remain in the location of the arc-flash. It is likely that a person exposed to an arc-flash will move away quickly if it is physically possible, and two seconds is a reasonable maximum time for calculations. A person in a bucket truck, or a person who has crawled into equipment will need more time to move away.*

For example, is the worker standing in front of the switchboard with plenty of clearance, or is he/she kneeling or lying down in front of the gear? Is the worker on the ground or up in a bucket working on a bus duct? Can the worker easily escape the room or could he or she become trapped in the vault?

NFPA 70E and IEEE 1584 have developed some good tools for assessing the arc-flash hazard and the efforts in this area continue. However, the industry does not presently have tools to assess the arc-blast hazard. Generally, as the risk of the arc-flash energy increases, the risk of the arc-blast energy increases too.

Even though electrical equipment may have a main overcurrent device and disconnecting means, if it is possible to create a fault on the line side of the main, the opening time and let-through characteristics of the overcurrent protective device which feeds the main device should be considered. For example an industrial machine that has a main fusible disconnect switch or circuit breaker fed by a bus plug. When the machine doors are open, it is possible to initiate a fault on the line terminals of the fused switch or circuit breaker, therefore the device in the bus plug must be considered for the flash hazard analysis.

In test labs, arcing fault current magnitudes can vary widely from test to test, even under the same test circumstances. The industry has learned a great deal in the past decade, but there is still a great deal more to be learned. The methods that have been developed from actual testing can be used with a degree of confidence. However, the actual arcing fault currents can vary based on many variables. This can affect the speed of response of the overcurrent protective device supplying the circuit. Some overcurrent protective devices may not operate as intended or specified if periodic maintenance has not been performed. The more one knows about arcing faults, the more one understands that the best strategy in electrical safety is avoidance. Strive to only work on or near exposed conductors that have been placed in an electrically safe work condition.

F. Personal protective equipment (PPE)

OSHA and *NFPA 70E* recognize that, on occasion, electrical work must be performed while the equipment or circuit is energized. Effective procedures, PPE, and personnel training are key elements for executing live work without injury. These issues must be considered when designing electrical systems.

NFPA 70E requires that any body part within the flash protection boundary area be protected, using appropriate PPE. The OSHA standards for various types of PPE are provided in Annex C, Table XIV(B). *NFPA 70E* identifies PPE that should be worn in 70E-130.7.

70E-Tables 130.7(C)(10) and 130.7(C)(11) are used together to properly select the PPE required for working on or near energized parts. 70E-Table 130.7(C)(10) lists the specific PPE items that are required for a given Hazard Risk Category. 70E-Table 130.7(C)(11) (that follows) identifies the required minimum arc rating of the PPE required in each Hazard Risk Category.

NFPA 70E, 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 Joules/cm² (cal/cm²)
0	Non-melting, flammable materials (i.e., untreated cotton, wool, rayon, or silk, or blends of these materials) with a fabric weight at least 4.5oz/yd² (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 multi-layer flash suit (3, or more)	167.36 (40)

Note: *Arc Rating is defined in Article 100 and can be either ATPV or EBT. 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. EBT 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. EBT is reported when ATPV cannot be measured due to FR fabric breakopen.*

The following table shows some typical articles of clothing and PPE required for each Hazard Risk Category. This is to illustrate the type of equipment that may be required to work on energized circuits. It is not intended to be used to select PPE. *NFPA 70E* should be consulted for specific information on selecting appropriate PPE. Layering of FR clothing and protective equipment may provide a higher level of arc-flash protection. *NFPA 70E* has more information on layering of protective clothing and substitutions permitted by layering. Although not required or mentioned in any standards, one might consider wearing a more protective arc rated face shield rather than just safety glasses even for all 0 and 1 hazard risk category tasks. Facial disfigurations are among those injuries that are extremely difficult to overcome from a social prospective.

Typical Protective Clothing and PPE
[Information compiled from Tables 70E-130.7(C)(10) and 70E-130.7(C)(11)]

Category	Minimum Arc Rating (cal/cm²)	Non-meling or Untreated Natural Fiber Clothing	FR Clothing (Note 1)	FR Equipment (Note 1)
0	N/A	Long-sleeve shirt Long pants		Safety glasses
1	4	T-shirt Long pants	Long-sleeve shirt Long pants	Hard hat Safety glasses
2	8	T-shirt Long pants	Long-sleeve shirt Long pants	Hard hat Safety glasses or goggles Arc-rated face shield†† Hearing protection Leather gloves Leather work shoes
3	25	T-shirt Long pants	Long-sleeve shirt Long pants	Hard hat Safety glasses or goggles Flash suit hood Hearing protection Leather gloves Leather work shoes
4	40	T-shirt Long pants	Long-sleeve shirt Long pants	Flash suit jacket (multi-layer) Flash suit pants Hard hat Safety glasses or goggles Flash suit hood Hearing protection Leather gloves Leather work shoes

†† - A category 2* requires a flash suit hood instead of an arc-rated face shield.

Note 1: Substitutions may be allowable per 70E-Table 130.7(C)(10). For more information consult *NFPA 70E.*

Any body part extended within the appropriate risk boundary must be protected from the hazard(s) existing within that boundary. If a hand is within the flash protection boundary, then the hand must be protected by PPE. If a person's head is within the flash protection boundary, the head must be protected. Unless the electrical equipment is placed into an electrically safe work condition, locked out, tagged, and tested for voltage according to proper procedures, the system must be considered energized, requiring that appropriate PPE be used.

NFPA 70E also makes it clear [70E-130.6(D) and 70E-130.6(E)] that conductive materials, tools and equipment that are in contact with any part of an employee's body be handled in a manner that prevents accidental contact with exposed energized conductors or circuit parts. This includes articles of jewelry such as rings, conductive watchbands and metal frame glasses. In most instances, wearing flame-resistant clothing continuously is an effective safety measure for personnel who are frequently exposed or potentially exposed to arc-flash.

> *OSHA 1910.335 (a)(1)(i)*
>
> *Employees working in areas where there are potential electrical hazards shall be protected with, and shall use, electrical protective equipment that is appropriate for the specific parts of the body to be protected and for the work to be performed.*

Proper care and use of PPE is an important part of any electrical safety program. PPE should be inspected before every usage. PPE should be maintained in accordance with manufacturer's recommendations and the requirements contained in the Tables XIV(C)(1) and XIV(C)(2) in Annex C. Improper care of PPE can cause the equipment to lose its protective properties. For example, rubber goods can lose some of their insulating properties if not properly stored and protected from corrosive materials. Rubber goods may require periodic dielectric testing to verify the insulating capabilities. FR clothing may require special care during laundering and may need to be replaced if torn or if fabric becomes worn after prolonged usage.

G. Lockout/Tagout

OSHA 1910.147-Procedure for applying the Lock/Tag

The Lockout/Tagout Standard has been in effect since 1989. It was created to help reduce the death and injury rate caused by the unexpected energization or start-up of machines or the release of stored energy. Normal production operations, cords and plugs under exclusive control, and hot tap operations are not covered. This standard applies to energy sources such as electrical, mechanical, hydraulic, chemical, nuclear, and thermal.

Lockout is the placement of a key or combination lock on an energy isolation device (disconnect switch, circuit breaker, etc.) to ensure that the energy-isolating device and equipment being controlled cannot be operated until the lockout device is removed. Lockout devices hold an energy-isolating device in a safe position and prevent the energization of a machine or equipment. The lockout device must be substantial enough to prevent removal without use of excessive force or unusual techniques.

If the lockout/tagout includes working on or near exposed de-energized electrical parts (not yet in an electrically safe work condition) then OSHA 1910.333(b)(2) Note 2 shall also apply:

> *OSHA 1910.333(b)(2) Note 2*
>
> *Lockout and tagging procedures that comply with paragraphs (c) through (f) of 1910.147 will also be deemed to comply with paragraph (b)(2) of this section provided that:*
> *(1) The procedures address the electrical safety hazards covered by this Subpart; and*
> *(2) The procedures also incorporate the requirements of paragraphs (b)(2)(iii)(D) and (b)(2)(iv)(B) of this section.*

1910.333(b)(2)(iii)(D) requires if a tag is used without a lock, then the tag shall be supplemented with at least one additional safety measure that provides a level of safety equivalent to a lock.

1910.333(b)(2)(iv)(B) requires the testing for the **absence of voltage** on any equipment in which electrical circuit parts may be exposed to workers.

Tagout is the placement of a tag or other prominent warning device and a means of attachment on an energy-isolating device to indicate that the energy-isolating device and the equipment being controlled may not be operated until the tagout device is removed. Tagout devices shall be non-reusable, attached by hand, self-locking, and non-releasing, with a minimum unlocking strength of no less than 50 pounds. They at least must be equivalent to an all-environment tolerant nylon cable tie.

Lockout devices must be used unless the employer can demonstrate that the use of a tagout system can provide full employee protection.

Applying the Lock/Tag

Step 1 — Understand the Hazards before the Shutdown: Before an authorized or affected employee turns off machinery or equipment, he or she should have knowledge of the type and magnitude of energy, the hazards of the energy to be controlled, and the method or means to control the energy. It might be helpful to have floor drawings, single-line diagrams, and the assistance of the facility electrician and employees who work with the equipment.

Step 2 — Power Down: The machine or equipment shall be turned off or shut down in an orderly manner, using established procedures.

Step 3 — Isolate the Power Source: All energy-isolating devices that are needed to control the energy to the machine or equipment shall be physically located and operated in such a manner as to isolate the machine or equipment from the energy source(s). This might involve such tasks as flipping a power switch, breaking a circuit, and closing a valve. If the equipment has more than one shutdown point, the worker must be sure that all are isolated from power.

Step 4 — Apply the Lock and/or Tag: Lockout or tagout devices shall be affixed to each energy-isolating device by authorized personnel. Lockout devices, where used, shall be affixed in a manner that holds the energy-isolating devices in a "safe" or "off" position. Tagout devices, where used, shall be affixed in a way that clearly indicates that operation or movement of energy isolating devices from the "safe" or "off" position is prohibited.

Additional requirements for electrical lockout/tagout (OSHA 1910.333(b)(2) Note 2):

Step 4A- If there are exposed electrical parts and only tagout is used, then another additional measure shall be used that provides a level of safety equivalent to a lock.

Step 4B- If there are exposed electrical parts, then using the **appropriate PPE and other safety measures,** a worker must **verify the absence of voltage.**

Step 5 — Release Residual Energy: Following the application of lockout/tagout devices, all potentially hazardous stored or residual energy shall be relieved, disconnected, restrained, and otherwise rendered safe. If a possibility of reaccumulation of stored energy to a hazardous level exists, verification of isolation shall be continued until the servicing or maintenance is completed, or until the possibility of such accumulation no longer exists.

Step 6 — Try to Power Up: Before starting work on machines or equipment that have been locked out or tagged out, authorized personnel shall verify that isolation and de-energization of the machine or equipment has been accomplished. This requires personnel to turn all controls of the equipment or machinery in the "on" position to ensure that all energy sources have been isolated and that the equipment does not start up while work is being performed on it. Before trying to power up, the worker must be sure that no one is near the equipment or machinery in case the equipment continues to have power. Lastly, the employee should verify that the isolation point cannot be moved to the "on" position. The employee then can continue servicing or maintaining the equipment.

Removing the lock/tag

Step 1 — Inspect the Machine and/or Equipment: The work area shall be inspected to ensure that all nonessential items (e.g., tools, spare parts, debris) have been removed, and that machine or equipment components are operationally intact.

Step 2 — Notify Personnel: All personnel in the vicinity shall be notified before removal of the lockout and start up. The person in charge of the lockout/tagout shall ensure that no one is in the way of possible danger upon start up.

Step 3 — Remove the Lockout/Tagout Device: Each lockout/tagout device should be removed by the person who placed it. When more than one person has applied a lock, the last person to remove his or her lock should remove the hasp or other multiple lock device. When all locks have been removed and the machine/equipment is determined to be operating safely, other personnel may be notified that the equipment is now operational.

H. Stored energy systems

Simply because the electrical circuit has been opened might not mean the system is safe to work on. The following cautions should be understood:

- Capacitors can store hazardous energy even after the equipment has been de-energized and can build up a dangerous residual charge without an external source.
- Capacitors also can be used to store large amounts of energy. An internal failure of one capacitor in a bank frequently results in an explosion when all other capacitors in the bank discharge into the fault.
- High-voltage cables should be treated as capacitors because they have capacitance and thus can store energy.

I. IP2X (finger-safe) ratings

NFPA 70E requires that a guard be used to prevent access to voltages above 50V. Guarding and the installation of insulating barriers must be complete if work is to be performed while the equipment is energized.

Note: *The placement of barriers might effectively protect personnel from shock hazards but might not protect personnel from arc-flash hazards. Therefore, placement of barriers might reduce the chance for electrical shock but does not always eliminate the requirements of flash protection if the task involves work inside the flash hazard boundary.*

Guarding, however, also might prevent accidental contact by tools and other conductive materials that could cause an arc-flash. A practical approach to providing these guards would be to adopt standards that address this issue. IEC 60204-1 is entitled "Electrical Equipment Used in Industrial Machines." Section 6 of the standard refers to the requirements for protecting people against electrical shock. In general, electrical equipment must provide protection against people coming into direct or indirect contact with energized electrical parts within an enclosure.

When a person is working in an enclosure with energized components, the standard requires the worker to be protected against contact to at least IP1X (the letter "X" here is used in place of the second number to indicate that tests for ingress of liquid is neither required nor applicable). The worker must be protected from direct contact with live parts that could be touched easily while resetting, adjusting, or replacing nearby components to at least an IP2X rating.

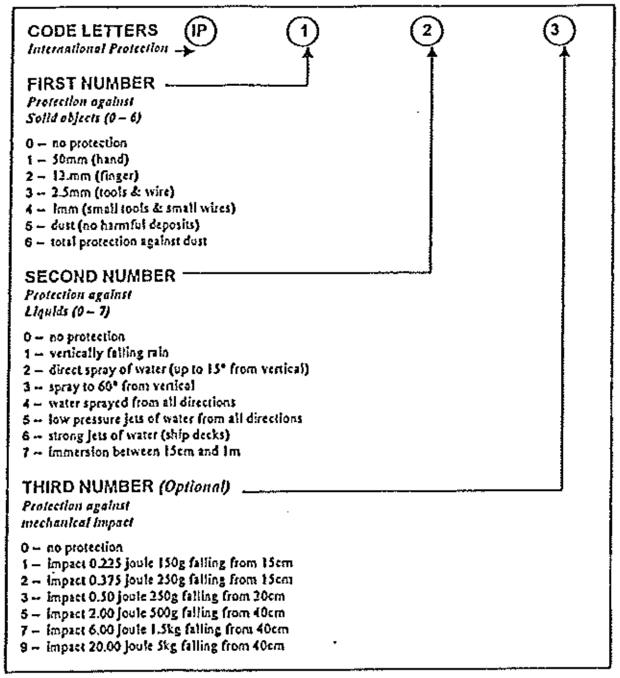


Figure IX(I). IP Environmental Ratings for Enclosures (IEC 529)

Note: *The terminology used for this program includes the term finger-safe for any product with an IP2X designation. IP20 rated products represent products with no protection against liquids.*

IP2X is often referred to as "finger-safe," meaning that a probe the approximate size of a finger must not be able to access or make contact with hazardous energized parts. The standard detailing the rating system used is IEC 529. Principally, this standard defines the degree of protection provided by an enclosure (barriers/guards) classified under the International Protection (IP) Code and the testing conditions required to meet these classifications.

J. Grounding and Ground Fault Circuit Interrupters (GFCI)

A key element of a safe installation is effective grounding. The term ground has many different meanings, but all are related to a connection with the earth. Ground is used to refer to a return path used for a fault to enable the proper operation of an overcurrent device.

Safety Grounding Equipment

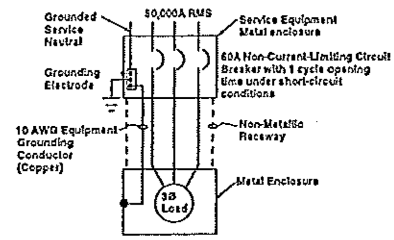
Minimizing any voltage difference between adjacent or nearby conductive points is important. To avoid a voltage difference (shock), a low impedance path is required between the two (or more) conductive surfaces. Should a person be in contact with both surfaces when a fault occurs, no significant voltage is impressed across the person's body, eliminating possible current flow.

Protecting Equipment Grounding Conductors (EGC)

The discussion of safety is not complete without an analysis of equipment grounding conductors (EGC). Table 250.122 of the 2002 NEC provides minimum sizing for EGCs. As noted below the table, EGCs should be sized larger, to "be capable of safely carrying the maximum fault likely to be imposed on it" [NEC 250.4(A)(5)].

For the fuse to open or the circuit breaker to operate properly, a low impedance EGC must be available for fault current to return to its source. Otherwise, any equipment experiencing a fault becomes energized at the system voltage, presenting a shock hazard for the employee. Providing protection for the equipment grounding conductor, therefore, is a safety issue. Using a current-limiting overcurrent device is the best way to reduce the energy that could be seen by the grounding conductor.

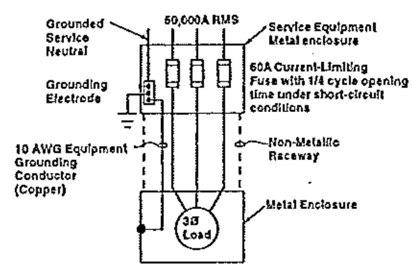
VIOLATION



Would need to increase Equipment Grounding Conductor to 2/0, per ICEA Std. P-32-382.

Violates NEC 110.10 and 250.4(A)(5) or 250.4(B)(4).

COMPLIANCE



Conforms to 110.10, Table 250.122, and 250.4(A)(5) or 250.4(B)(4)

Complies with NEC and 250.4(A)(5) or 250.4(B)(4). 110.10 and 250.4(A)(5).

Must increase EGC to a 2 AWG copper to remain tight under the lug after the fault occurs.

The problem of protecting EGCs was first recognized more than 30 years ago when Eustace Soares wrote a popular grounding book *Grounding Electrical Distribution Systems for Safety.* In his book, Soares states that the "validity rating" corresponds to the amount of current and time required to cause a copper conductor to become loose under a lug after the conductor has had a chance to cool down after a fault. This validity rating is based upon raising the copper temperature to 250°C (the annealing point of copper) and then reducing the temperature back to normal running temperatures.

Good engineering practice, then, requires an investigation of the adequacy of the important ground-return path. Let-through currents for overcurrent protective devices must be compared with the short-circuit ratings of the equipment grounding conductors. Wherever let-through values exceed the minimum equipment grounding conductor withstand ratings, the equipment grounding conductor size must be increased until the withstand ratings are not exceeded.

Ground fault circuit interrupters (GFCIs)

GFCIs are designed to protect a person from electric shock when he or she simultaneously contacts a "live" (usually 120V) wire or part and a grounded object. The GFCI works by sensing a difference between the supply and return currents. When the difference exceeds 4 - 6 mA, indicating that current is flowing to ground (through the person), the device is designed to open the circuit.

GFCIs do not protect against a line-to-neutral or a line-to-line shock. Although the GFCI is an effective safety device, it is not a guarantee against shock in every situation. In addition, if GFCI-protected equipment contains transformers, a ground fault (shock) on the secondary side of the transformer might not trip the GFCI.

GFCIs normally are installed as either circuit breakers or receptacles. In either case, the GFCI might be wired to protect multiple receptacles. Individual GFCI plug-in adapters are also available.

K. Voltage testing 1,000V and less

Three basic safety issues are associated with the task of testing for voltage in instances where the maximum voltage level is 1,000V and less. The first issue involves selecting and using the right meter for the job at hand. The second issue is protecting the person from potential exposure to an energized source, and the third issue is the work process of executing the test.

On occasion, voltage-testing devices can be the source of an incident or injury, as in the following instances:

- Leads can fall out of their plugs and initiate a phase-to-phase short circuit.
- Internal components can fail, resulting in a phase-to-phase short circuit.
- Probes can slip while a reading is being observed.
- Leads can be inserted into the wrong plugs, resulting in failure.
- The device indication can be confusing, resulting in incorrect observations.
- Hands can slip off the probe.

The selected voltage-testing device must minimize all of these possibilities.

When a voltage test is performed, the person should perform the work practice as if the energy source is present (i.e., the source is energized). Even if the disconnecting means has been opened and locked-out/taggedout, until the absence of voltage has been satisfactorily verified, an electrically safe work condition does not exist. The person performing the test should be protected from any accidental release of energy until the absence of voltage has been satisfactorily verified.

Selecting a Voltage-Testing Device

Voltage testers should be selected based upon the intended use. Several types of voltage testers are manufactured for specific uses, and each device has limitations. When used to test for the absence or presence of voltage as a part of establishing an electrically safe work condition, voltage testers should have the following characteristics where direct contact can be made:

- Retractable, insulated-tip test probes
- Self-contained fault protection or limitation devices, such as internal current-limiting fuses or probe current-limiting resistors
- Voltage/current path from the probes that is not routed through the mode switch

In addition, voltage testers should conform to national consensus standards, such as UL 1244, MIL-T-28800C.

Along with the above requirements, voltage testers that are used only to test for the absence or presence of voltage should have the following characteristics:

- Single-function, voltage-only test devices or automatic mode devices that check for voltage before switching to other modes (e.g., resistance, continuity)
- Test leads that cannot be improperly connected (e.g., only two jacks are present or leads are permanently connected)

NOTE: *High-impedance voltage testers are subject to "phantom" readings from induced voltage. Verification of the absence of voltage should be required with a low-impedance voltage tester, such as a solenoid-type voltage tester. However, solenoid testers can have an adverse effect on digital control systems (DCS), programmable logic controllers (PLC), or similar equipment.*

NOTE: *Solenoid-type voltage testers typically are assigned a "duty cycle" by the manufacturer. In most instances, this duty cycle is 15 seconds. The duty cycle rating must not be exceeded.*

Personal Protective Equipment (PPE)

Before opening doors or removing covers for access to electrical conductors, a person should conduct a hazard analysis. The hazard analysis should be as formal and detailed as warranted by the task to be performed. Any PPE necessary to avoid injury should be in place and worn before any existing enclosure is abridged (i.e., any cover removed or any door opened). The hazard analysis must consider both shock and arc-flash.

NOTE: *Many arc-flash incidents occur at the moment a door is opened or a cover removed. The person performing the test should be aware of this fact and exhibit an appropriate mind set. The mind set should consider that all electrical conductors and contact points within the enclosure are energized.*

In determining appropriate PPE, the hazard analysis must consider the flash protection boundary as well as the shock approach boundaries, paying particular attention to the prohibited and restricted boundaries. Where the task involves measuring a voltage, the probes, of course, cross the prohibited boundary. Therefore, the person must be protected from unintended contact with conductive parts. Voltage-testing devices that meet the above criteria include a preventive method to minimize the possibility of a person's hand or fingers slipping down the probes. Therefore, electrical insulation is not necessarily required. However, if hands (or other body parts) are inside the enclosure while the person is executing the task, some exposure to shock exists through unintentional contact with energized or potentially energized parts. Voltage-rated gloves should be worn. They do not hinder the task and can avoid unintentional contact with electrical conductors or contacts.

In every instance where an electrical circuit is present, a flash protection boundary exists. Depending upon the flash protection boundary, flash-protective equipment should be worn. Any body part that is within the flash protection boundary must be protected from arc-flash. If the flash protection boundary is 2 inches or less, leather gloves and ordinary safety glasses for the eyes provide sufficient protection. As the flash protection boundary extends beyond 2 inches, flame-resistant clothing and face protection should be worn. Leather gloves that are one component of voltage-rated gloves provide arc-flash protection for hands. Therefore, appropriate voltage-rated gloves should be worn. Voltage-rated gloves selected in accordance with ASTM D 120 provide protection from both shock and arc-flash, in most instances.

NOTE: *Class 00 gloves have a voltage limit of 500V and are adequate in many instances for measuring voltage.*

Executing the Task

The person testing for voltage should be trained to understand how the meter works and what each possible meter indication means. After the person selects the appropriate voltmeter, reacts to the hazard analysis, and understands how to interpret any meter indication, he or she should execute the following sequence of steps:

1. Open the disconnecting means.
2. Open the door or remove the cover(s)
3. Inspect the compartment interior for missing barriers, signs of arcing or burning, and any extraneous parts or components.
4. Inspect the voltmeter and probes for signs of mistreatment; verify that the probe covers move freely.
5. Insert one probe into the holder on the meter; place the meter in a stable position or ask a second person to hold the meter, if necessary, to see the indication. (Any second person must wear the same PPE as the first person.)
6. Verify that the voltmeter functions satisfactorily on a known energized voltage source.

NOTE: *If the meter is auto ranging, a nearby 110V receptacle is satisfactory. If not auto ranging, the known source must be within the same voltage range.*

7. Place the probe that is in the meter holder into good physical contact with a grounded point within the compartment.
8. Place the second probe into good physical contact with the opened side of the disconnecting means and before (ahead of) any fuses or any other circuit element.

NOTE: *Normally, in the case of a disconnect switch, the movable side of the knife blades is available to contact with the probe. In case of a circuit breaker, the load conductor termination should be contacted.*

9. Read and interpret the meter indication.
10. Repeat steps 7 and 8 for phases B and C.
11. Place the probe that is in the meter holder into good physical contact with phase A on the opened side of the disconnecting means and before (ahead of) any fuses or other circuit elements.

NOTE: *Normally, in the case of a disconnect switch, the movable side of the knife blades is available to contact with the probe. In case of a circuit breaker, the load conductor termination should be contacted.*

12. Place the probe in the meter holder into good physical contact with phase B in the same relative physical location.
13. Repeat steps 11 and 12, except contact phases B and C.
14. Repeat steps 11 and 12, except contact phases A and C.

NOTE: *Tests for absence of voltage should be conducted at each point within the enclosure. If the compartment contains fuses, a voltage test should be conducted at both the line and load sides of each fuse, both between phases and between each phase conductor and ground. Each test should be taken at the fuse clip instead of at the fuse ferrule (endbell).*

15. Measure voltage between each point within the enclosure where contact is expected.
16. Verify that the voltmeter functions satisfactorily on a known energized voltage source.

NOTE: *If the meter is auto ranging, a nearby 110V receptacle is satisfactory. If the meter is not auto ranging, the known energized source must be within the same voltage range.*

X. Suggestions for Limiting Arc-Flash and Shock Hazards

There are many considerations creating an electrically safe workplace for employees. Electrical safety starts with the **design** of the electrical system. The selection and layout of the system components/equipment can have considerable impact on the probability of an incident and on the severity of hazard if an incident does occur. For existing electrical systems, it may be possible to improve electrical safety conditions for workers by **upgrading** components and also by following proper equipment **maintenance procedures.** Also, there are safe **work practices** in which the workers must be trained and qualified to perform. This includes understanding the electrical hazards, the types of PPE and work procedures that are necessary.

The following start with some work practice and maintenance suggestions and then moves to electrical system design and upgrade suggestions.

A. Avoidance is the surest electrical safety measure.

If workers do not "work on or near" exposed energized components, worker safety is enhanced. Management and workers should insist on putting equipment into an **electrically safe work condition** prior to commencing electrical work. Per OSHA 1910.333(a)(1) and *NFPA 70E* 130.1, workers shall not work on or near exposed live parts except for two demonstrable reasons:

A. De-energizing introduces additional or increased hazards (such as cutting ventilation to a hazardous location) or

B. Infeasible due to equipment design or operational limitations (such as when performing diagnostics and testing for startup or troubleshooting and this work can only be done when circuits are energized).

B. Avoidance: implement energized electrical work permit procedures requiring signature by management.

NFPA 70E 110.8(B)(2) & 130.1(A)(1)

If live parts are not placed in an electrically safe work condition (i.e., for the reasons of increased or additional hazards or infeasibility per 130.1) work to be performed shall be considered energized electrical work and shall be performed by written permit only.

NFPA 70E 130.1(A)(3) Exemptions to Work Permit

Work performed on or near live parts by qualified persons related to tasks such as testing, troubleshooting, voltage measuring, etc., shall be permitted to be performed without an energized electrical work permit provided appropriate safe work practices and personal protective equipment in accordance with Chapter 1 are provided and used.

70E-130(A)(2) provides the elements of energized electrical work permits that include a work description, justification of why the work must be done energized, a shock hazard analysis, a flash hazard analysis, the PPE required and more. One of the most important aspects is signature approval by an authorized person, which typically should be an owner or an executive. Experience by companies that effectively use energized electrical work permits is that most work gets performed under electrically safe work conditions. That is, the energized electrical work permits rarely get approved. Usually in the process of getting the electrical work permit approved, management finds a means to do the work under electrically safe work conditions. *NFPA 70E* has an example energized work permit form in Annex J.