Introduction to Arc Flash

Extension Service
West Virginia University
Safety and Health Extension

Worker Training of Electrical Hazards Including Arc Flash SH-16614-07

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Overview

- Introduction
- Revisions to the NFPA 70E
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- Energized Electrical Work Permit
- Flash Protection Boundary and Limits of Approach
- NFPA 70E Boundaries and Spaces
- Flash Protection Calculations
- Choosing Correct PPE
- Reducing the Arc Flash Hazard

Introduction

- What is Arc Flash?
  - Arc flash results from an arcing fault, where the electric arcs and resulting radiation and shrapnel cause severe skin burns, hearing damage, and eye injuries.

Introduction

Why are we so interested in Arc Flash now?

- Numerous workers are injured and/or killed each year while working on energized equipment. Many of these casualties are a result of arc flash.
- Working on energized equipment has become commonplace in many industries.

Introduction

Injuries that can result from an arc flash:

- Burns
- Respiratory system damage
- Hearing damage
- Skin penetration from flying debris
- Eye and face injuries

Introduction

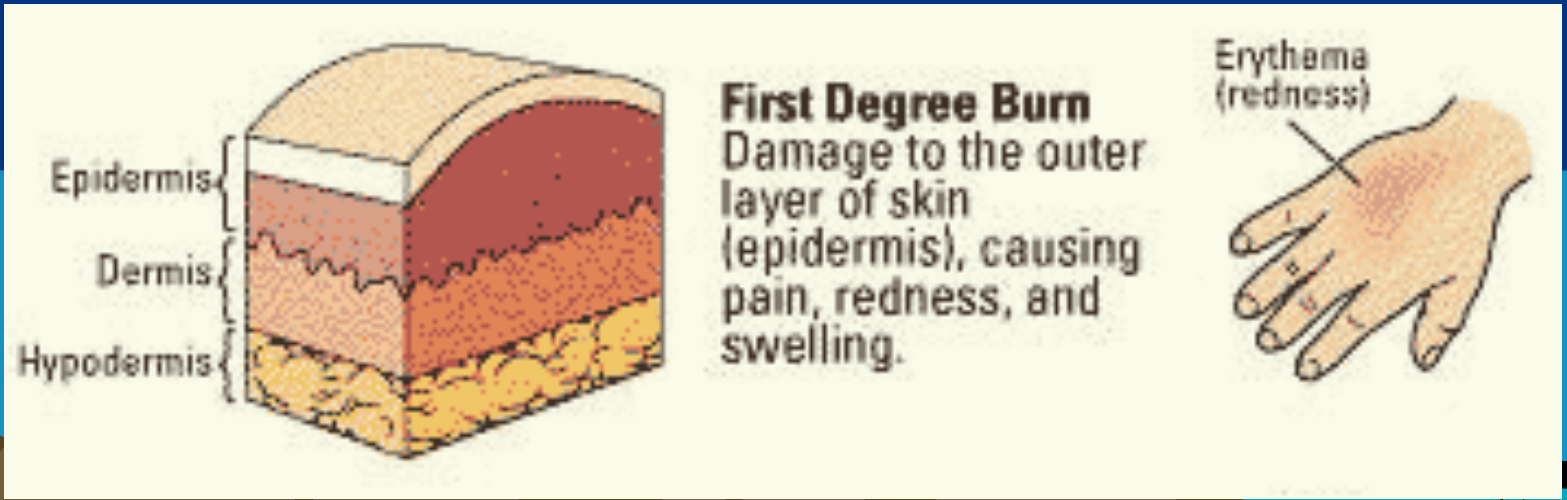
Important Temperatures

Skin temperature for curable burn	176°F
Skin temperature causing cell death	205°F
Ignition of clothing	752°-1472°F
Burning clothing	1472°F
Metal droplets from arcing	1832°F
Surface of sun	9000°F
Arc terminals	35,000°F

Introduction

- A First Degree Burn is red and sensitive to touch. There is minimal skin damage and only the skin surface is involved.

  Example: Sunburn

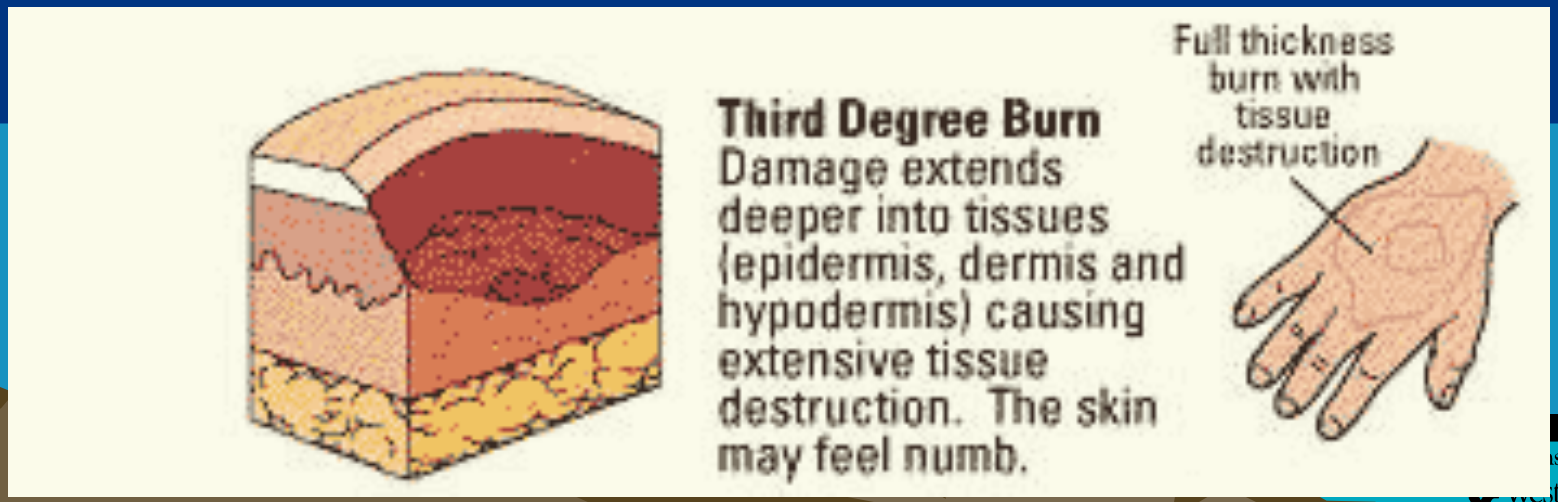


Introduction

- A Second Degree Burn involves the first and second layers of skin. The skin reddens intensely and blisters develop. Severe pain and swelling occur and chance for infection is present.

Introduction

- A Third Degree Burn causes charring of skin and coagulation of blood vessels just below the skin surface. All three layers of skin are affected. Extensive scarring usually results.



Introduction

- Skin damage will occur based on the intensity of the heat generated by an electrical arc accident. The heat reaching the skin of the worker is dependant on the following three factors:
  - Power of the arc at the arc location
  - Distance of the worker to the arc
  - Time duration of the arc exposure

Introduction

- The intent of NFPA 70E regarding arc flash is to provide guidelines which will limit injury to the onset of second degree burns.

Introduction

Inhalation Injuries

In addition to burns, an arc flash can cause inhalation injuries. More than a hundred known toxic substances are present in fire smoke. When inhalation injuries are combined with external burns the chance of death can increase significantly.

Introduction

- The pressure of an arc blast is caused by the expansion of the metal as it vaporizes and the heating of the air by the arc energy. This accounts for the expulsion of molten metal up to 10 feet away.
- In addition, the sudden expansion of an arc blast creates loud sounds that can cause hearing damage.

Revisions To The NFPA 70E

As a result of the injuries and deaths related to arc flash, changes/additions have been incorporated into the National Fire Protection Association publication number 70E, the most recent version being NFPA 70E-2004.

Revisions To The NFPA 70E

1. Only qualified persons shall be permitted to work on electrical conductors or circuit parts that have not been put into an electrically safe work condition. (reference: NFPA 70E-2004 Section 110.8(A)(2) NFPA).

2. A flash hazard analysis shall be done in order to protect personnel from the possibility of being injured by an arc flash. (reference: NFPA 70E-2004 Section 130.3 NFPA).

Revisions To The NFPA 70E

1. Employees working in areas where electrical hazards are present shall be provided with, and shall use, protective equipment that is designed and constructed for the specific part of the body to be protected and for the work to be performed (reference: NFPA 70E-2004 Section 130.7(A) NFPA).

Revisions To The NFPA 70E

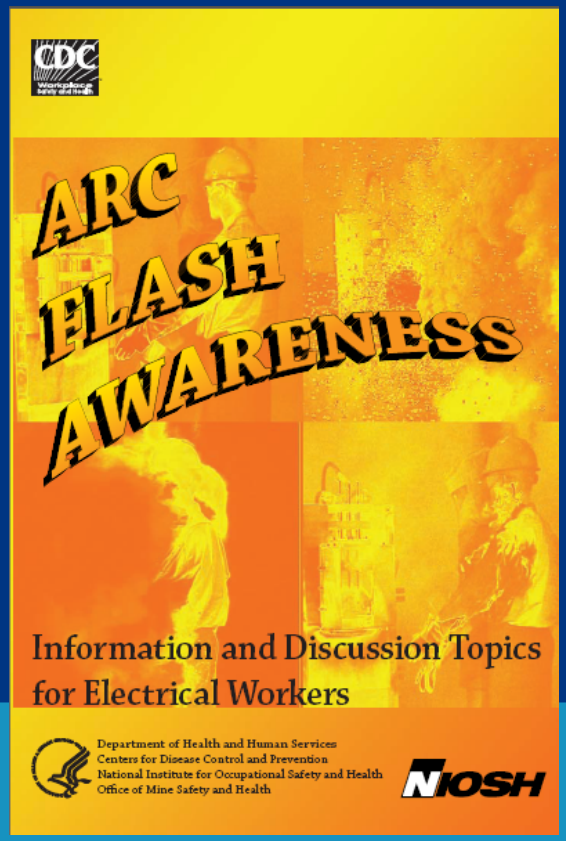
1. Personal protective equipment shall conform to the standard given in Table 130.7(C)(8) (reference: NFPA 70E-2004 130.7(C)(8) ©NFPA).

2. Arc Flash Protective Equipment:

The entire flash suit, including the hood's face shield, shall have an arc rating that is suitable for the arc flash exposure (reference: NFPA 70E-2004 Section 130.7(C)(13)(a)).

Arc Flash Awareness

- NIOSH DVD:
  Arc Flash Awareness
  - Information and discussion about arc flash and comments from workers injured by an arc flash



Electrically Safe Work Conditions

- The equipment is not and cannot be energized:

To ensure an electrically safe work condition:

- Identify all power sources,
- Interrupt the load and disconnect power,
- Visually verify that a disconnect has opened the circuit,
- Locking out and tagging the circuit,
- Test for absence of voltage, and
- Ground all power conductors, if necessary.

Electrically Safe Work Conditions

- Lockout/Tagout
  - A single qualified person de-energizing one set of conductors.
  - An unqualified person may never perform a lockout/tagout, work on energized equipment, or enter high risk areas.

Energized Electrical Work Permit

- When live parts over 50 volts are not placed in an electrically safe work condition it is considered energized electrical work and must be down under a written permit.
- Permit gives conditions and work practices needed to protect employee from arc flash or contact with live parts.

Energized Electrical Work Permit

An Energized Electrical Work Permit will include:

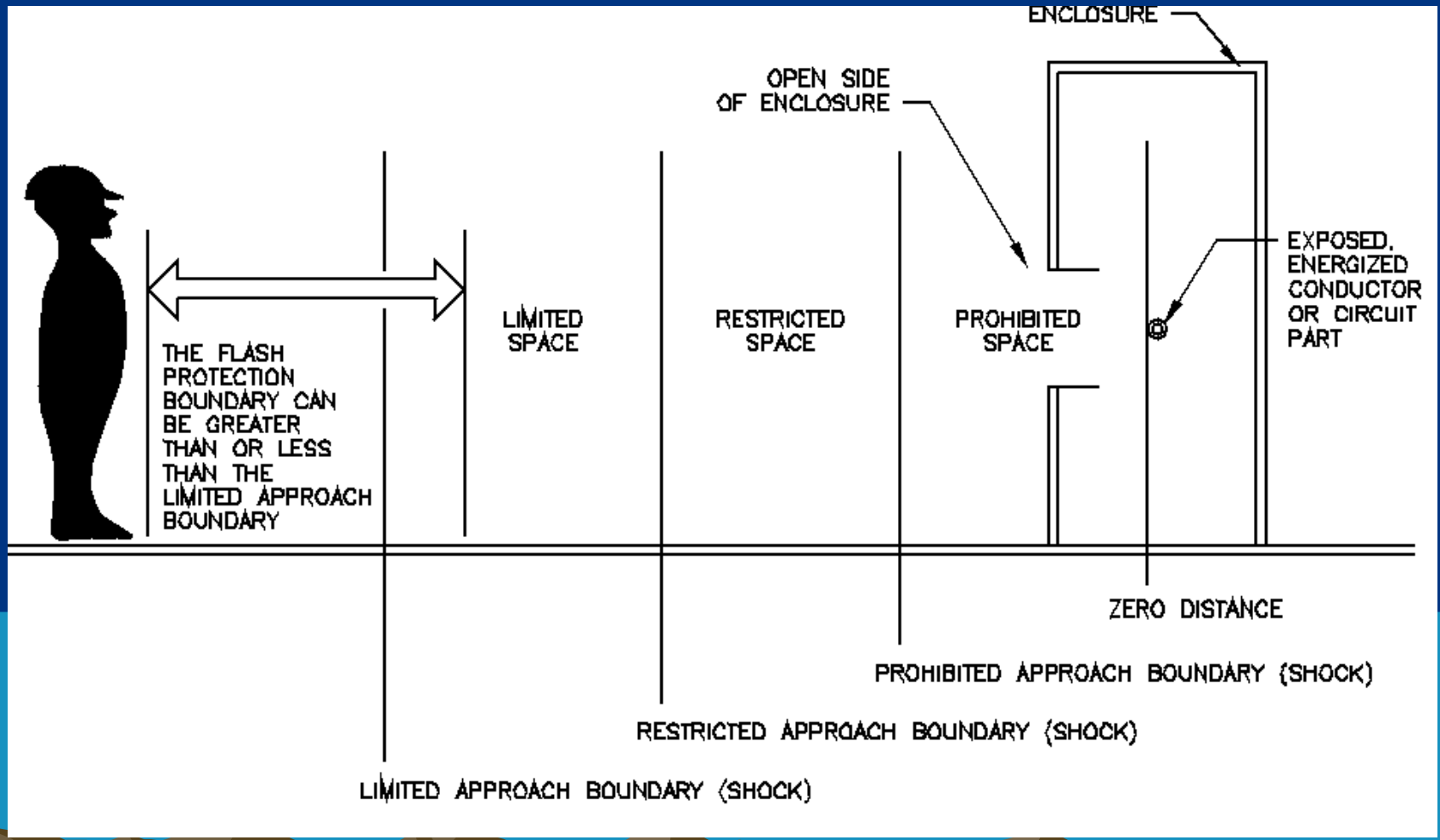
- Circuit, equipment and location
- Why working while energized.
- Shock and arc flash hazard analysis
- Safe work practices
- Approach boundaries
- Required PPE and tools
- Access control
- Proof of job briefing

Flash Protection Boundary and Limits of Approach

- Definitions of Boundaries and Spaces

  The closer you approach an exposed, energized conductor or circuit part, the greater the chance of an inadvertent contact and the greater the injury that an arc flash will cause. NFPA 70E-2004, Annex C defines approach boundaries and work spaces. The diagram on the next slide illustrates these.

Flash Protection Boundary and Limits of Approach



Approach/Flash Protection Boundaries

Flash Protection Boundary and Limits of Approach

- Flash Protection Boundary

  When an energized conductor is exposed, you may not approach closer than the flash boundary without wearing appropriate personal protective clothing and personal protective equipment.

Flash Protection Boundary and Limits of Approach

- Flash Protection Boundary

  IEEE defines “Flash Protection Boundary” as: An approach limit at a distance from live parts operating at 50 V or more that are un-insulated or exposed within which a person could receive a second degree burn.

Flash Protection Boundary and Limits of Approach

How Does Flash Protection Boundary Relate to Working On Or Near Exposed Energized Parts?

- The radiant energy and molten material that is released by an electric arc is capable of seriously injuring or killing a human being at distances of up to twenty feet.

The flash protection boundary is the closest approach allowed by qualified or unqualified persons without the use of arc flash PPE.

Flash Protection Boundary and Limits of Approach

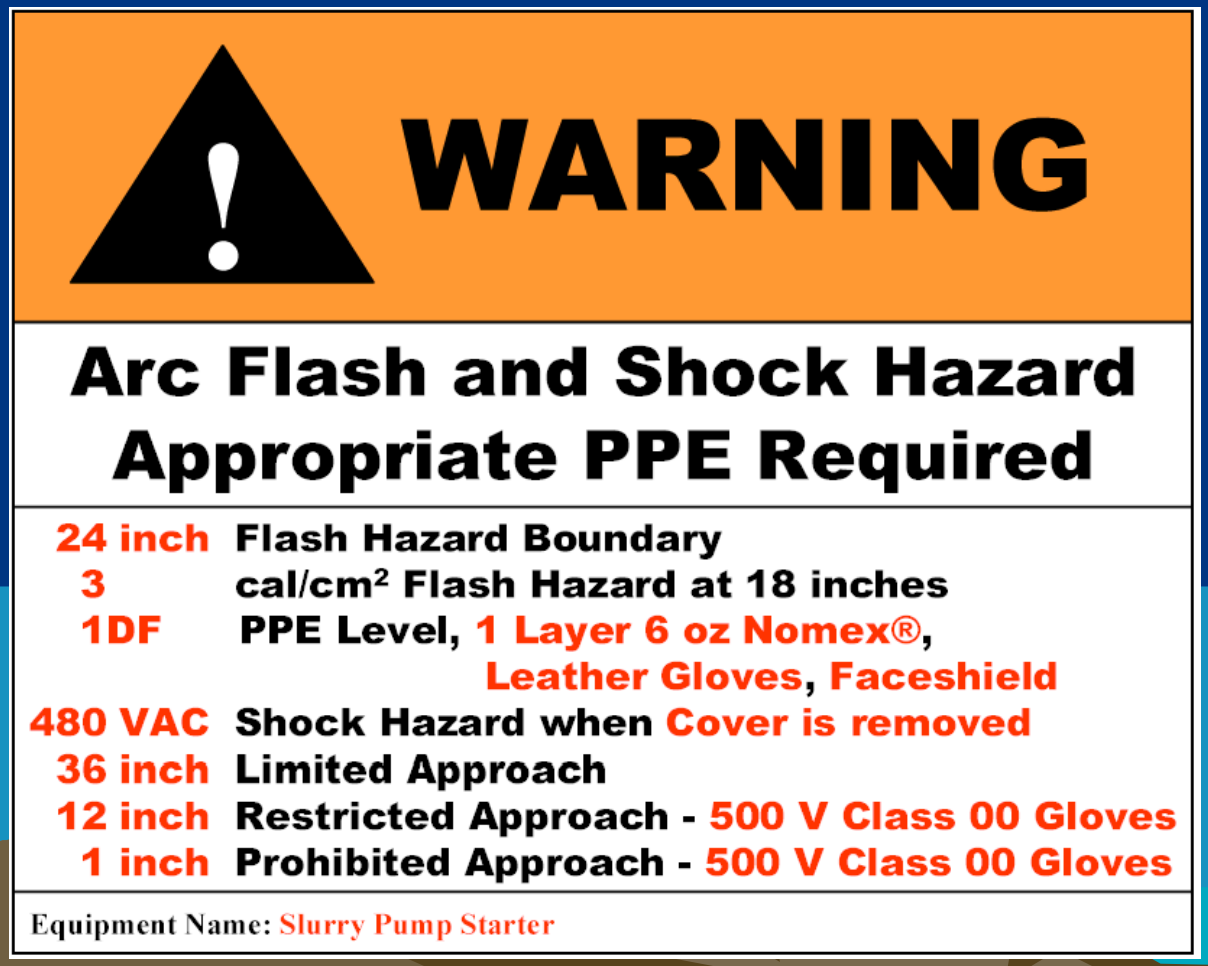
NFPA 70E 2004, Table 130.2(C) NFPA Approach Boundaries to Live Parts for Shock Protection. (All dimensions are distance from live part to employee.)				
(1)	(2)	(3)	(4)	(5)
Nominal System Voltage Range, Phase to Phase	Limited Approach Boundary[1]		Restricted Approach Boundary[1]; Includes Inadvertent Movement Adder	Prohibited Approach Boundary[1]
	Exposed Movable Conductor	Exposed Fixed Circuit Part		
Less than 50	Not specified	Not specified	Not specified	Not specified
50 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.

Flash Protection Boundary and Limits of Approach

Typical NEC Label

Flash Protection Boundary and Limits of Approach

Typical Detailed Label



NFPA 70E Boundaries and Spaces

Good safety practices minimize risk:

- Switch remotely if possible.
- Standing aside and away as much as possible during switching.
- Avoid leaning on or touching switchgear and metallic surfaces.
- Use proper tools and PPE.

NFPA 70E Boundaries and Spaces

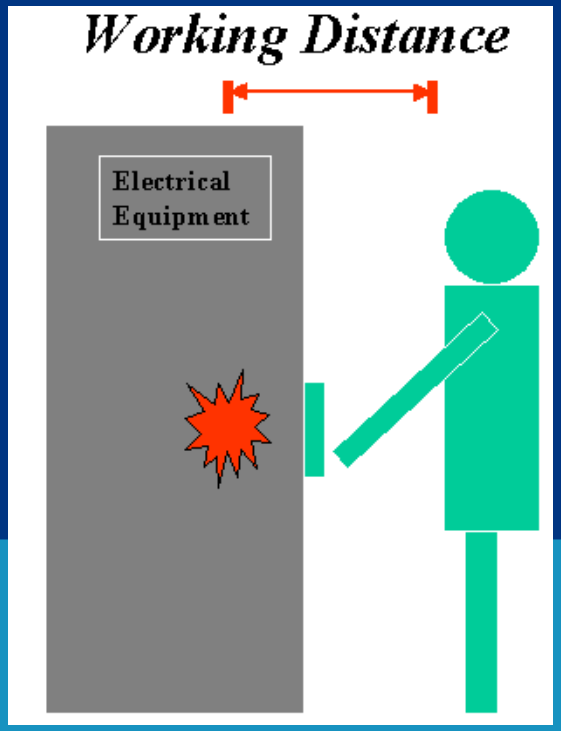
- **NFPA 70E, Section 130.3(B) states:**

- If work will be performed within the flash protection boundary, the flash hazard analysis shall determine, and the employer shall document, the incident energy exposure of the worker in (cal/cm2).

NFPA 70E Boundaries and Spaces

NFPA 70E, Section 130.3 (B) states:

- The incident energy exposure level shall be based on the working distance of the worker's face and chest areas from a prospective arc source for the specific task to be performed.



NFPA 70E Boundaries and Spaces

- NFPA 70E, Section 130.3(B) states:

  Flame Resistant (FR) Clothing and Personal Protective Equipment (PPE) shall be used by the employee based upon the incident energy exposure associated with the specific task.

Flash Protection Calculations

- The Incident Energy and Flash Protection Boundary can be calculated in an Arc Flash Hazard Analysis.

- There are two methods:
  - NFPA 70E-2004, Annex D
  - IEEE Std 1584TM

Flash Protection Calculations

Step 1

- Collect the System Installation Equipment Data

Step 2

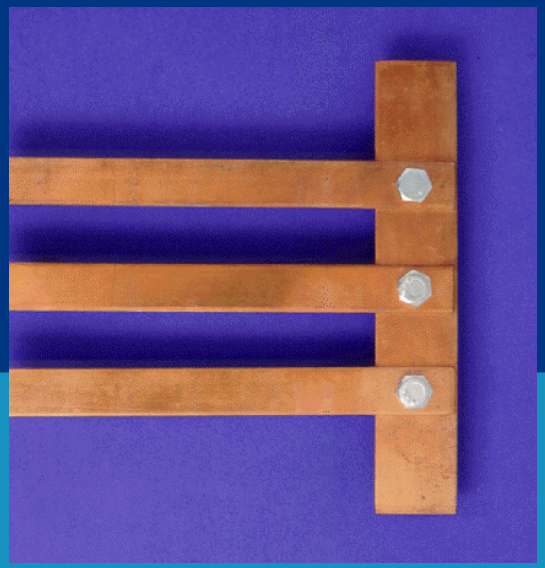
- Determine the Power System's Modes of Operation
  - Normal operation, tie switched closed, dual feeds
  - Perform analysis for worst case condition

Flash Protection Calculations

Step 3

- Determine the Bolted Fault Currents
  - Find symmetrical RMS current and X/R ratio at each point of concern.

- Theoretically worst case fault magnitude
- Determines equipment interrupting ratings
- Impedance at fault location is considered to be zero ohms



Flash Protection Calculations

Step 4

- Determine the Arc Fault Currents
  - The arc fault current for each location where an arc flash hazard exists and the portion of the current that flows through the closest upstream device that will clear this fault must be determined

Flash Protection Calculations

Arcing Fault Current is fault current flowing through an electrical arc plasma.

- Faults which are not bolted
- Poor electrical connection between conductors can cause arcing
- Arcing results in tremendous heat (35,000)

Flash Protection Calculations

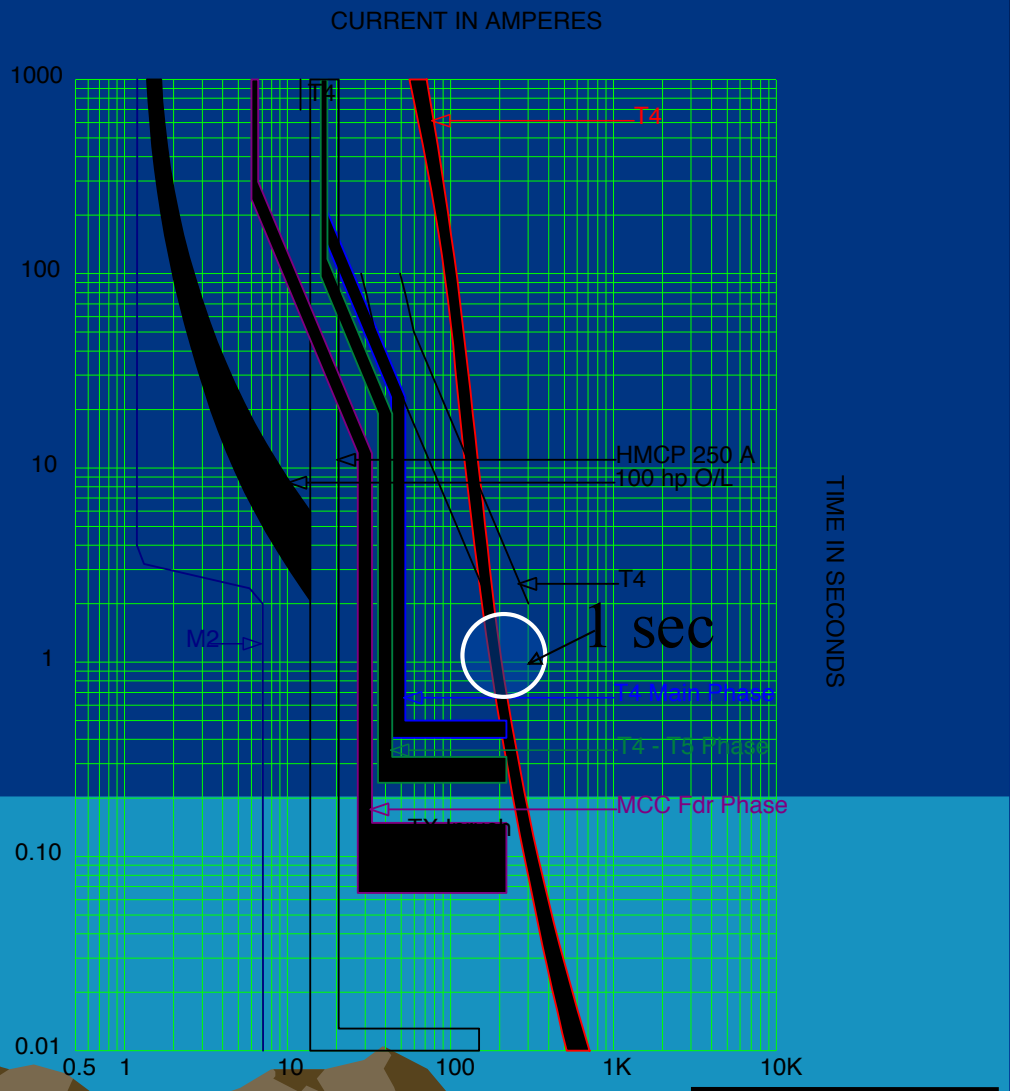
Step 5

- From the Protective Device Characteristics, Find the Arcing Duration
  - The total clearing time of the fault will determine the “time” factor in the incident energy equation.

Flash Protection Calculations

The fault clearing time is determined from the Coordination Study's Time Current Curves.

The total clearing time of the primary fuse for a secondary side fault is 1 second.



Flash Protection Calculations

Step 6

- Record the System Voltages and Equipment Classes
  - For each bus or arc hazard location

Step 7

- Determine Working Distances
  - Arc flash protection is always based on the incident energy to a person's face and body at the working distance

Flash Protection Calculations

Step 8

- Determine Incident Energy
  - This is best done using a software package.
- Calculating incident energy requires the following parameters:
  - Max. bolted 3-ph fault current available at the equipment
  - Total protective upstream device clearing time max fault current
  - Distance of worker from the arc

Flash Protection Calculations

Step 9

- Determine the Flash Protection Boundary for All Equipment
  - The incident energy for the flash-protection boundary must be set at the minimum energy beyond which a second degree burn could occur - 1.2 cal/cm2

Flash Protection Calculations

Let's take a quick look at the NFPA 70E-2004 equations

Flash Protection Calculations

The estimated incident energy for an arc in open air is:

EMA = 5271*DA*-1.9593 *tA*[0.0016*F* 2-0.0076*F*+0.8938]

EMA=maximum open arc incident energy (cal/cm2)

DA=distance from arc electrodes (inches)

tA=arc duration (seconds)

F=bolted fault current in kA (16kA-50kA)

Flash Protection Calculations

The estimated incident energy for an arc in a box is:

$$EMB = 1038.7DB\text{-}1.4738\ tA[0.0093F2\text{-}0.3453F+5.9675]$$

EMB=max 20 in. cubic box incident energy (cal/cm2)

DB=distance from arc electrodes (inches) for 18 in. and greater

tA=arc duration (seconds)

F=bolted fault current in kA (16kA-50kA)

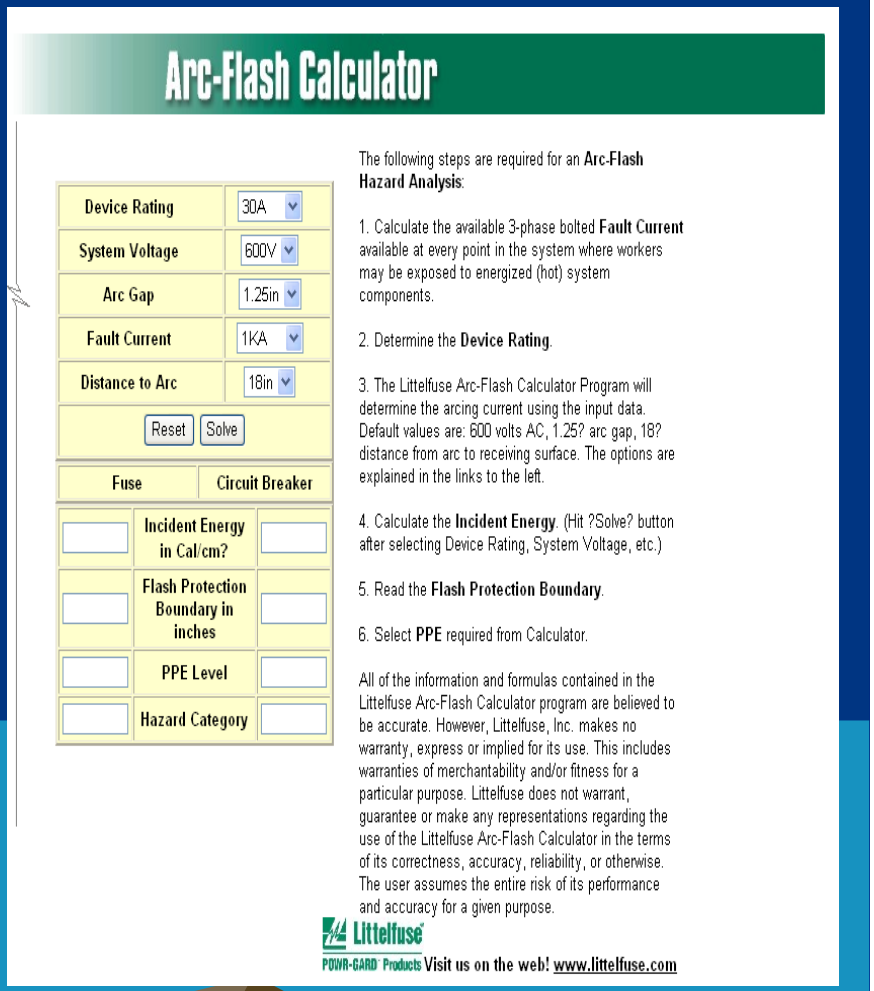
Flash Protection Calculations

- Test results have shown that the incident energy for an open air arc is approximately inversely proportional to the distance squared.
- Enclosing a 3-ph arc in a box can increase the incident energy from 1.5 to 3 times depending upon the arc parameters and box dimensions when compared to an open air arc with the same parameters.

Flash Protection Calculations

There are resources on the internet to assist in calculations:

- http://www.littelfuse.com/arccalc/calc.html
- http://www.pnl.gov/contracts/esh-procedures/forms/sp00e230.xls
- http://www.bussmann.com/arcflash/index.aspx



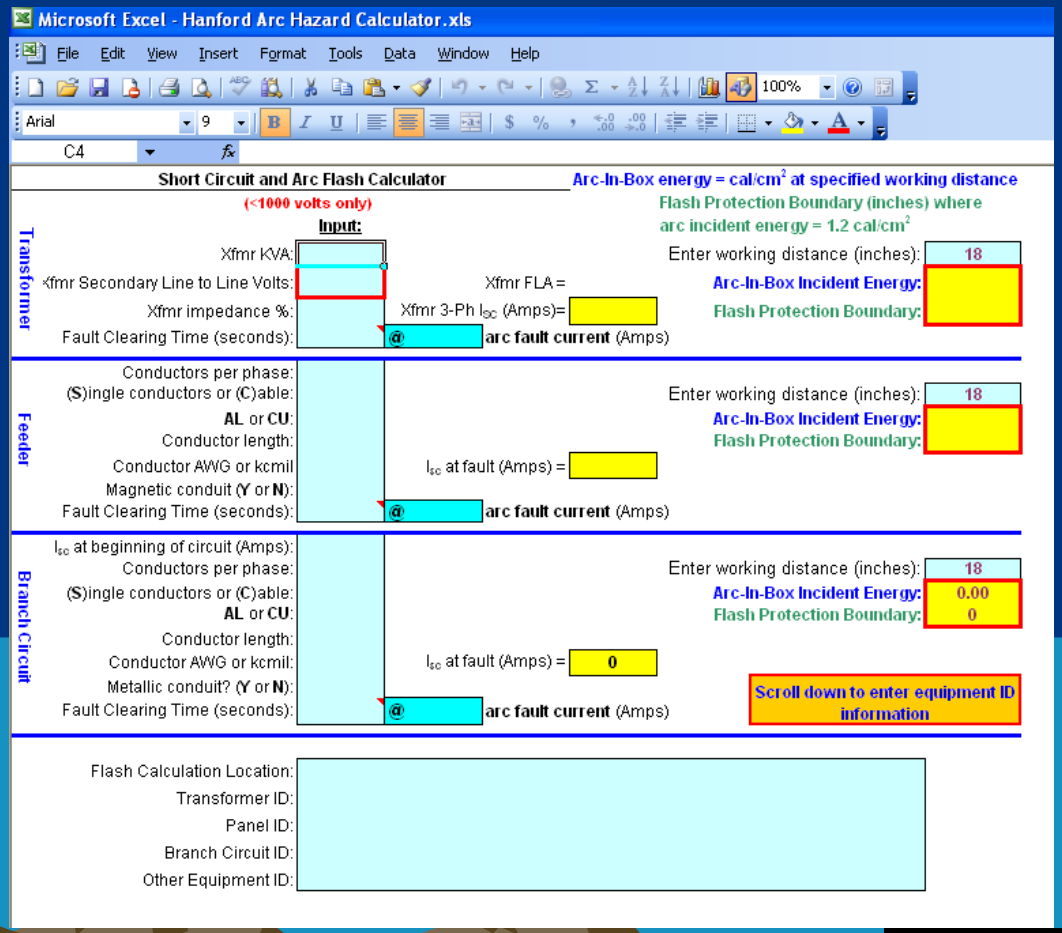
Flash Protection Calculations

As well as software and spreadsheets:

EasyPower®

etap
Thinking Power

SKM
Systems Analysis, Inc.



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Choosing Correct PPE

Section 130.7(A) states that employees working in areas where there are electric hazards shall be provided with, and shall use, protective equipment that is designed and constructed for the specific part of the body to be protected and for the work to be performed.

Choosing Correct PPE

- Personal Protective Equipment, PPE, for the arc flash is the last line of defense.
- It is not intended to prevent all injuries, but is intended to mitigate the impact of an arc flash, should one occur.

Choosing Correct PPE

- After the Arc-Flash Hazard Analysis has been performed, PPE is selected as follows:

  Clothing's ATPV or EBT (in cal/cm2)

  ≥

  Calculated Hazard Level (in cal/cm2)

*ATPV can be obtained from clothing manufacturer

Choosing Correct PPE

ATPV - Arc Thermal Performance Exposure Value

EBT - Breakopen Threshold Energy Rating

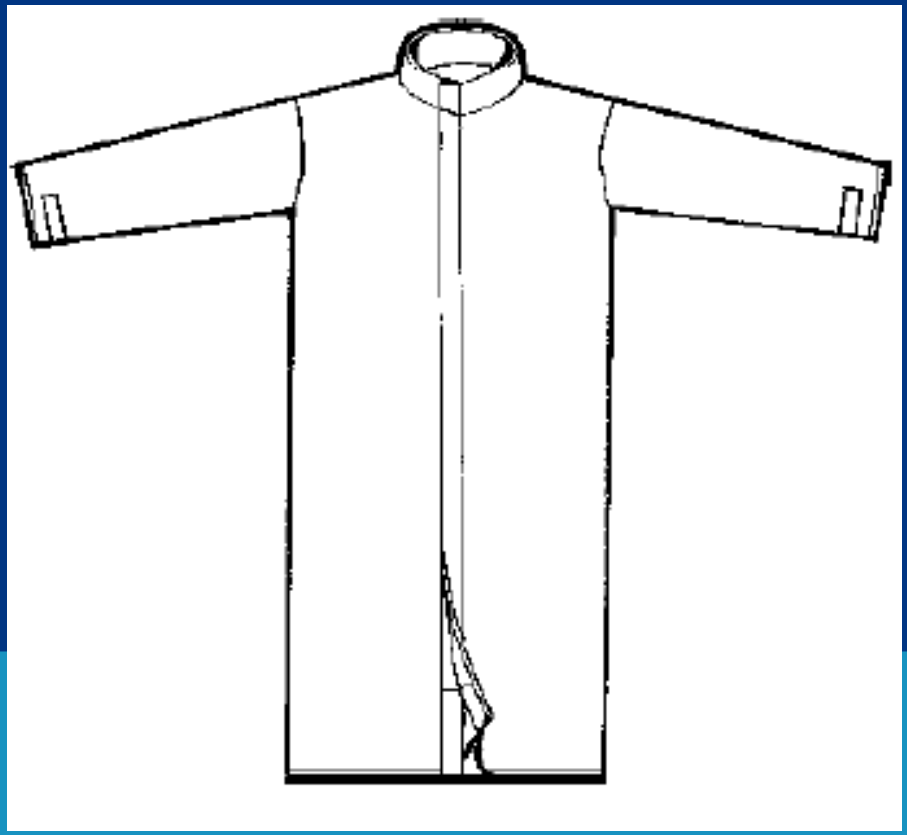
Calculated Hazard Level - Incident Energy in cal/cm2

Choosing Correct PPE

- Specialized Arc-Flash Protection Equipment:
  Flash Suit
- Use: Hazard/Risk Category 4

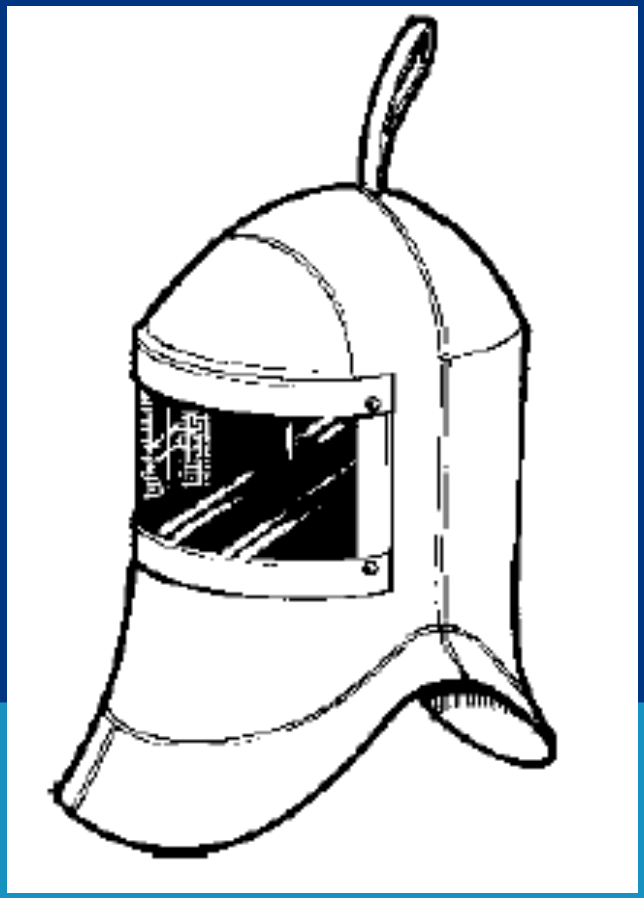
Choosing Correct PPE

- Specialized Arc-Flash Protection Equipment:
  - Switching Coat,
  - ATPV = 42 cal/cm2
- Use: Hazard/Risk Category 4



Choosing Correct PPE

- Specialized Arc-Flash Protection Equipment:
  Hood,
  ATPV = 42 cal/cm2
- Use: Hazard/Risk Category 4



Choosing Correct PPE

- Specialized Arc-Flash Protection Equipment:

  Face Shield -- Attaches to Hard Hat

- Use: Hazard/Risk Category 2

Choosing Correct PPE

- Specialized Arc-Flash Protection Equipment:
  - Gloves and Leather Protectors,
  - (ATPV Values not Established for Rubber)
- Use: Hazard/Risk Category 2, 3, and 4 for the Leather Protectors

Choosing Correct PPE

- NFPA 70E, Section 130.7(C)(9)(a) states:
  - When selected in lieu of the flash hazard analysis of 130.3(A), Table 130.7(C)(9)(a) shall be used to determine the hazard/risk category for each task.
- NFPA 70E, Section 130.7(C)(10) states:
  - Once the Hazard/Risk Category has been identified, Table 130.7(C)(10) shall be used to determine the required personal protective equipment (PPE) for the task.

Choosing Correct PPE

The tables in NFPA 70E-2004 provide the simplest methods for determining PPE requirements. They provide instant answers with almost no field data. The tables provide limited application and are conservative for most applications.

*These tables are not intended as a substitution for an arc hazard analysis, but only as a guide.

Choosing Correct PPE

A simplified two-category approach is found in NFPA 70E-2004, Table H-1 of Annex H NFPA. This table assures adequate PPE for electrical workers within facilities with large and diverse electrical systems.

Choosing Correct PPE

The clothing listed in Table H-1 fulfills the minimum FR clothing requirements of NFPA 70E-2004, Tables 130.7(C)(9)(a) and 130.7(C)(10) NFPA and should be used with the other PPE appropriate for the Hazard/ Risk Category that is found in of NFPA 70E-2004, Table 130.7(C)(10) NFPA.

Choosing Correct PPE

Everyday Work Clothing	Applicable Tasks
FR long sleeve shirt (minimum arc rating of 4) worn over an untreated cotton T-shirt with FR pants (minimum arc rating of 8) Or FR coveralls (minimum arc rating of 4) worn over an untreated cotton T-shirt with untreated natural fiber pants.	All Hazard/Risk Category 1 or 2 tasks listed in Table 130.7(C)(9)(a) NFPA On systems operating at less than 1000 V, these tasks include all work except: - Insertion or removal of MCC buckets - Insertion or removal of power circuit breakers with switchgear doors open - Removal of bolted covers from switchgear On systems >1000 V, also includes operation, insertion or removal of switching devices with equipment enclosure doors closed.

Choosing Correct PPE

Electrical "Switching" Clothing	Applicable Tasks
Multilayer FR flash jacket and FR Bib overalls worn over FR coveralls (minimum arc rating of 4) Or Insulated FR coveralls (minimum arc rating of 25) worn over untreated natural fiber long sleeve shirt with cotton blue jeans and worn over an untreated cotton T-shirt.	All Hazard/Risk Category 1 or 2 tasks listed in NFPA 70E, Part II, Table 3-3.9.1 NFPA On systems 1000 V, tasks include work on exposed energized parts of all equipment On systems <1000 V, tasks include insertion or removal of LV MCC buckets, insertion or removal of power circuit breakers with the switchgear enclosure doors open, and removal of bolted covers from switchgear

Choosing Correct PPE

- NFPA 70E-2004, Section 130.7(C), Table 130.7(C)(9)(a) lists common work tasks with respective Hazard/Risk category of each task.
- After the Hazard Risk Category has been determined from Table 130.7(C)(9)(a), then Table 130.7(C)(10) is used to determine the Protective Clothing and Personal Protective Equipment required for the task.

Choosing Correct PPE

Task (Assumes Equipment Is Energized, and Work Is Done Within the Flash Protection Boundary)	Hazard/ Risk Category	V-rated Gloves	V-rated Tools
CB or fused switch operation with enclosure doors closed	0	N	N
Reading a panel meter while operating a meter switch	0	N	N
CB or fused switch operation with enclosure doors open	1	N	N
Work on energized parts, including voltage testing	2*	Y	Y

Choosing Correct PPE

- NFPA 70E, Table 130.7(C)(11) lists the characteristics and degrees of protection for various Flame Resistant (FR) clothing systems.

Choosing Correct PPE

NFPA 70E Table 130.7(C)(11) Typical Protective Clothing Systems			
Hazard Risk Category	Clothing Description (Number of clothing layers is given in parenthesis)	Total Weight	Minimum Arc Thermal Performance Exposure Value (ATPV)* or Breakdown Threshold Energy (E_{BT})* Rating of PPE
		oz/yd^2	cal/cm^2
0	Untreated Cotton (1)	4.5 - 7	N/A
1	FR shirt and FR pants (1)	4.5 - 8	5
2	Cotton underwear plus FR shirt and FR pants (2)	9 - 12	8
3	Cotton underwear plus FR shirt and FR pants plus FR coverall (3)	16 - 20	25
4	Cotton underwear plus FR shirt and FR pants plus double layer switching coat and pants (4)	24-30	40

* ATPV is defined as the incident energy that would just cause the onset of a second degree burn.

* E_{BT} is defined as the highest incident energy which did not cause FR fabric breakopen and did not exceed the second degree burn criteria. E_{BT} is reported when ATPV cannot be measured due to fabric breakopen.

Choosing Correct PPE

The equations in NFPA 70E-2004 provide more accurate methods than tables for determining PPE requirements. System data and studies are required. The equations are based upon limited fuse and circuit breaker data.

Choosing Correct PPE

- Remember: PPE is the last line of defense. PPE cannot prevent all injuries and will only lessen the impact of an arc flash. In many cases the use of PPE has saved lives or prevented serious injury.

Reducing The Arc Flash Hazard

OSHA 1910.333 severely limits the situations in which work is performed on or near equipment or circuits that are or may be energized.

Reducing The Arc Flash Hazard

EQUIPMENT ALTERNATIVES

- Metal-Clad Switchgear

  Structural design reduces the possibility of arcing faults within the enclosure.

Reducing The Arc Flash Hazard

EQUIPMENT ALTERNATIVES

- Arc Resistant Switchgear

  EEMAC Standard G14-1 defines the requirements for arc resistant switchgear. Includes robust design and pressure relief vents.

Reducing The Arc Flash Hazard

EQUIPMENT ALTERNATIVES

- Current-Limiter Power Circuit Breakers

  Reduces the clearing time which reduces the incident energy.

Reducing The Arc Flash Hazard

EQUIPMENT ALTERNATIVES

- Current-Limiting Reactors

  Reduces the magnitude of fault current which reduces the incident energy.

Reducing The Arc Flash Hazard

EQUIPMENT ALTERNATIVES

- Zone Selective Interlocking of Circuit Breakers

Deactivates the preset delay on the circuit breaker closest to the fault, which then trips with no intentional delay.

Reducing The Arc Flash Hazard

Whatever the analysis method or proposed method of solution, each work task must be analyzed assuming worst case conditions.

Reference Materials

- *Standard for Electrical Safety in the Workplace*, NFPA 70E 2004 Edition
- Controlling Electrical Hazards. OSHA Publication 3075, (2002). Also available as a 350 KB PDF, 71 pages. Provides a basic overview of electrical safety on the job, including information on how electricity works, how to protect against electricity, and how OSHA can help.
- *Electrical Safety: Safety and Health for Electrical Trades Student Manual*. US Department of Health and Human Services (DHHS), National Institute for Occupational Safety and Health (NIOSH), Publication No. 2002-123, (2002, January), 1.7 MB PDF, 88 pages. This student manual is part of a safety and health curriculum for secondary and post-secondary electrical trades courses. It is designed to engage the learner in recognizing, evaluating, and controlling hazards associated with electrical work. http://www.cdc.gov/niosh/pdfs/02-123.pdf
- Electrocutions Fatality Investigation Reports. National Institute for Occupational Safety and Health (NIOSH) Safety and Health Topic. Provides information regarding hundreds of fatal incidents involving electrocutions investigated by NIOSH and state investigators
- *Working Safely with Electricity*. OSHA Fact Sheet, 353 KB PDF, 2 pages. Provides safety information on working with generators, power lines, extension cords, and electrical equipment. http://www.osha.gov/OshDoc/data_Hurricane_Facts/elect_safety.pdf
- *Lockout/Tagout*. OSHA Fact Sheet, (2002), 212 KB PDF, 2 pages. A 92 KB PDF (Spanish version) is also available. http://www.cdc.gov/nasd/docs/d001501-d001600/d001514/d001514.html
- Lockout-Tagout Interactive Training Program. OSHA. Includes selected references for training and interactive case studies. http://www.osha.gov/dts/osta/lototraining/index.htm
- NIOSH Arc Flash Awareness, NIOSH Publication No. 2007-116D

Questions?