

Arc Flash Hazard — The Basics

OK. I've heard a lot about this arc flash hazard, calculations, and labels. What exactly is it?

We hope to give you an easy explanation of what arc flash is, and answer the following most asked questions:

Question #1: **What is Arc Flash?**

Question #2: **What Causes Arc Flash Hazards?**

Question #3: **Why Should I be Concerned about Arc Flash?**

Question #4: **What is Incident Energy?**

Question #5: **What are the Limited, Restricted, Prohibited, and Flash Protection Boundaries?**

Question #6: **What is PPE?**

Question #7: **What is an Arc Flash Warning Label?**

Question #8: **What is an Arc Flash Hazard Study?**

Question #9: **What is next? Do I really need an Arc Flash Hazard Study?**

Question #1: What is Arc Flash?

Electrical short circuits and faults are extremely dangerous and are potentially fatal to personnel. Arc flash occurs when phase conductors are shorted and ionization of the air occurs. When this happens, the arc faults produce large amounts of heat that can severely burn human skin and even set clothing on fire. Also, molten metal is blasted from the fault location outward in a radial direction. The arcing faults also produce large shock waves that can blow personnel off their feet.

Other exposure risks to arcing faults include:

- 1) Shock hazard due to touching energized conductors.
- 2) Expanding gases, known as arc blasts, that can cause:

- a) Flying debris
- b) Pressure waves that can knock a person off balance
- c) Sound waves that cause ear damage
- 3) Bright light (from arc plasma) that can result in temporary or permanent blindness.
- 4) Arc plasma or heat that can result in a fire.
- 5) Metal vaporization that can splatter on surfaces and will condense on cooler materials.

When an arcing fault occurs, the heat from the arc can damage equipment and cause personnel injury. Personnel injury is the biggest concern and is why the arc flash heat exposure program was developed in an attempt to educate workers and reduce the number of injuries and deaths.

Question #2: What Causes Arc Flash Hazards?

In short, electrical short circuits cause the arc flash hazard. Electrical faults on electrical systems can be in the form of phase-to-ground, double phase-to-ground, and three phase. The amount of energy in an arc can be enormous in some cases. Electrical arcs create plasma, hot vapors, and gases that can rise to 23,000 °F. The heat produced can ignite clothing more than 10 feet away. The amount of burning is based upon the amount of Incident energy (See Question #4) created by the fault.

The faults create intense thermal radiation and damaging noise levels. The explosive expansion of the surrounding air can create pressure waves that can blow personnel across rooms and up against walls. Arcing faults cause the vaporization of copper components. This copper vaporization is projected outward along with the Incident energy.

At this time, only arc flash hazards from three phase faults (arcing faults) in enclosures have been studied and researched. There is little test information on arc flash hazards produced by phase-to-phase and phase-to-ground faults. Arc flash hazards have not been studied for a bolted fault because it does not radiate any flash energy.

Question #3: Why Should I be Concerned about Arc Flash?

As stated in the answers for questions #1 & #2, a tremendous amount of heat is generated when these arcing faults occur. This can be extremely hazardous to personnel working on or near the location where the fault occurs. The number one reason to be concerned about arc flash is for the safety of these personnel. Arc Flash Hazard Studies are performed to determine the risk to personnel, warn them of the hazards, and to instruct them as to what kind of personal protective equipment that they must wear.

Another reason to be concerned about Arc Flash Hazards is liability and government regulations. OSHA regulations apply to every worker that may approach or be exposed to energized electrical equipment. Failure for an employer to conform and follow OSHA and NEC requirements can lead to employee injuries, fines, penalties, and expensive law suits.

There are several regulations that address arc flash hazards. They are:

- National Fire Protection Association (NFPA) Standard 70 or better known as “The National Electric Code.” The NEC® 2002 addresses the arc flash hazard in Article 110.16
- NFPA 70B 2002 “Recommended Practice for Electrical Equipment Maintenance.”
- NFPA 70E 2000 “Standard for Electrical Safety Requirements for Employee Workplaces”
- OSHA Standards 29-CFR, Part 1910 Sub part S (electrical) Standard number 1910.333.

Question #4: What is Incident Energy?

Incident energy is the energy per unit area received on a surface located a working distance away from the flash location. The working distance is the distance from where the worker stands to the flash location. This is basically an arm length away or approximately 24 inches for low voltage equipment. The distance is longer as the voltage increases.

The unit of incident energy is cal/cm^2 . The threshold value of incident energy for 2nd degree burn of human skin is about $1.2 \text{ cal}/\text{cm}^2$. One cal/cm^2 is equivalent to the amount of energy produced by a cigarette lighter in one second. It is the incident energy that causes burns to the human skin. Table 1 shows the damage that incident energy can impart.

Incident Energy (cal/cm^2)	Degree burn
1.2	2 nd degree burn to bare skin
4	Ignite a cotton shirt
8	3 rd degree burn to bare skin

Table 1: Incident Energy and damage level

Incident energy is both radiant and convective. It is inversely proportional to the working distance squared. It is directly proportional to the time duration of the arc and to the

available bolted fault current. Time has a greater effect than the available bolted fault current.

Both the NFPA-70E and IEEE Standard 1584 uses the assumption that an arc flash generating 1.2 cal/cm^2 ($1.2 \text{ cal/cm}^2 = 5.02 \text{ Joules/cm}^2 = 5.02 \text{ Watt-sec/cm}^2$) for 0.1 second will result in a second-degree burn. It is also assumed that a second-degree burn will be curable and will not result in death. (Figure 1)

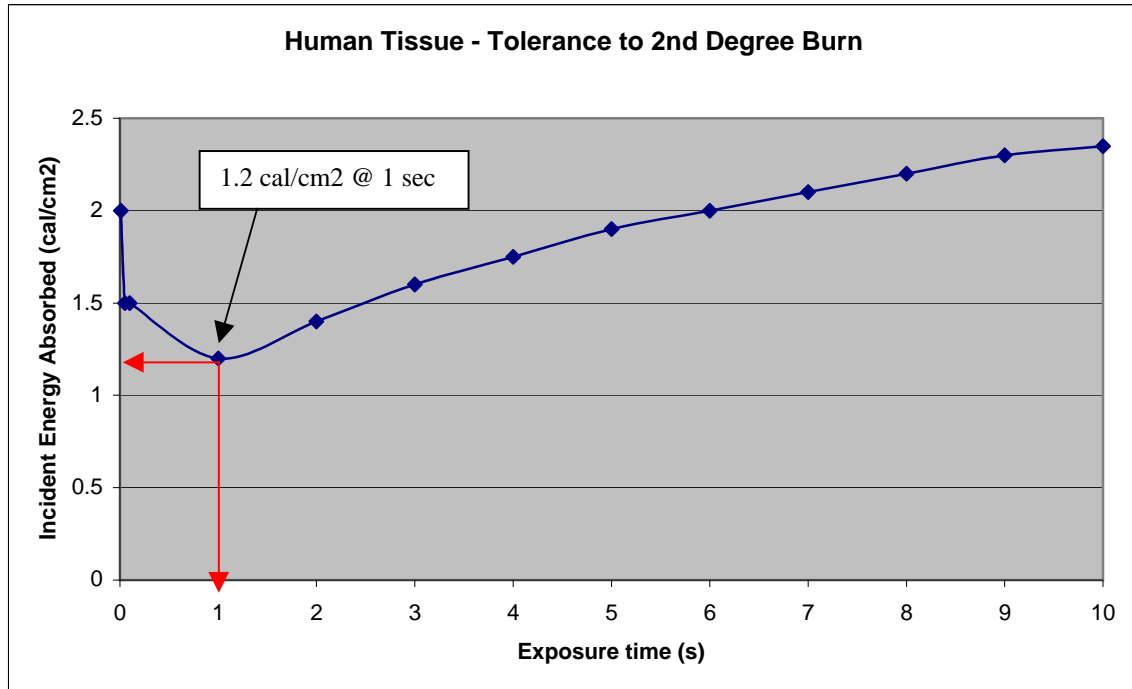


Figure 1: Human Tissue – Tolerance to 2nd Degree Burn

Question #5:

What are the Limited, Restricted, and Prohibited, and Flash Protection Boundaries?

NFPA 70E has developed several protection boundaries based upon the employee's training and personal protective equipment. The Limited Approach, Restricted, and Prohibited Boundaries are based on the voltage of the energized equipment. The Flash Protection Boundary is based not only on voltage, but also on the available fault current and the time it takes for the upstream protective device to operate and clear the fault. These boundaries are summarized below:

Limited Approach Boundary

The limited approach boundary is the minimum distance from the energized item where untrained personnel may safely stand. No unqualified (un-trained) personnel may approach any closer to the energized item than this boundary. The boundary is

determined by NFPA 70E Table 2-1.3.4 and is based on the voltage of the equipment (2000 Edition).

Restricted Approach Boundary

The restricted approach boundary is the distance where qualified personnel may not cross without wearing appropriate personal protective equipment (PPE). In addition, they must have a written approved plan for the work that they will perform. This boundary is determined from NFPA Table 2-1.3.4 (2000 Edition) and is based on the voltage of the equipment.

Prohibited Approach Boundary

Only qualified personnel wearing appropriate personal protective equipment (PPE) can cross prohibited approach boundary. Crossing this boundary is considered the same as contacting the exposed energized part. Therefore, personnel must obtain a risk assessment before the prohibited boundary is crossed. This boundary is determined by NFPA 70E Table 2-1.3.4 (2000 Addition) and is based upon the voltage of the equipment.

Flash Protection Boundary

The flash protection boundary is the closest approach allowed by qualified or unqualified persons without the use of personal protection equipment (PPE). If this Flash Protection Boundary is crossed, PPE must be worn. The boundary is a calculated number based upon several factors such as voltage, available fault current, and time for the protective device to operate and clear the fault. It is defined as the distance at which the worker is exposed to 1.2 cal/cm² for 0.1 second.

IEEE Std 1584 - 2002 details the procedure and needed equations for arc flash calculations. The equations are used to calculate the incident energy and flash boundary, It is valid for voltages ranging from 208 volts to 15, 000 volts with gap ranges between 13mm (0.5 inches) and 153 mm (6 inches).

For low voltage systems below 600 Volts, the flash boundary can be calculated as shown below. Please note that these equations make several assumptions that may not be valid for your facility.

- 1) Locations where the total fault exposure is less than 5,000 amperes-seconds (fault current in amperes multiplied by the upstream device clearing time.): Flash Boundary is 4 feet.
- 2) Above 5,000 ampere-seconds or under engineering supervision use the following formula:

$$D \equiv \sqrt{2.65 \times MVA_{bf} \times t}$$

Or

$$D \equiv \sqrt{53 \times MVA \times t}$$

Where:

D = Flash boundary radius

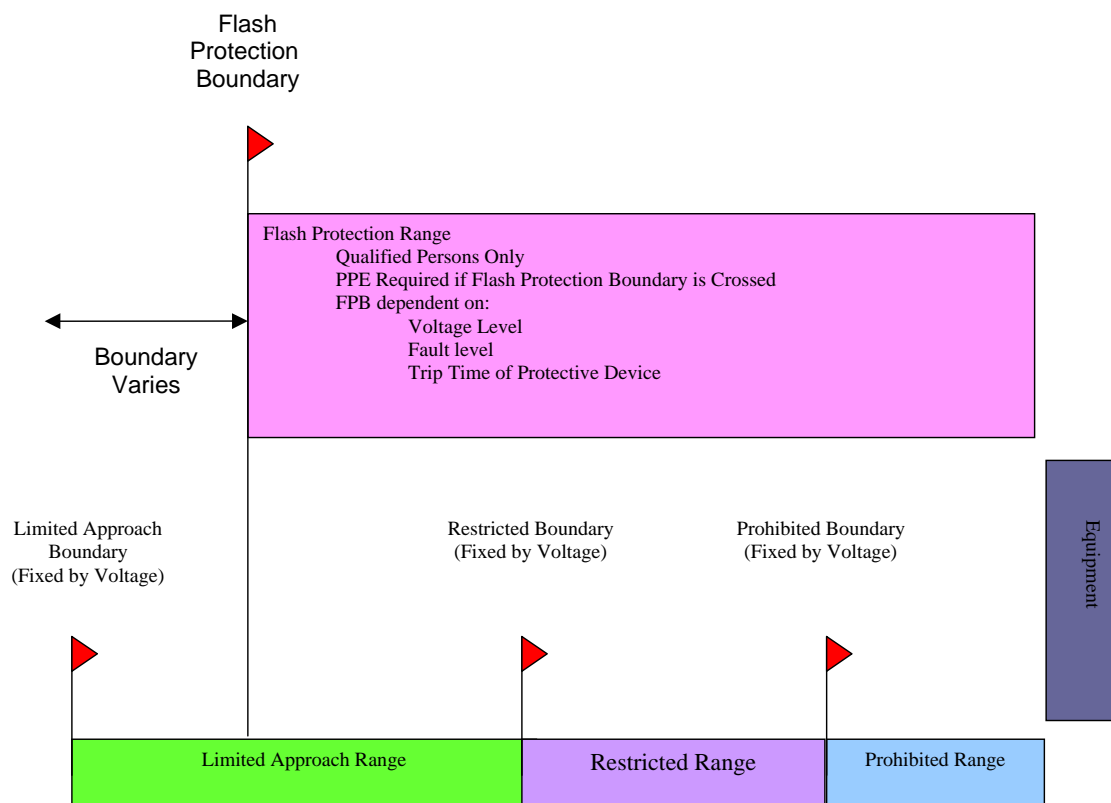
MVA_{bf} = The bolted fault MVA at the point of the energized item

MVA = The maximum fault MVA from the transformer feeding the circuit

T = The time of exposure (based on protective device operation)

For voltages above 600 V, please refer to the IEEE Standard 1584 for the proper calculations, procedures, and equations.

The main thing to remember about the calculation of the Incident Energy level and Flash Boundary is that the time it takes for the protective device to operate plays a bigger role than the amount of available fault current. Longer protective device delay times equate to higher incident energy levels. Lower fault currents cause longer protective device delay times.



Limited Approach Range: Qualified or unqualified persons*
 *Only if accompanied by Qualified Person

Restricted Boundary: Qualified Persons Only, PPE required

Prohibited Boundary: Qualified Persons Only. PPE required as if direct contact with energized part

Figure 2: Working Boundaries

Question #6: What is PPE?

Personnel can be protected from some of these flash hazards by wearing personal protective equipment (PPE) such as clothing, gloves, tools, face protection, and glasses. The main thrust of arc flash protection is to prevent burns to the body that could cause death. The head and chest areas are the most critical and must be protected. Although burns on the person's limbs are serious, they usually are not likely to cause death.

Different types of clothing have different ratings. For example, gloves have a voltage rating to protect from electrical shock. Table 2 below shows the glove classifications required when working at different voltages. Cotton and fire retardant (FR) clothing all have thermal ratings. Table 3 lists the thermal capabilities for some clothing articles typically worn by personnel. These tables are all from NFPA 70E-2000. Table 4 is a

PPE Rating Table. It has divided the personal protective equipment (PPE) requirements into six risk categories.

Glove Class	Voltage Rating
00	2.5 kV
0	5.0 kV
1	10 kV
2	20 kV
3	30 kV
4	40 kV

Table 2: Glove Class Required for Various Voltages

Apparel	PPE Rating (cal/cm ²)
Untreated cotton 4.0 oz. Weave	2.0
Single layer FR cotton 7.5 oz. Weave	6.0
Single layer FR cotton 9.3 oz weave	7.9
PBI fiber blend 4.5 oz. Weave	6.1
Single layer Aramid 4.5 oz. Weave	4.6
Single layer Aramid 6.0 oz. Weave	6.4
Nomex III 4.5 oz. Weave	9.1
Nomex III 6.0 oz. Weave	13.7
Nomex (2 layers) 12 oz. Weave	22.6
6.0 oz. Aramid over 10 FR Cotton	31.0
12 oz Cotton (4 oz) under FR cotton (8 oz)	12.5
Switching suit of FR coverall 24-30 oz. weave	40.0 ⁺
Clear U/V Face Shield	1.2
Gold Reflective U/V Face Shield	7.33
Electrical Arc Hood	45-75

Table 3: PPE Rating for various Apparel

PPE Class	Incident Energy Range (cal/cm ²)	Min PPE Rating (cal/cm ²)	Clothing Description
0	0-2	N/A	Untreated Cotton
1	2-5	5	FR Shirt&Pants
2	5-8	8	FR Underwear+FR shirts & Pants
3	8-25	25	Cotton Underwear+FR shirts & Pants
4	25-40	40	Cotton Underwear+FR Shirt & Pant FR Coverall
5	40-100	100	Cotton underclothing plus FR shirt, pants, plus multi-layer switching suit

Table 4: PPE Class, PPE Rating, and Required Clothing

Question #7: What is an Arc Flash Warning Label?

Section 110.16 of the NEC 2002 code requires switchboards, panelboards, industrial control panels, and motor control centers to be field marked to warn personnel of the potential electric arc flash hazards. The markings are to be located so they are visible to the personnel before examination, adjustment, servicing, or maintenance of the equipment. An example of an arc hazard label is shown below.

! WARNING	
Arc Flash and Shock Hazard Required	
43 inch	Flash Hazard Boundary
3.16	cal/cm² Flash Hazard at 24 inches
Class 1	FR Shirt & Pants
480 VAC	Shock Hazard when cover is removed
42 inch	Limited Approach
12 inch	Restricted Approach
1 inch	Prohibited Approach
Bus Name:	MCC Bus, Prot Device: 1600 T/M LVB

Note that the Flash Hazard Boundary takes precedence over your Approach Boundaries (Limited, Restricted, or Prohibited). The Approach Boundaries are based only upon the equipment voltage. In this example, although the Limited Approach Boundary would have allowed a qualified person to stand within 42 inches of the energized equipment, Flash Hazard Boundary calculations take precedence and require a qualified person to stand 43 inches from the energized equipment and wearing Class 1 fire retardant shirt and pants.

It is also interesting to note, in this example, that the calculated incident energy of 3.16 Cal/cm² is measured at 24 inches from the energized equipment. This distance of 24 inches represents a standard arm length. It is at this distance that required flash protective clothing is determined since it is crucial to prevent burns to the body that could result in death. As noted earlier, burns on the person's limbs would be serious, but not likely to cause death.

Currently, the NEC does not require the label to list the Flash Hazard Boundary, Incident Energy, Approach Boundaries (Limited, Restricted, or prohibited), or PPE requirements.

Only the top two information boxes are required (Warning! Arc Flash and Shock Hazard). Future NEC revisions will require the incident energy and required PPE to be listed.

Question #8: What is an Arc Flash Hazard Study?

An Arc Flash Hazard Study is an analysis and assessment of the arc flash and shock hazards at a facility. The purpose of the study is to identify the appropriate level of Personal Protective Equipment (PPE) for the personnel at various locations throughout the facility. These locations include switchgear, switchboards, substations, panelboards, motor control centers, and industrial control panels.

The arc flash study is a combination of a short circuit study and protective device coordination study. Both of these studies must be completed before an Arc Flash Hazard Study can be completed. The bolted 3-phase current (short circuit current) is needed at each location as well as the upstream device operating time (protective device coordination study) for the reduced arcing fault current.

The arc flash study will determine energy levels, boundary distances and assist the owner in complying with the NFPA guidelines that are enforced by OSHA inspectors. The results of the arc flash study will include:

- 1) Short Circuit Current Values
- 2) Protective Device Settings (Protective Device Coordination Study)
- 3) Arc Flash Incident Energy Levels
- 4) Boundary Distances for
 - a) Arc Flash Protection
 - b) Limited Approach
 - c) Restricted Approach
 - d) Prohibited Approach
- 5) Personal Protective Equipment (PPE)
- 6) Arc Flash and Shock Hazard Warning Labels (listing items #3 and #4a-d) for select equipment.
- 7) Complete report including
 - a) Introduction
 - b) Executive Summary
 - c) Short Circuit Study
 - d) Short Circuit Equipment Summary Sheets
 - e) Protective Device Coordination Study
 - f) Protective Device Setting Sheets
 - g) Time Current Curves
 - h) Arc Flash and Shock Hazard Study
 - i) Arc Flash Calculations

Question #9: What is next?

Do I really need an Arc Flash Hazard Study?

The short answer is “Yes, you need to do an Arc Flash Hazard Study for your facility!”

The Occupational Safety and Health Administration (OSHA) inspectors are currently enforcing National Fire Protection Association (NFPA) document NFPA 70E. This document states that a “flash hazard analysis shall be done before a person approaches any exposed electrical conductor...”. Even though you may think you will not be getting a visit from you friendly OSHA inspector anytime soon, you certainly would want to be in compliance if you do.

On the other hand, your chances of seeing an electrical inspector may be pretty high. The National Electric Code (NEC) states in Article 110.16 that Arc Flash labels must be applied to your electrical equipment. The current NEC (2002) only requires “generic” warning labels stating: “Warning! Arc Flash and Shock Hazard Exists”. However, the fine print notes of NEC Article 110.16 references NFPA 70E. And as we just discussed, NFPA 70E describes the flash hazard analysis and goes on to describe how to perform the calculations.

So...where does this leave us? Clearly, the intent of the Standards is to increase the safety of your employees and protect them from the hazards of arc flash. Currently, NFPA 70E requires arc flash calculations, and NEC Article 110.16 references arc flash calculations. But the trend is increasingly toward the requirement for facilities to have arc flash calculations done.

Although the current NEC code only requires “generic” warning labels, future code revisions (NEC 2005) will require labels reflecting detailed calculations. These future labels will require that the incident energy level, protective boundaries, and level of personal protective equipment be displayed. Due to the complexity of these studies, it is highly recommended that trained, experienced personnel specializing in performing power system studies perform these studies.

You need an Arc Flash Hazard Study to:

- 1) Reduce Shock Hazards
- 2) Reduce Arc Flash injuries
- 3) Increase Personnel Safety
- 4) Comply with NEC, OSHA and NFPA requirements.

Power Systems Engineering can perform this study for your facility. Feel free to call us, fax us, or e-mail us. We would be happy to talk to you about your facility and ways to comply with the OSHA and NEC requirements.

Telephone: (253) 639-8535
Fax: (253) 639-8685
E-mail: fuhr@powerstudies.com
Web: www.powerstudies.com

About the Authors

Robert Fuhr graduated with a B.S.E.E. from the University of Wisconsin in 1980. Before graduating, Mr. Fuhr worked for Madison Gas and Electric in Madison, WI and Tennessee Valley Authority in Knoxville, TN. After graduation, he worked for General Electric Company from 1980 to 1986 as a Field Engineer, performing commissioning and start up tests on many different types of power distribution equipment. Mr. Fuhr worked as a Senior Facilities Engineer at the University of Washington from 1986-1989. There he re-commissioned the electrical power distribution system for University Hospital.

In 1986, Mr. Fuhr established Power Systems Engineering, a consulting firm that specializes in power systems studies, power quality services, and commissioning services. He also teaches classes in protective relaying, electrical systems, safety, power factor correction, harmonics and filter design. Mr. Fuhr is a Professional Engineer registered in Washington, Oregon, California, and Alaska.

Mr. Fuhr has been actively involved in Institute of Electrical and Electronic Engineers (IEEE) and the Industrial Applications Society (IAS) since 1986. He served as an officer for IAS from 1988 to 1992 and was the 1991-92 Chairperson of IAS and was a Member-at-large for the Seattle Section of IEEE from 1992-93. Mr. Fuhr is an IEEE Senior Member, a member of the Building Commissioning Association, and a member of the Electric League of the Pacific Northwest.

Viet Tran graduated from Washington State University in 2003 with a B.S.E.E degree. Prior to graduation, Viet interned at Power System Engineering in Covington, WA. As an Intern Student, he performed various tasks including short circuit and protective device coordination studies.

After graduation, Viet was hired by Power System Engineering to work as a staff Electrical Engineer. Viet had done various power system studies on industrial and commercial projects.