SIGN the Attendance Sheet

You are at risk of losing one percentage point off your quiz score for every minute you are late!

Electrical Safety in the Workplace

110.2 Training Requirements.

Δ (A) **Electrical Safety Training.** The training requirements contained in 110.2(A) shall apply to employees exposed to an electrical hazard when the risk associated with that hazard is not reduced to a safe level by the applicable electrical installation requirements. Such employees shall be trained to understand the specific hazards associated with electrical energy. They shall be trained in safety-related work practices and procedural requirements, as necessary, to provide protection from the electrical hazards associated with their respective job or task assignments. Employees shall be trained to identify and understand the relationship between electrical hazards and possible injury.

Informational Note: For further information concerning installation requirements, see *NFPA 70, National Electrical Code.*

(1) **Qualified Person.** A qualified person shall be trained and knowledgeable in the construction and operation of equipment or a specific work method and be trained to identify and avoid the electrical hazards that might be present with respect to that equipment or work method.

(a) Such persons shall also be familiar with the proper use of the special precautionary techniques, applicable electrical policies and procedures, PPE, insulating and shielding materials, and insulated tools and test equipment.

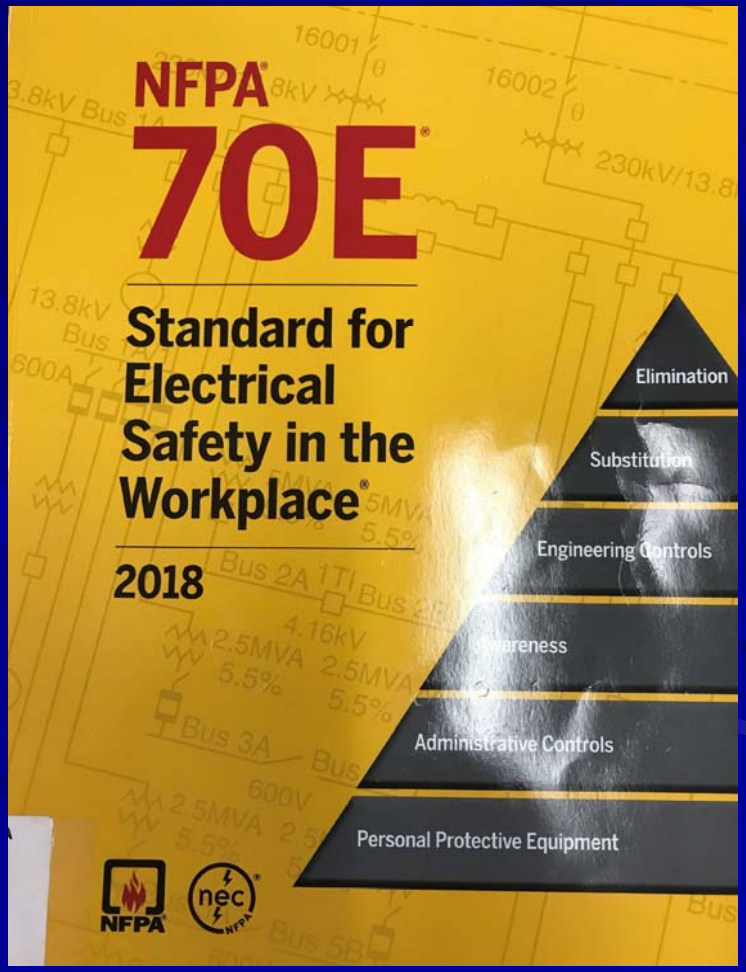
(b) A person can be considered qualified with respect to certain equipment and tasks but still be unqualified for others.

(c) Such persons permitted to work within the limited approach boundary shall, at a minimum, be additionally trained in all of the following:

(1) Skills and techniques necessary to distinguish exposed energized electrical conductors and circuit parts from other parts of electrical equipment

(2) Skills and techniques necessary to determine the nominal voltage of exposed energized electrical conductors and circuit parts

(3) Approach distances specified in Table 130.4(D)(a) and Table 130.4(D)(b) and the corresponding voltages to which the qualified person will be exposed



FN000385/CR

Objectives

- At the end of this training the student will be able to:
  - State the hazards and physical effects of the hazards of electricity
  - State Fermilab's Policy on working on energized circuits
  - Recall the basic tenets of Fermilab's Electrical Safety Program
  - Understand the significance of NFPA 70E and why it exists
  - Understand requirements of NFPA 70E as related to the AC Power Distribution System and Utilization Equipment

Objectives

- Understand terms presented in NFPA 70E
- Understand the process and means for mitigating electrical hazards
- Understand how to protect yourself against the hazards of electrical shock
- Understand how to protect yourself against the hazards arc -flash
- Understand the importance of Single Line Electrical Diagrams (SLEDs)

Objectives

- State where to procure, how to maintain, and limitations of Personal Protective Equipment (PPE) and tools
- Describe proper methods to verifyde-energization (zero voltage verification, a.k.a. ZVV)
- Discuss the Electrical Hazard Analysis Work Permit (EHAWP) found in FESHM 9110 and 9120
- State requirements for rescue, including use of Cardiopulmonary Resuscitation (CPR)
- State requirements for Task Manager and Construction Coordinator (TM/CC) as it applies to their oversight responsibilities of subcontractors

Most Important Objectives

- Protect the Worker
- Understand the Work and the Hazard
- Identify the Shock and Flash Boundaries
- Identify the Arc-flash PPE Category
- Identify What PPE Must be Worn
- Understand How NFPA 70E Helps to Figure Out All of This
- Understand Where to Go for Advice and Guidance

Why?

- We Care About Your Safety
- We Want to Provide a Safe Work Environment
- We Want to Continue to Avoid Injuries
- Required to Comply with NFPA 70E Requirements
- Consequences are Unacceptable

Consequences of an Arc-Flash Incident

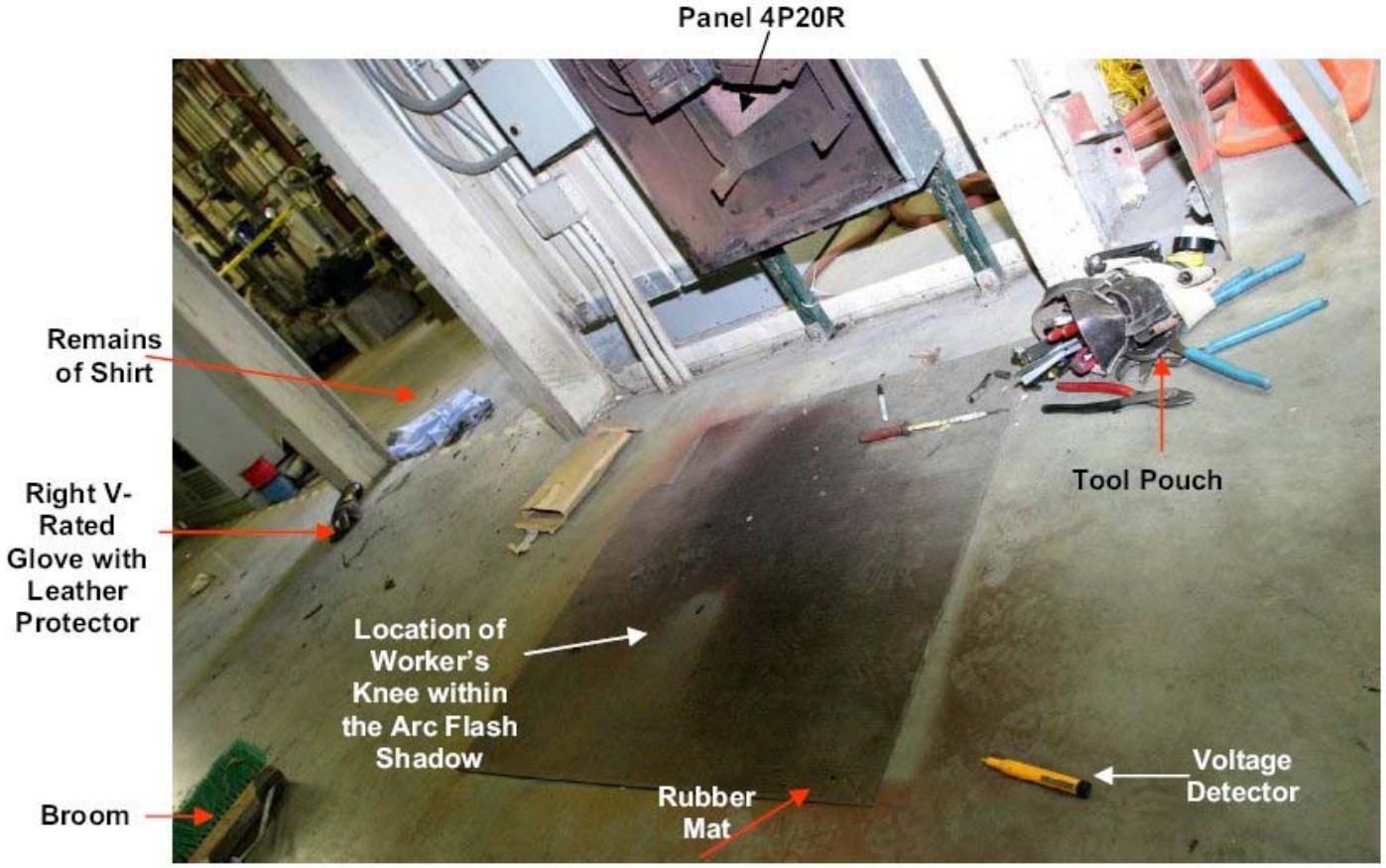


Figure 2-3. The insulating mat with the outline of BSE-1's knee in the arc flash shadow

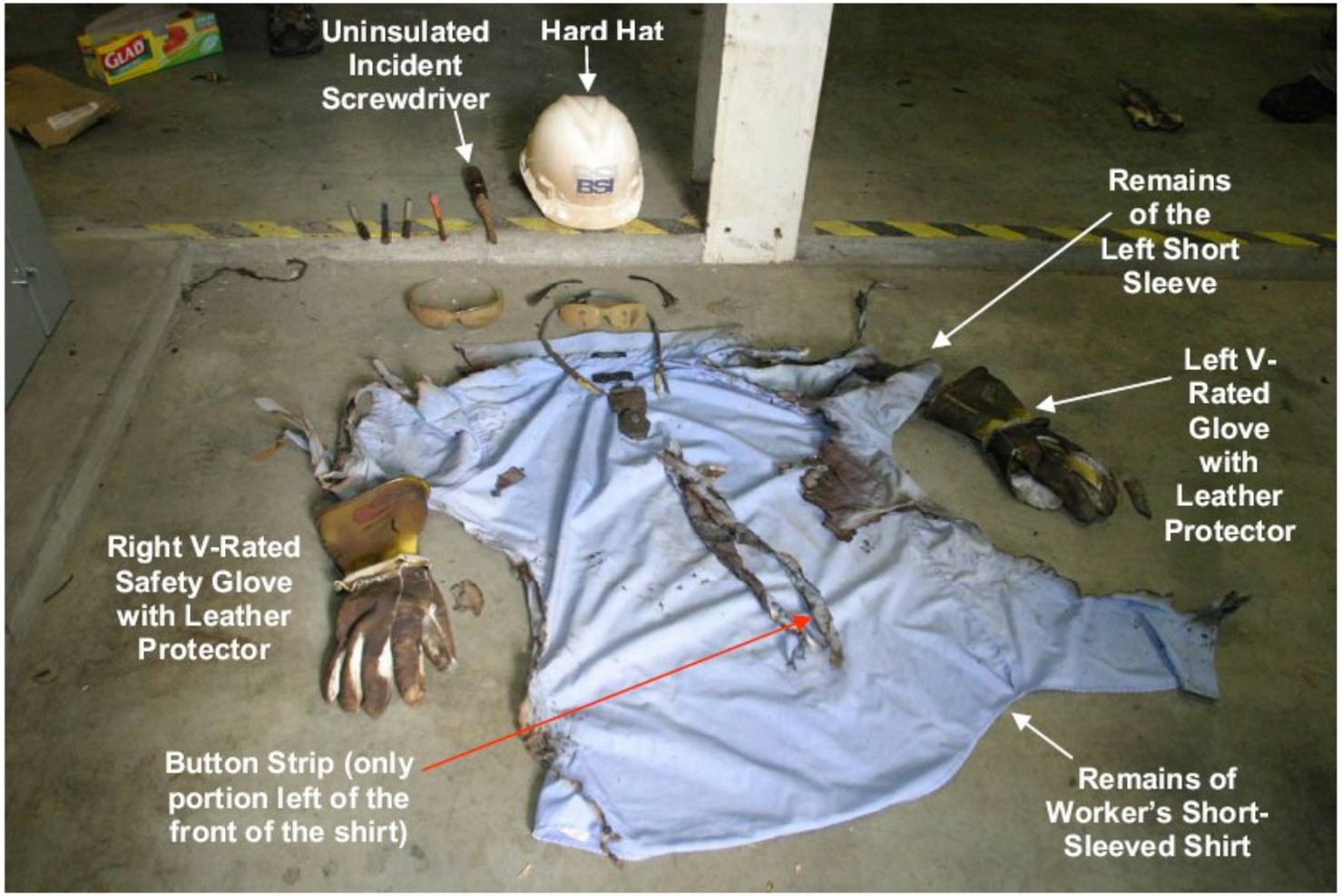


Figure 2-6. BSE-1's burned shirt and his flash-damaged PPE and tools

Some Statistics

- 286 Fatalities and 4,100 cases of lost time injuries due to electrical shock or electrical burns each year from 1992-1998
  - 98% of the fatalities due to electrical shock
  - 38% injuries were due to arc flash burns
- 239 construction workers electrocuted in 2010
- 5 to 10 arc flash explosions occur daily in the US
- Financial costs can be staggering
  - Can exceed $13 Million for one incident
- Programmatical costs for Fermilab would be astronomical

Hazards of Electricity

Familiar to Most of You But They Bear Repeating

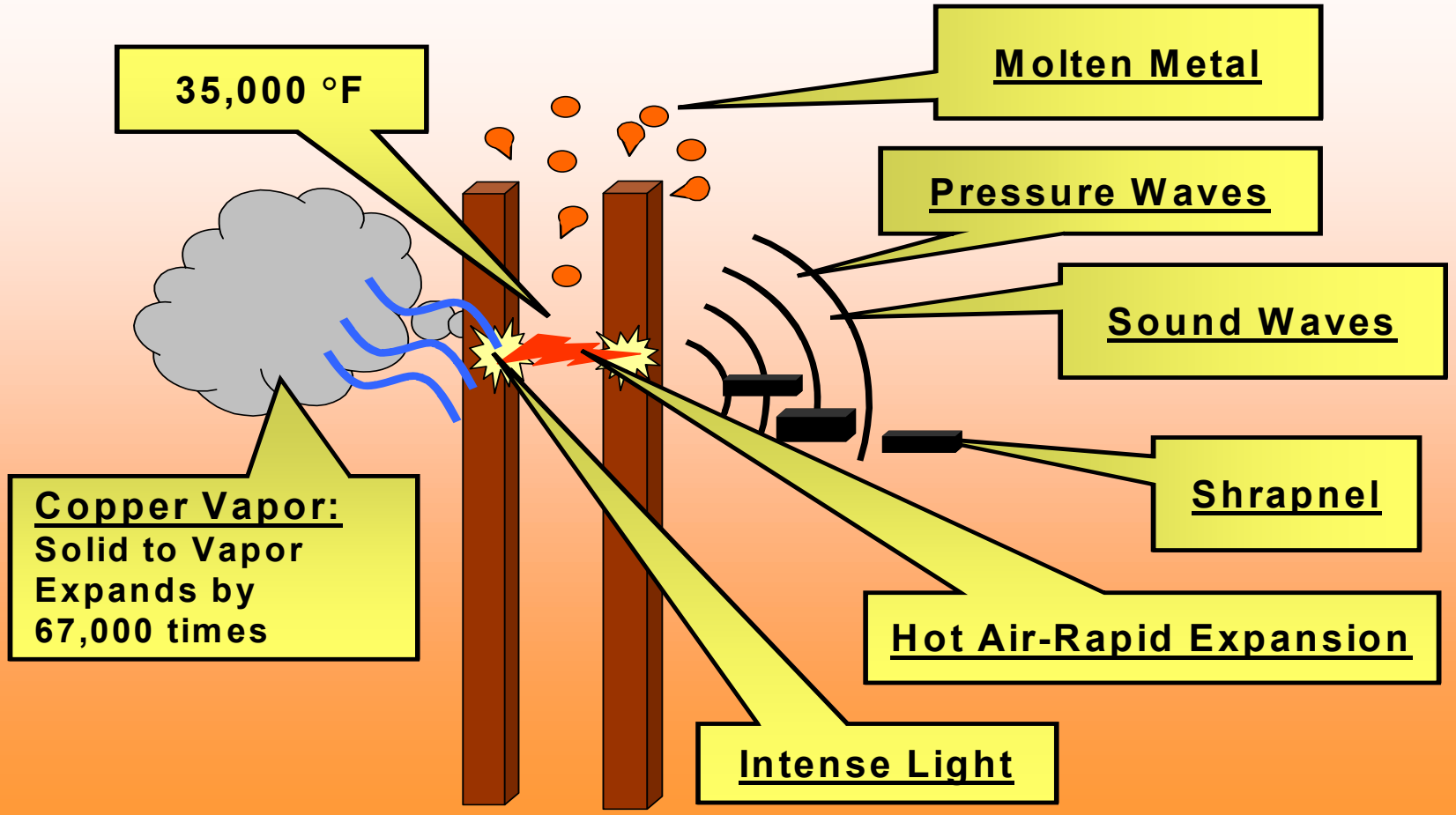
Hazards of Electricity

- Electric Shock
  - Temporary paralysis
  - Internal tissue burns
  - Muscular and skeletal damage
  - Death (Electrocution)
- Arc-Flash
  - Surface burns due to high heat and molten metal
  - Fire Ignition
- Arc-Blast
  - Hearing loss due to pressure wave
  - Lacerations/Punctures from blast debris
  - Internal organ damage

Arc-Flash

- Electric current passes through air, between a “Hot” conductor and ground, or between “Hot” conductors
- Temperatures can reach 35,000 Degrees F three times the surface temperature of the sun
- Exposure can easily cause skin burns & ignite clothing
- Clothing or PPE that Burns and Melts is a Real Problem

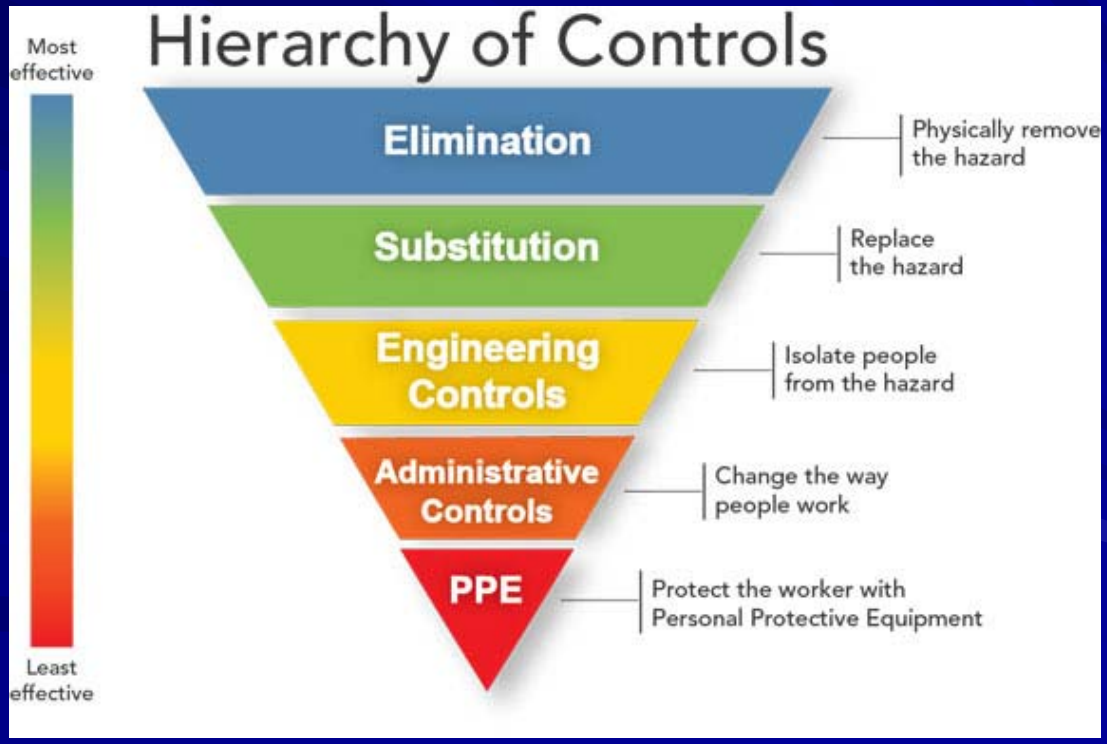
Electrical Arc



Arc Flash Video

Mitigation of Electrical Hazards

- NFPA incorporates the Hierarchy of Controls published by the National Institutes of Safety and Health as a guide to effective hazard mitigation.



Mitigation of Electrical Hazards

- Work De-Energized
- Engineer Out the Hazard
  - Prevention through Design, a.k.a. Safety by Design
- Follow Electrical Safe Work Practices
  - Employ Lockout/Tagout of Hazardous Electrical Energy Sources
  - Use Voltage Insulating PPE and Equipment
  - Use PPE for Arc-Flash Protection
  - Use Ground Fault Circuit Interrupters

Fermilab's Electrical Safety Program

- Electrical systems and equipment and all design, construction, installation, inspection, testing, and operational activities shall be in accordance with established electrical safety standards
- Electrical work activities at Fermilab are preferentially performed on de-energized circuits
- Implementation of Lockout/Tagout (LOTO) procedures is central to our Program

Fermilab's Electrical Safety Program

- FESHM 9100 – Overall Program
- FESHM 9110 – Utilization Equipment Safety
- FESHM 9120 – AC Electrical Power
- FESHM 9130 – Cable Trays
- FESHM 9140 – Exposed Electrical Bus
- FESHM 9150 – HV Coaxial Connectors
- FESHM 9160 – Low Voltage, High Current
- FESHM 9170 – AC Power Back Up Systems
- FESHM 9180 – Safe Work Practices and PPE
- FESHM 9190 – Grounding Requirements
- FESHM 2100 – Lockout Tagout

Electrical Safety Program Audits

- NFPA 70E requires that the electrical safety program be periodically audited. Three audits are required:
  - Electrical Safety Program Audit. NFPA is updated on a 3 – year cycle, so this audit must be is done every 3 years as well
  - Field Work Audit must be done annually
  - Lockout / Tagout program audit must be done annually for program, procedures, and field work. This is coordinated with LOTO inspections
- Your cooperation with audits is appreciated!

Energized Work

Diagnostic or Manipulative

What is Energized Work?

- Any activity On or Near exposed energized conductors where a hazard exists from contact or equipment failure that can result in electric shock, arc flash burn, or arc blast.

- Working On - Coming in contact with live parts with the hands, feet, or other body parts, with tools, probes or with test equipment

- Working Near – Inside the Limited Approach Boundary

Diagnostic Energized Work

- Inspection, testing, voltage and/or current measurements, phase alignment, troubleshooting, circuit and signal tracing, thermal imaging, etc. that are performed on or near exposed live parts within the Limited Approach Boundary
- Verification Associated with LOTO
- Performed by Qualified Persons Utilizing Appropriately Rated Measurement Equipment and Required PPE.

Manipulative Energized Work

- Making, tightening or breaking of energized electrical connections or the replacement, removal, or addition of electrical or mechanical components

- Examples include:
  - Replacing a duplex outlet, light switch, fluorescent fixture ballast, fuses, circuit breakers
  - Drilling or punching holes in a panelboard
  - Pulling conductors into a panelboard

Fermilab Policy for Energized Work

- Do Not work on energized electrical equipment unless absolutely necessary
- Diagnostic Energized Work is allowed only when the diagnostic activity is not feasible with the circuit de-energized
- Manipulative Energized Work is prohibited at Fermilab unless it can be demonstrated that de-energization introduces additional or increased hazards or is infeasible due to equipment design or operational limitations
- Directorate Approval Required for Manipulative Energized Work
- These policies and NFPA 70E apply to both the equipment of the AC Power Distribution system and to Utilization Equipment
- Infeasible is not Inconvenient

NFPA 70E
Electrical Safety in the Workplace

NEC - OSHA - NFPA 70E

- NEC – National Electric Code NFPA 70
  - How electrical equipment is installed
- OSHA 1910 (General Industry Safety)
  - 1910.269: Electric power generation, T&D
- OSHA 1910 Subpart S
  - 1910.301-308: Electrical Installation
  - 1910.331-335: Electrical Safety
  - 1910.399: Definitions
- OSHA 1926 (Construction Safety) Subpart K
  - 1926.400-449 Electrical

NFPA 70E

- OSHA comes into existence in 1970.
- OSHA adopts NEC in 1972
- Problem: OSHA works only with people. NEC is all about equipment, not how people work.
- OSHA solicits expert groups to write an electrical safe work standard in 1976
- First NFPA 70E published in 1978
  - Only Part 1: Installation Safety Requirements
- Second edition published in 1981
  - Added Part 2: Electrical Safe Work Practices

NFPA 70E

- Third edition published in 1983
  - Added Part 3: Safety-Related Maintenance Requirements
- Fourth edition in 1988, minor revisions
- In 1992 70E committee revamped, focus shifts from installations to safety programs
- Fifth edition published in 1995
  - Major part 1 revision
  - Limits of Approach and Arc-Flash hazards first appear

NFPA 70E

- Sixth edition published in 2000
  - Added Part 4: Safety Requirements for Special Equipment
  - Part 1 updated again, part 2 gets more detail on arc flash boundaries and PPE (HRC 1-4)
- 2004 (7th) edition a complete reorganization
  - Chapter 1: Safety-Related Work Practices
    - HRCs now -1, 0, 1, 2, 3, and 4
  - Chapter 2: Safety-Related Maint. Reqs.
  - Chapter 3: Reqs for Special Equipment
  - Chapter 4: Installation Safety Requirements

NFPA 70E

- 2009 (8th) edition
  - Chapter 4 disappears
  - HRCs now 0, 1, 2, 2*, 3, and 4
  - Article 350 for R&D Laboratories added
- 2012 (9th) edition
  - AC and DC shock and arc-flash hazards treated separately
  - HRC 2 disappears, HRC 2* now called HRC 2

NFPA 70E

- 2015 (10th) edition
  - Five times increase in arc-flash testing data allows more precise protection
  - HRCs renamed Arc-Flash PPE Categories, now back to 1, 2, 3, and 4
- 2018 (11th) edition
  - Adds “Normal Operating Condition” and tasks with negligible arc-flash hazard
  - Permits use of permanently installed NRTL-listed Zero Voltage Verification devices
- These are only highlights!

2018 NFPA 70E Organization

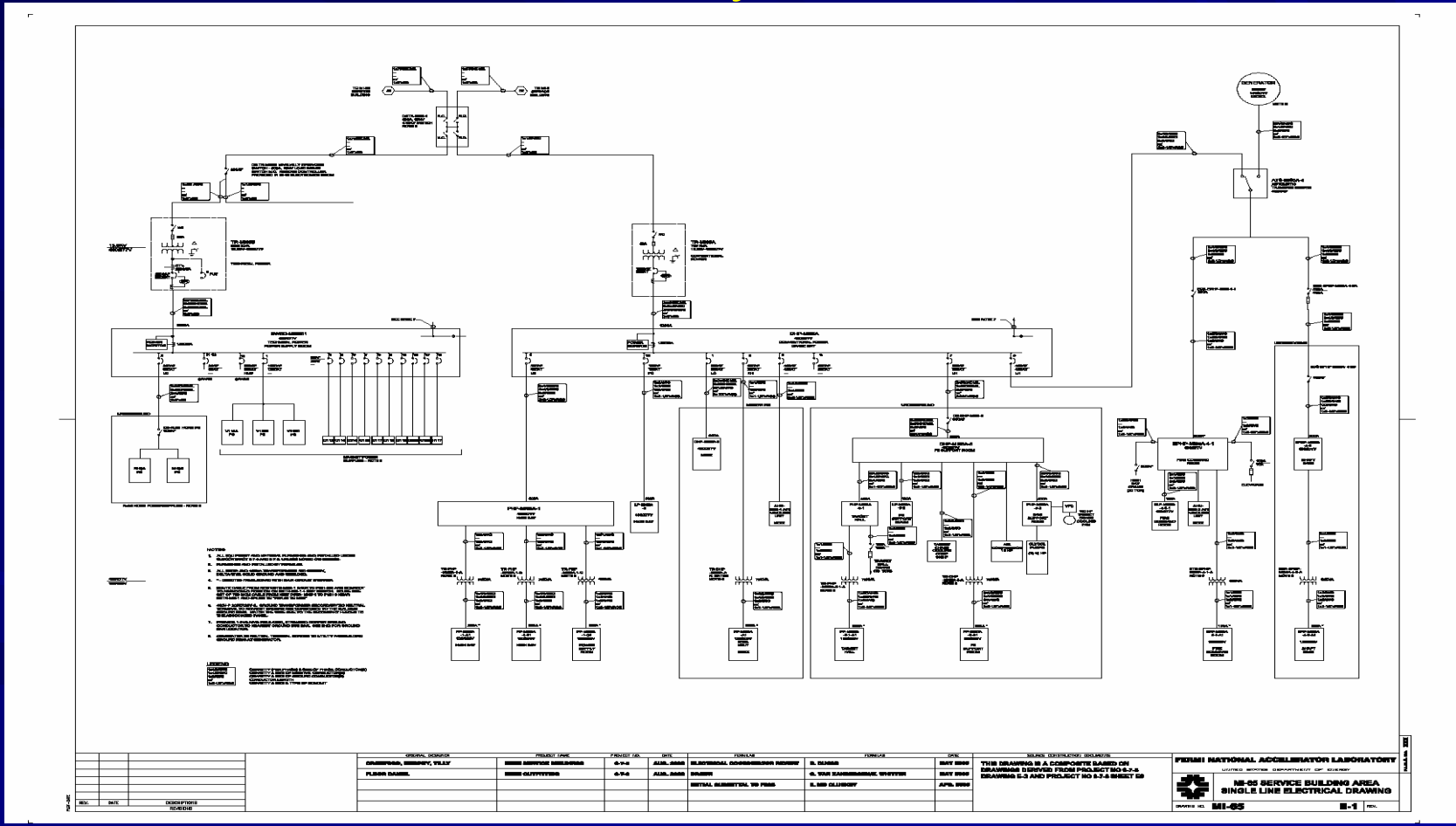
- 3 Chapters and 17 Informative Annexes
- Chapter 1 “Safety Related Work Practices”
  - Article 100 - Definitions
  - Article 105 – Safety-Related Work Practices
  - Article 110 - General Requirements
  - Article 120 - Establishing an Electrically Safe Work Condition
  - Article 130 – Work Involving Electrical Hazards
- Chapter 2 “Safety Related Maintenance Requirements”
- Chapter 3 “Safety Requirements for Special Equipment”

Some General Article 100 Definitions

- Qualified Person
  - One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training on the hazards involved
- Electrically Safe Work Condition
  - The equipment is de-energized and free of hazardous electrical energy.
  - See Article 120.4 for Details of the Process

Electrical Single-Line Diagram (SLED)

Block diagram of major elements of a local AC Power Distribution System



NFPA 70E Requirements

Article 130

Article 130 - Working on or Near Live Parts

- Working on or near live parts must be justified
- Diagnostic Energized Work is allowed when the diagnostic activity is not feasible with the circuit de-energized
- Manipulative Energized Work is prohibited at Fermilab unless it can be demonstrated that de-energization introduces additional or increased hazards or is infeasible due to equipment design or operational limitations.
  ** Requires Directorate Approval **

Article 130 Requirements

- A Permit is Required for Energized Work
  - But Diagnostic Work is not subject to permit
  - FESHM 9110 & 9120 EHAWP is our Permit
- Boundaries for Shock and Arc-Flash
- Arc-Flash PPE Categories
- Determination of the degree of protection required to safeguard workers involves both a Shock and Arc-Flash Hazard Analysis

Shock Hazard and Protection

It Helps to Consider this Aspect of 70E
Separate from the Arc-Flash Hazard

Shock Hazard and Protection

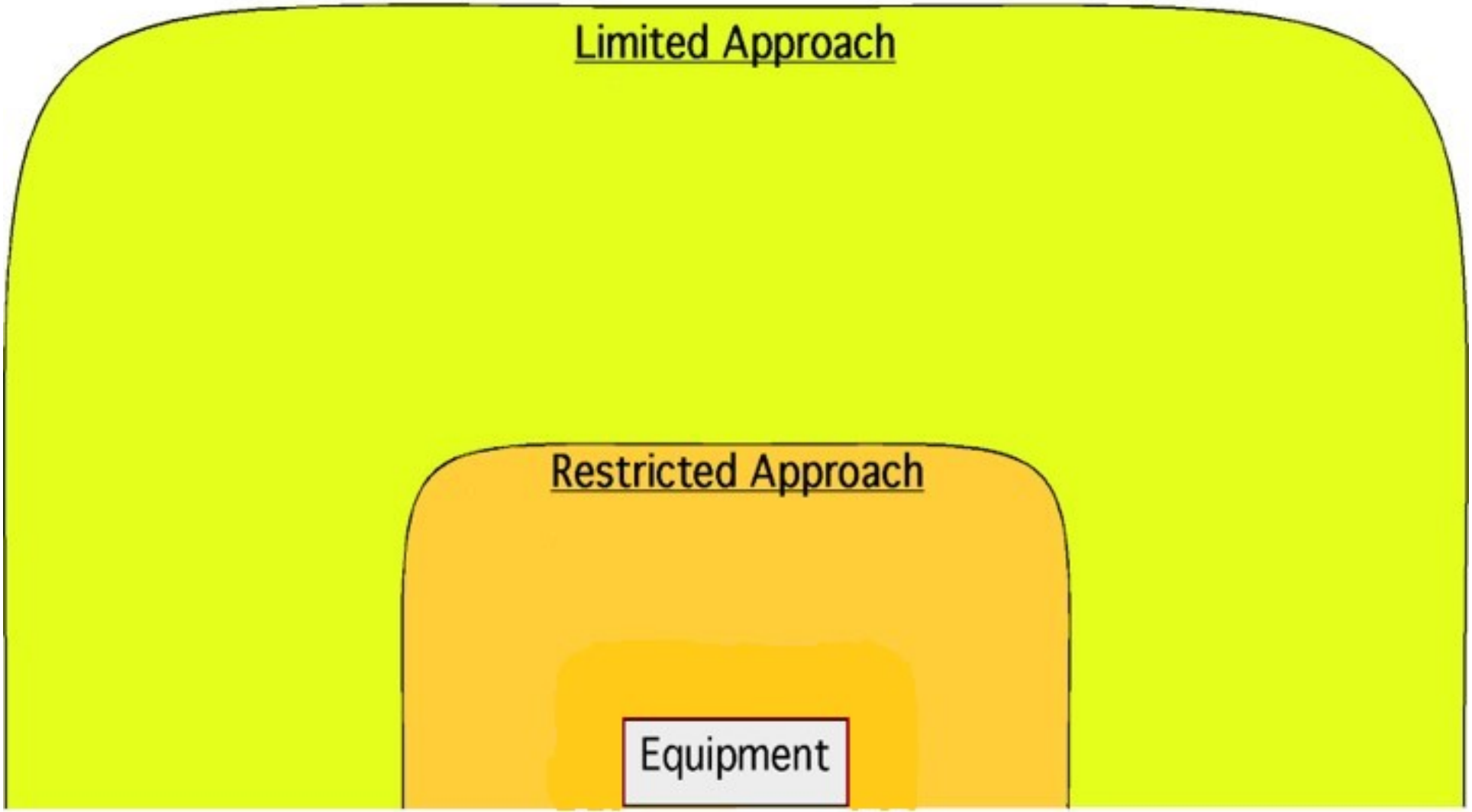
- Ensuring protection from a shock hazard is fairly straightforward:
  - The degree of protection is determined primarily by voltage of the exposed energized part(s) and the distance of the worker from those parts
    - The distances are expressed as the Limited Approach Boundary (LAB) and the Restricted Approach Boundary (RAB)
    - Test instruments and shock protection PPE and instruments are marked with the maximum rated voltage on which they can be used

Shock Hazard and Protection

- The best shock protection is barriers between the energized part and the worker
  - This is not a new idea at all
  - What about work which requires us to open the box?

Image courtesy Square D / Schneider Electric

Shock Protection Boundaries



Shock Protection Boundaries

- Limited Approach Boundary (LAB)
  - Distance from an exposed live part within which a shock hazard exists
  - Note that this Boundary is significant to Fermilab's definition of Energized Work

Shock Protection Boundaries

- Restricted Approach Boundary (RAB)
  - Distance from an exposed live part within which there is an increased risk of shock due to electrical arc over, combined with inadvertent movement, for personnel working in close proximity to the live part
-
  - NFPA 70E editions 2012 and earlier defined a Prohibited Approach Boundary. It is not present in the 2015 edition and later.
  - Fermilab no longer uses this boundary

Shock Protection

- Shock Hazard Analysis
  - Defined at 130.2 (A)
- Shock Protection Boundaries
  - Defined at Table 130.2 (C)

Table 130.4(D)(a) for alternating current

Table 130.4(D)(a) Shock Protection Approach Boundaries to Exposed Energized Electrical Conductors or Circuit Parts for Alternating-Current Systems

(1)	(2)	(3)	(4)
	Limited Approach Boundary[2]		
Nominal System Voltage Range, Phase to Phase[3]	Exposed Movable Conductor[4]	Exposed Fixed Circuit Part	Restricted Approach Boundary[5]; Includes Inadvertent Movement Adder
Less than 50 V	Not specified	Not specified	Not specified
50 V–150 V[6]	3.0 m (10 ft 0 in.)	1.0 m (3 ft 3 in.)	Avoid contact
151 V–750 V	3.0 m (10 ft 0 in.)	1.0 m (3 ft 3 in.)	0.3 m (1 ft 0 in.)
751 V–15 kV	3.0 m (10 ft 0 in.)	1.5 m (5 ft 0 in.)	0.7 m (2 ft 2 in.)
15.1 kV–36 kV	3.0 m (10 ft 0 in.)	1.8 m (6 ft 0 in.)	0.8 m (2 ft 9 in.)
36.1 kV–46 kV	3.0 m (10 ft 0 in.)	2.5 m (8 ft 0 in.)	0.8 m (2 ft 9 in.)
46.1 kV–72.5 kV	3.0 m (10 ft 0 in.)	2.5 m (8 ft 0 in.)	1.0 m (3 ft 6 in.)
72.6 kV–121 kV	3.3 m (10 ft 8 in.)	2.5 m (8 ft 0 in.)	1.0 m (3 ft 6 in.)
138 kV–145 kV	3.4 m (11 ft 0 in.)	3.0 m (10 ft 0 in.)	1.2 m (4 ft 0 in.)
161 kV–169 kV	3.6 m (11 ft 9 in.)	3.3 m (11 ft 0 in.)	1.3 m (4 ft 3 in.)
230 kV–242 kV	4.0 m (13 ft 0 in.)	4.0 m (13 ft 0 in.)	1.7 m (5 ft 6 in.)
345 kV–362 kV	4.7 m (15 ft 0 in.)	4.7 m (15 ft 4 in.)	2.9 m (9 ft 2 in.)
500 kV–550 kV	5.8 m (19 ft 0 in.)	5.8 m (19 ft 0 in.)	3.6 m (11 ft 8 in.)
765 kV–800 kV	7.2 m (23 ft 9 in.)	7.2 m (23 ft 9 in.)	4.9 m (16 ft 1 in.)

Notes

(1) For arc flash boundary, see 130.5(A).

(2) All dimensions are distance from exposed energized electrical conductors or circuit parts to employee.

(3) For single-phase systems under 250 volts, select the range that is equal to the system's maximum phase-to-ground voltage multiplied by 1.732.

(4) See definition in Article 100 and Table 130.4(D)(2) and informative Annex C for clearance zones.

(5) Exposed movable conductor assumes a condition in which the distance between the conductor and a person is not under the control of the person. This distance is normally kept free to avoid live conductors supported by poles.

(6) This includes circuits where the voltage does not exceed 150 volts nominal.

Table 130.4(D)(b) for direct current

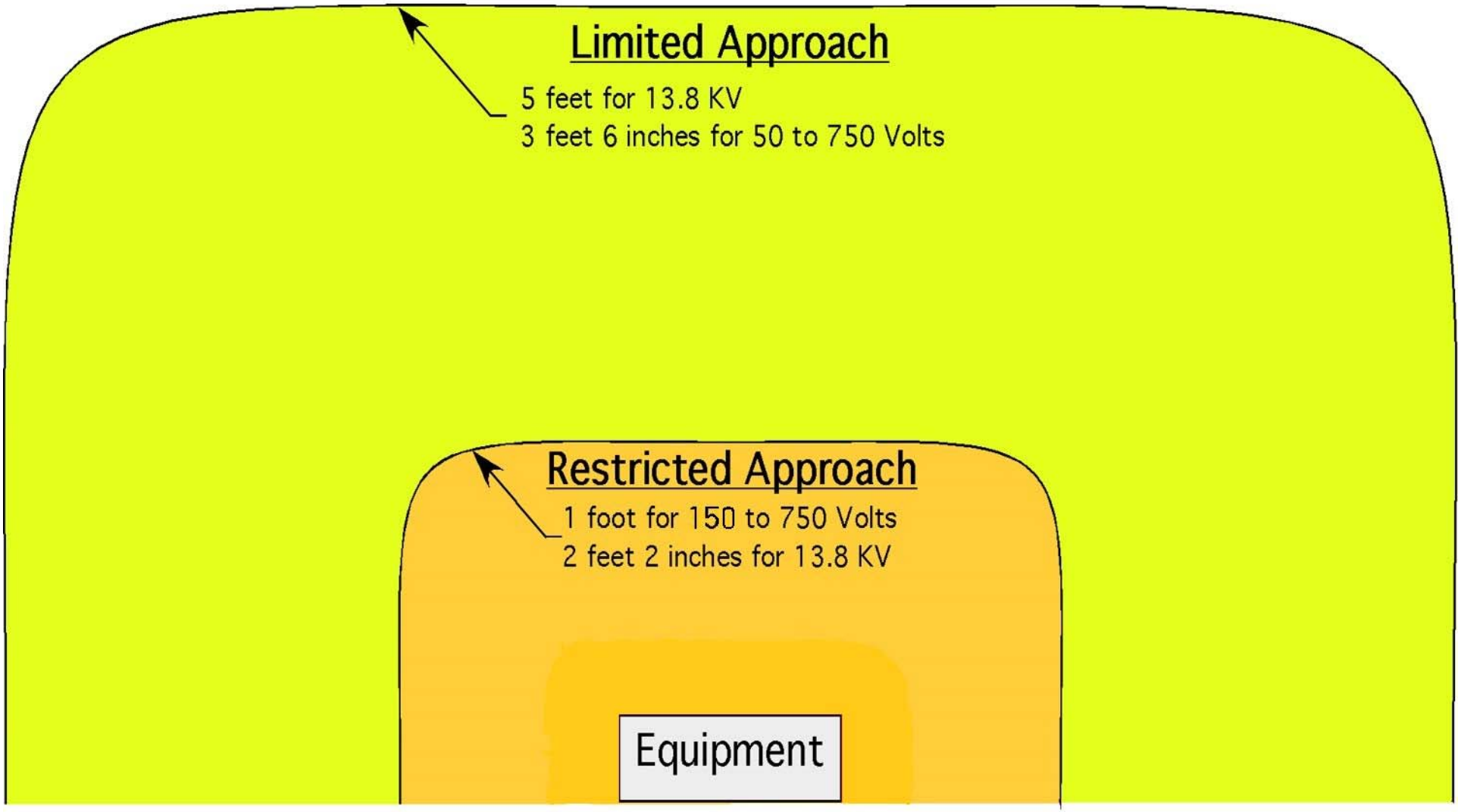
Table 130.4(D)(b) Shock Protection Approach Boundaries to Exposed Energized Electrical Conductors or Circuit Parts for Direct-Current Voltage Systems

(1)	(2)	(3)	(4)
	Limited Approach Boundary		Restricted Approach Boundary; Includes Inadvertent Movement Adder
Nominal Potential Difference	Exposed Movable Conductor[a]	Exposed Fixed Circuit Part	
Less than 50 V	Not specified	Not specified	Not specified
50 V–300 V	3.0 m (10 ft 0 in.)	1.0 m (3 ft 5 in.)	Avoid contact
301 V–1 kV	3.0 m (10 ft 0 in.)	1.0 m (3 ft 5 in.)	0.3 m (1 ft 0 in.)
1.1 kV–5 kV	3.0 m (10 ft 0 in.)	1.5 m (5 ft 0 in.)	0.5 m (1 ft 6 in.)
5 kV–15 kV	3.0 m (10 ft 0 in.)	1.5 m (5 ft 0 in.)	0.7 m (2 ft 2 in.)
15.1 kV–45 kV	3.0 m (10 ft 0 in.)	2.5 m (8 ft 0 in.)	0.8 m (2 ft 9 in.)
45.1 kV–75 kV	3.0 m (10 ft 0 in.)	4.5 m (15 ft 0 in.)	1.0 m (3 ft 6 in.)
75.1 kV–150 kV	3.0 m (10 ft 8 in.)	3.0 m (10 ft 0 in.)	1.2 m (3 ft 10 in.)
150.1 kV–250 kV	3.6 m (11 ft 8 in.)	3.6 m (11 ft 8 in.)	1.0 m (3 ft 3 in.)
250.1 kV–500 kV	6.0 m (20 ft 0 in.)	6.0 m (20 ft 0 in.)	3.5 m (11 ft 6 in.)
500.1 kV–800 kV	8.0 m (26 ft 0 in.)	8.0 m (26 ft 0 in.)	5.0 m (16 ft 5 in.)

Note: All dimensions are distances from exposed energized electrical conductors or circuit parts to workers.

[a] "Exposed movable conductor" describes a condition in which the distance between the conductor and a person is not under the control of the person. The term is normally applied to overhead line conductors supported by poles.

Shock Protection Boundaries



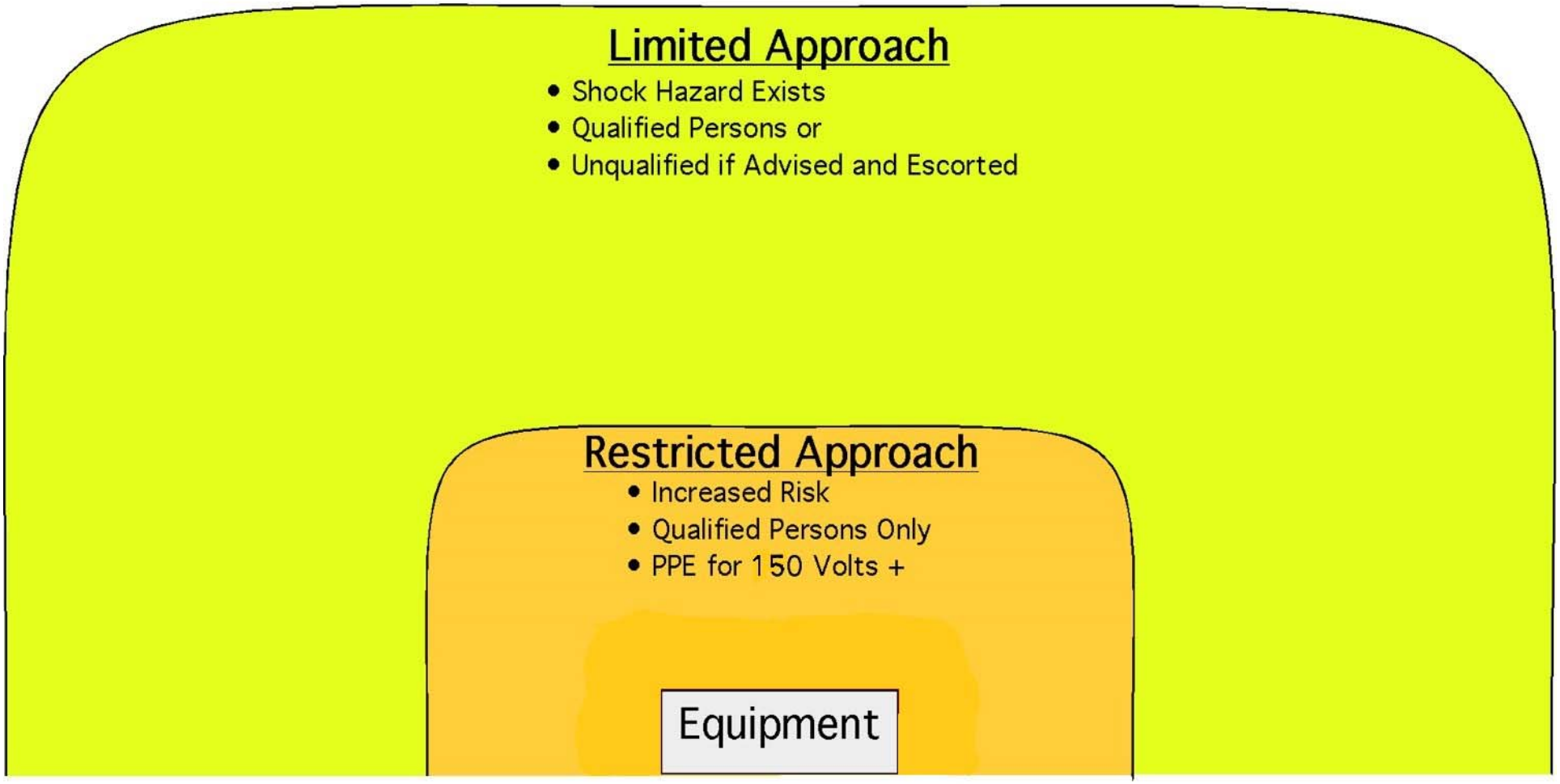
Limited Approach Boundary

- Limited Approach Boundary (LAB)
  - 3 feet 6 inches for 50 to 750 Volts
  - 5 feet for 13.8 KV
  - 15 feet 4 inches for 345 KV
- Occupancy generally limited to Qualified Workers
- Unqualified persons may enter if advised of hazards and continuously escorted
- Appropriately rated insulated tools and/or equipment must be used if they might (likely) make accidental contact with exposed live parts

Restricted Approach Boundary

- Restricted Approach Boundary (RAB)
  - Avoid Contact for 50 to 150 Volts
  - 1 foot for 151 to 750 Volts
  - 2 feet 2 inches for 13.8 KV
- Occupancy only by Qualified Workers
- May not cross boundary with conductive objects
- No uninsulated part of the body may cross this boundary
- For voltages greater than 150 Volts, must wear PPE for shock protection, such as insulating gloves and insulating sleeves

Shock Protection Boundaries



Approach Boundaries

- Limited Approach Boundary
  - Restricts the approach of unqualified persons
- Restricted Approach Boundary
  - Restricts the approach of qualified persons

Alternating Current (AC) Shock Protection Boundaries and PPE
Fermilab Summary for NFPA 70E, 2018 Edition. [Based on Table 130.4(D)(a).]

System Voltage Range Phase to Phase	Limited Approach Boundary (Fixed Parts) (LAB)	Restricted Approach Boundary (RAB)	Shock Protection Insulating PPE
50 to 150 Includes 120	3 Ft 6 In	Avoid Contact	LAB - None RAB - Wear/Use if Contact Likely
150 to 750 Includes 208, 240, 277 and 480	3 Ft 6 In	1 Foot	LAB - None RAB - Must Wear
751 to 15K Including 13.8K	5 Feet	2 Ft 2 In	LAB - None RAB - Must Wear
345K to 362K	15 Ft 4 In	9 Ft 2 In	LAB - None RAB - Must Wear

Within the Limited Approach Boundary	Non-Qualified Worker Allowed Within Only if Advised and Escorted by a Qualified Worker. Insulated Equipment/Tools if Contact Likely.
Within the Restricted Approach Boundary	Only Qualified Worker Allowed Within. May Not Cross Into with Conductive Objects. Conductive Objects Prohibited. Body Parts Must be Insulated.

(New Table) Direct Current (DC) Shock Protection Boundaries and PPE
Fermilab Summary for NFPA 70E, 2018 Edition [Based on Table 130.4(D)(b).]

System Voltage Range Phase to Phase [* NFPA 70E 350.9(2)]	Limited Approach Boundary (Fixed Parts) (LAB)	Restricted Approach Boundary (RAB)	Shock Protection Insulating PPE
100* to 300	3 Ft 6 In	Avoid Contact	LAB - None RAB - Wear/Use if Contact Likely
301 to 1000	3 Ft 6 In	1 Foot	LAB - None RAB - Must Wear
1001 to 5K	5 Feet	1 Ft 5 In	LAB - None RAB - Must Wear
5K to 15K	5 Feet	2 Ft 2 In	LAB - None RAB - Must Wear

Within the Limited Approach Boundary	Non-Qualified Worker Allowed Within Only if Advised and Escorted by a Qualified Worker. Insulated Equipment/Tools if Contact Likely.
Within the Restricted Approach Boundary	Only Qualified Worker Allowed Within. May Not Cross Into with Conductive Objects. Conductive Objects Prohibited. Body Parts Must be Insulated.
Capacitor energy limits [NFPA 70E 350.9(3)]	Consult with your D/S Electrical Coordinator if capaciitors operate at below 100 V and over 100 Joules, 100 to 400 volts and over 1 Joule, over 400 volts and over 0.25 Joule (1 Joule = 0.5 * C * V * V)

PPE and Equipment for Shock Protection

- PPE
  - Insulating gloves, matting, and blankets
  - “EH” rated footwear required where step or touch potential is a concern, does not reduce other shock protection PPE requirements
- Insulated tools, hot sticks, “shotguns,” static discharge sticks, rescue tools
- ALWAYS inspect tools and PPE before use and maintain as required
- Keep the tools and equipment clean

Tools and Equipment Shock Protection

- Hand and power tools
  - Rated for voltage on which they are used
  - Designed for environment and manner in which they are used
  - Inspected prior to use
- Fuse pullers, ropes and handlines, and ladder side rails must be non-conductive
- Tools for work in battery areas may need to be non-sparking

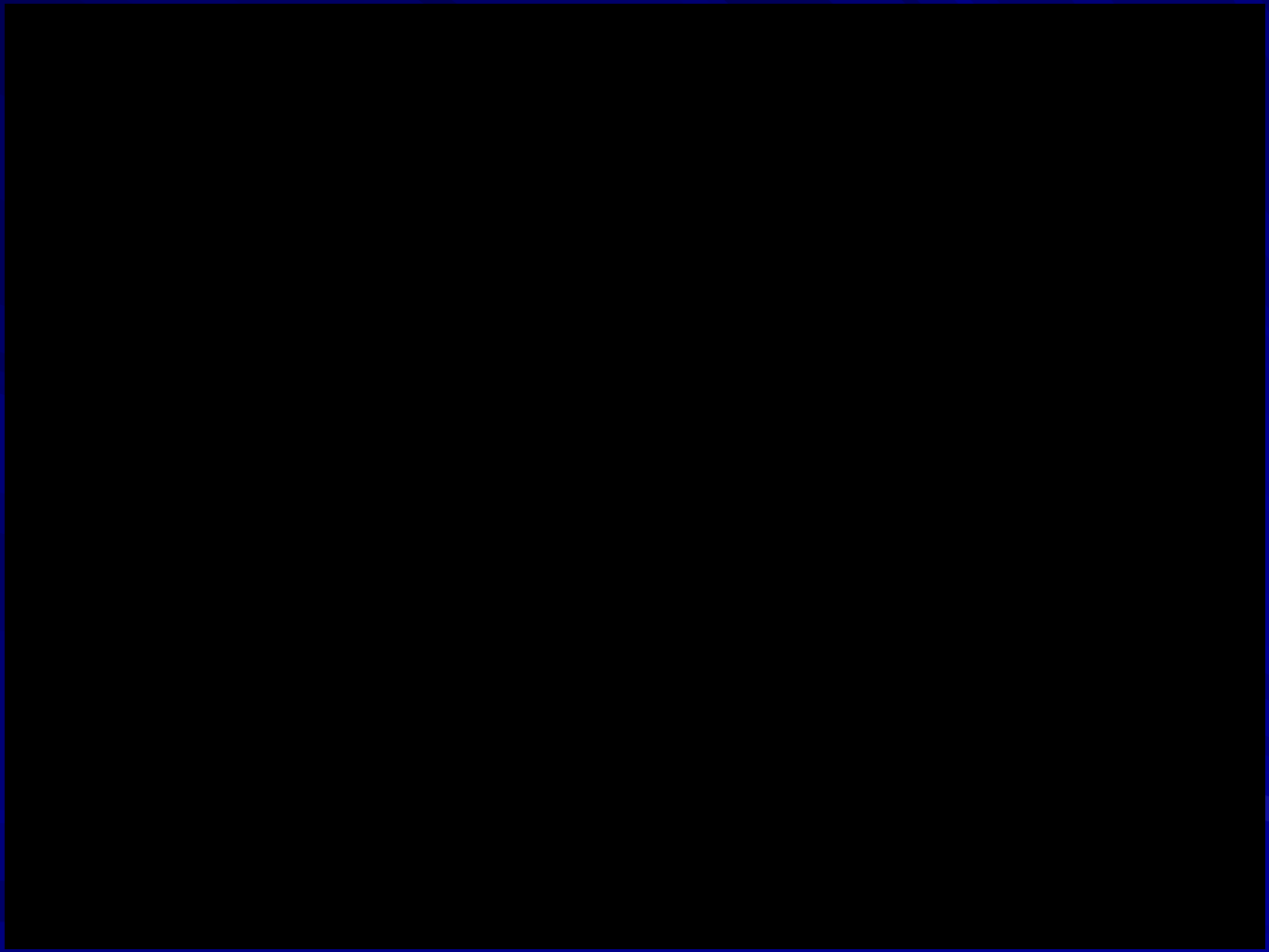
Electrically Insulating Gloves

- Glove Classes by Use Voltage

Class 00	500 volts	**Class 0**	**1,000 volts**
Class 1	7,500 volts	Class 2	17,000 volts
Class 3	26,500 volts	Class 4	36,000 volts

- Procure Through the ESH&Q Section
- Use Leather Protectors with Gloves
- Gloves must be tested after every 6 months of use through Fermilab's program (April 1 and October 1 are Scheduled Exchange Dates)

Gloves2



Courtesy of Salisbury

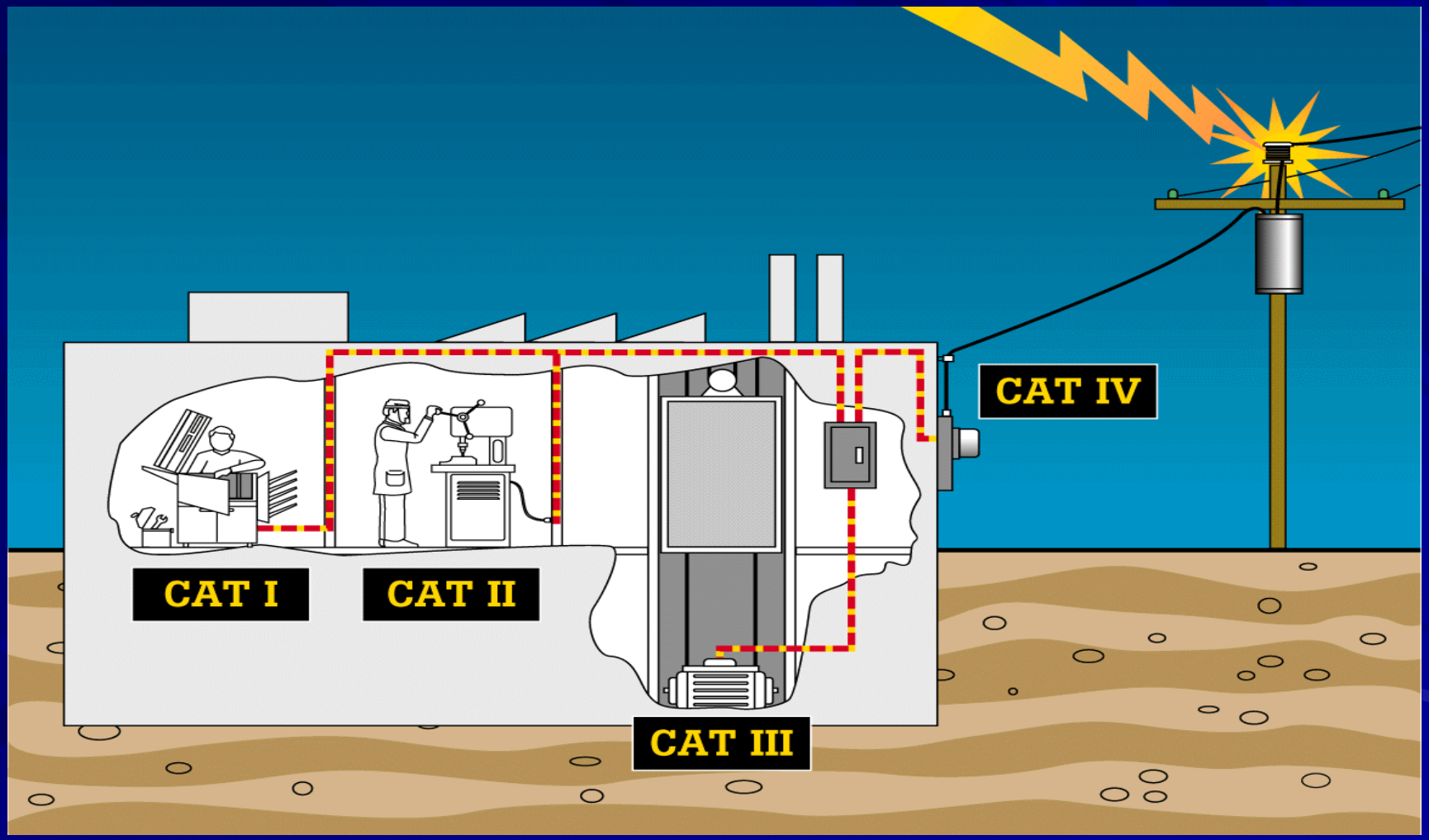
Over Voltage Category

- The level and energy of voltage impulses or surges is dependent on the location. The closer the location is to the power source, the higher the available fault current, the higher the category

- UL 61010 and IEC 61010 define four locations or categories:

CAT IV	"Origin of installation" Utility level and any outside cable run
CAT III	Distribution wiring, including "mains" bus, feeders and branch circuits; permanently installed loads.
CAT II	Receptacle outlet circuit; plug-in loads.
CAT I	Protected electronic circuits

Category Locations



Look for CAT III or CAT IV Markings

CAT III-
1000 V

CAT IV-600 V
CAT III-1000 V

CAT III-
600 V

Voltage Testing Equipment

- Meters
  - Use Cat III Rated 600 or 1000 Volt for Indoor Work (Fluke T3 Tester is Stocked)
  - Use Cat IV for Outdoor Work
  - Proximity – Inductive Voltage Probes
  - The Wiggy – No Longer Acceptable
- Calibration may be required, depending on task
  - Calibration is NOT required for LOTO zero voltage verification.

Meter Safety Checklist

- Watch for:
- Cracked or oily case
- Broken input jacks

No Meter is Safe When Improperly Used.

- Use meters within their rating.
- Meter probes must also be properly rated.
- Use meters designed for measurements on power circuits.
- Use replacement fuses approved by the manufacturer

Arc-Flash Hazard and Protection

Consider this Aspect of 70E Separate from the Shock Hazard

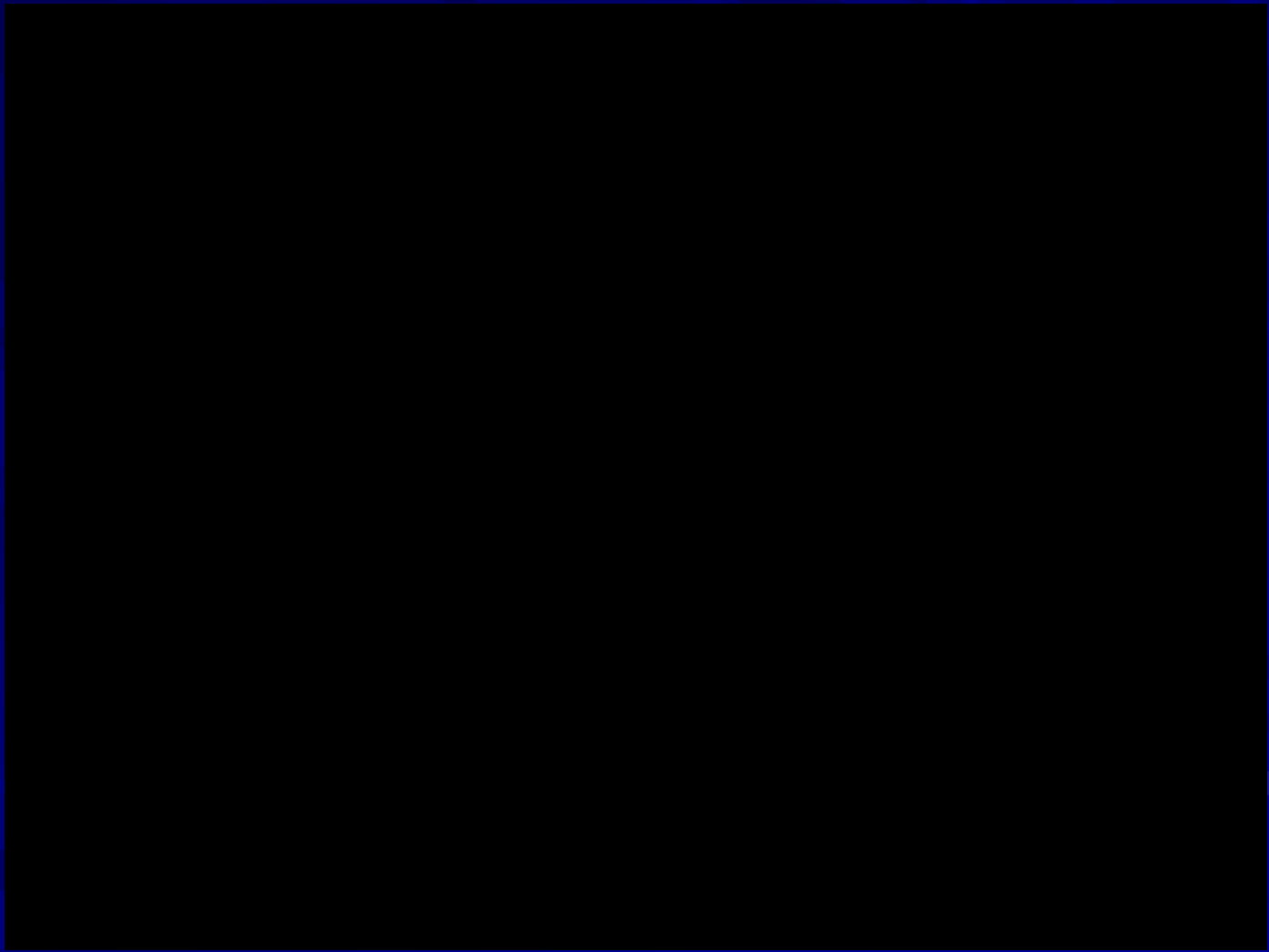
Arc-Flash

- An arc-fault is conduction of electrical current through the air that has become ionized
- The arc converts electrical energy into radiant and thermal energy
- Most often the result of mishaps while working on the equipment.
- May also be initiated by equipment failures
- System overvoltages from lightning events or contact between systems of different voltages also may initiate arc faults.

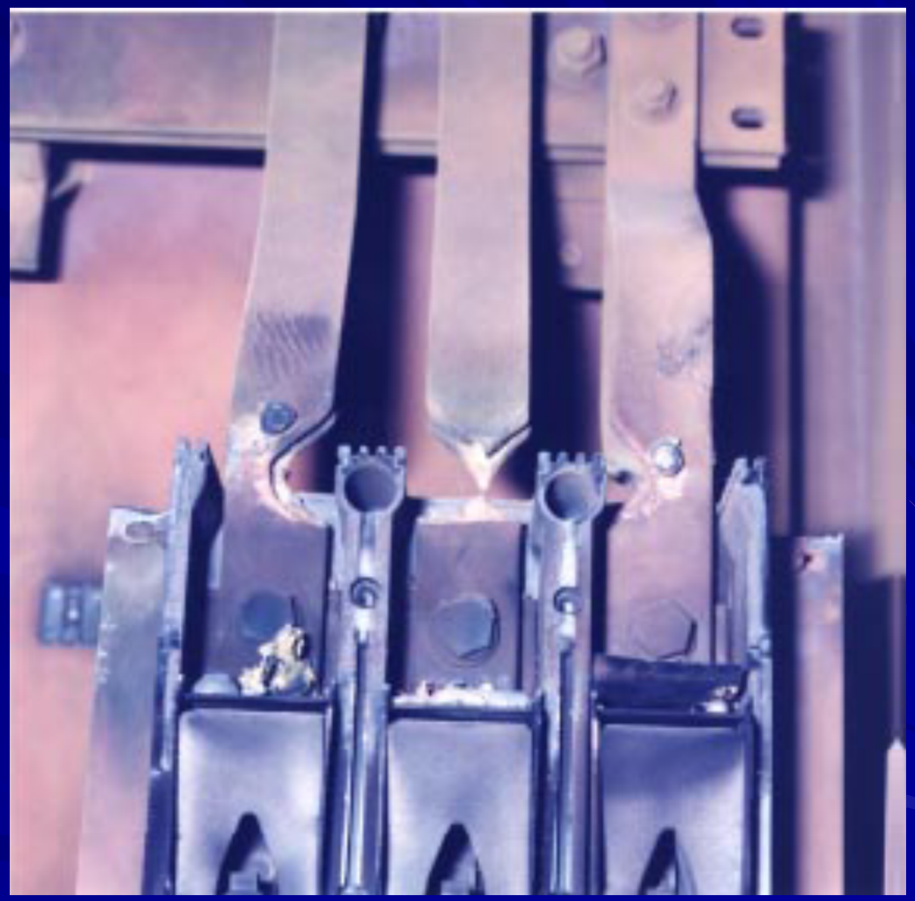
Arc-Flash

- Can start as an arc from an energized conductor to ground, neutral or another energized phase
- Single-phase AC arcs may self-extinguish when the current flow reverses
- Most serious arcs occur in 3-phase systems
- Likewise DC arcs are not likely to self-extinguish

Arc-Flash



1997 Arc-Flash Accident at F0 Compressor Room



Arc-Flash Hazard and Protection

- Determining the degree of an arc-flash hazard is not as simple as it is for shock hazards
  - The energy an arc-flash can deliver is much more dependent on where and how a piece of electrical equipment is connected to an electrical distribution system than on what type of equipment it is.
  - Identical equipment in different parts of an electrical system can have arc-flash energies that differ by a factor of 10 or more

Arc-Flash Hazard and Protection

- Like shock protection from a potential arc-flash, worker protection involves distance and personal protection from the arc's energy.
  - There is only one boundary for arc flash protection (next slide!)
  - Work inside that boundary requires protection of the worker's body against the radiant and thermal energy that could be released
  - Quantifying arc-flash exposure and protection
    - The Flash Hazard Analysis
    - NFPA 70E Article 130 Tables

Pertinent Definitions

- Arc - Flash Boundary
  - Distance from an exposed live part at which an arc-flash event could deliver 1.2 cal/cm2
  - 1.2 cal/cm2 is the amount of heat at which a 50% of a sample population will begin to experience a 2nd degree burn
  - A 2nd degree burn is the point at which treatment for a burn requires more than first aid

Pertinent Definitions

- Arc Thermal Performance Value (ATPV)
  - 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 2nd degree burh based on the Stoll Curve, expressed in cal/cm2
- Energy Breakopen Threshold (E_{BT})
  - The incident energy on a fabric or material that results in a 50% probability of a breakopen, expressed in cal/cm. Breakopen is defined as any open area at least 1.6 cm2, or 0.5 in2

Pertinent Definitions

- Arc Rated
  - Both ATPV and E_{BT} indicate garments and items that have successfully passed a standardized electrical arc discharge test. The reported Arc Rating is the lower of the two values
- Flame-Resistant (FR)
  - The property of a material whereby combustion is prevented, terminated, or inhibited following the application of a flaming or non-flaming source of ignition, with or without subsequent removal of the ignition source
- PPE with only an FR rating is not acceptable arc flash PPE!

Fault Current and Duration

Determine the Incident Energy of the Arc-Flash

What about Voltage?

- Assuming the resistance of an arcing fault to be essentially constant
- The arc Current = Potential / Resistance
  - $V / R = I$
- If the voltage is doubled,
  - $2V / R = 2I$
- So the effect of the system voltage is already accounted for in the calculated arc current

Electrical System Studies

- The preferred method for determining both fault current and fault duration is to create a computer model of the electrical distribution system and compute what will happen when a fault occurs
- Fermilab's modeling and analysis is completed for CD, APS-TD, and the FESS switchyards and 13.8 kV distribution system.
- Fermilab's interim methods for other areas is described in the next slides.

Fault Current

- Available fault current is not infinite
  - Limited by the utility generator, transformers, conductor sizes and lengths
- A transformer's effect on fault current is a function of its Transformer Impedance (%IZ)
  - The %IZ is determined by the mechanical construction of the transformer's iron core and copper or aluminum windings.
- Fermilab has used only a few sizes of transformers for most of its facilities, which simplifies determining arc fault currents

First Calculate the Transformer's Full Load Current

- I FLA = (Transformer KVA Rating x1000)/ (Secondary Voltage Line to Line X 1.732)

2,000 KVA, 13.8KV to 480 VAC	2,406 Amps
1500 KVA, 13.8 KV to 480 VAC	1,804 Amps
750 KVA, 13.8 KV to 480 VAC	902 Amps
500 KVA, 13.8 KV to 480 VAC	601 Amps
75 KVA, 480 VAC to 120/208 VAC	208 Amps
45 KVA, 480 VAC to 120/208 VAC	125 Amps

Then Calculate the Short Circuit Current

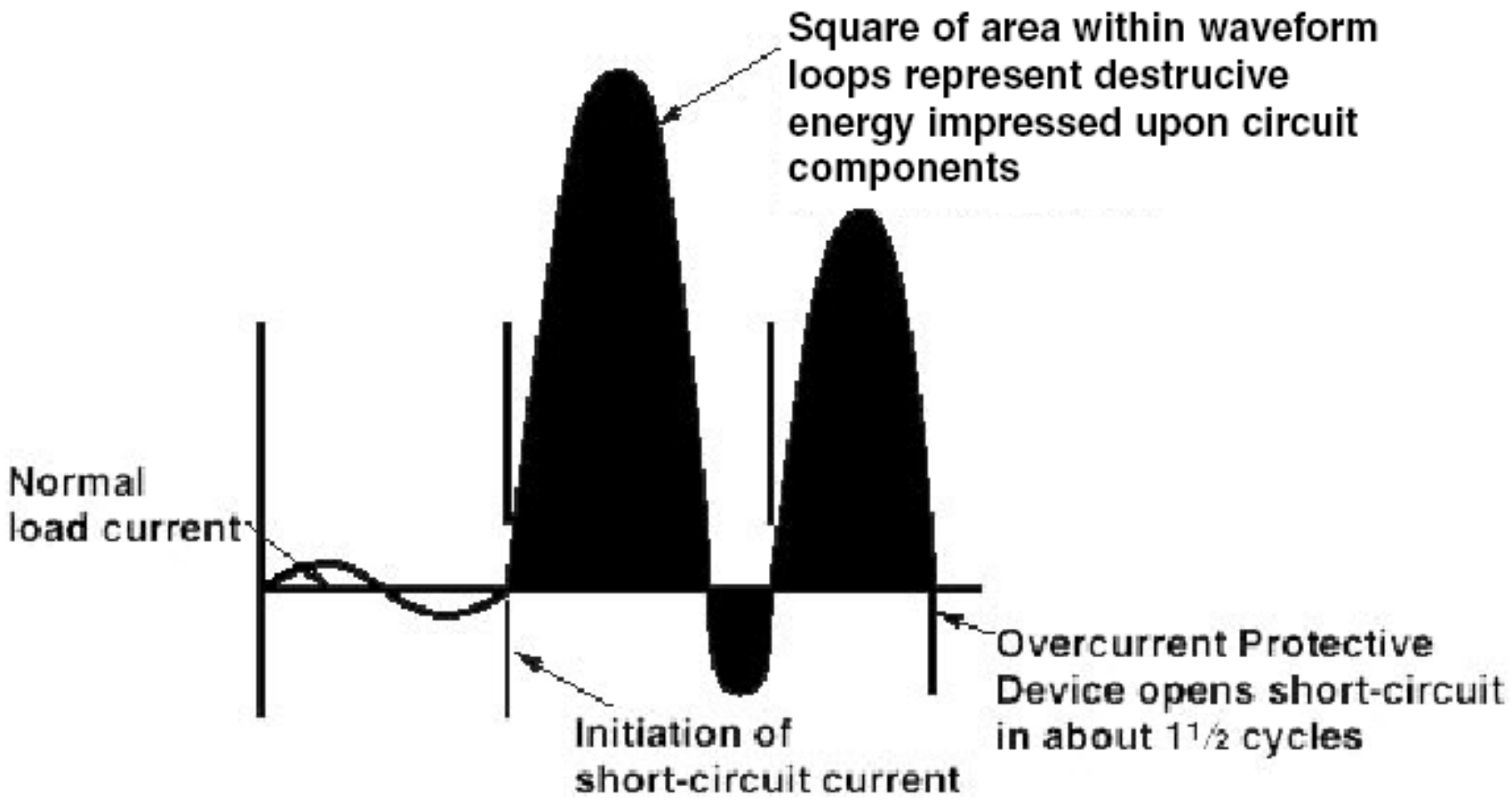
- I SCA = (1FLA X 100) / (Transformer %IZ x 0.9)

2000 KVA 480 VAC Out with 5.8%IZ	46,086 Amps
1500 KVA 480 VAC Out with 5.7%IZ	35,171 Amps
750 KVA 480 VAC Out with 5.75%IZ	17,433 Amps
500 KVA 480 VAC Out with 2.3%IZ	29,054 Amps
75 KVA 120/208 VAC Out with 4.3%IZ	5,379 Amps
45 KVA 120/208 VAC Out with 4.1%IZ	3,385 Amps

Arc Fault Duration

- Expressed in Time or Line Cycles
- Determined by Overcurrent Protective Devices (OCPD) upstream of the fault site
  - Circuit Breakers or Fuses
  - Trip Time or Clearing Time is dependent on the fault current
    - Circuit Breaker – 3-10 Line Cycles
    - Standard Fuses – 3-10 Line Cycles
    - Current Limiting Fuse – Less than 1 Line Cycle

NEC® 110.10 Component Protection



ACTION OF NON-CURRENT-LIMITING OVERCURRENT PROTECTIVE DEVICE

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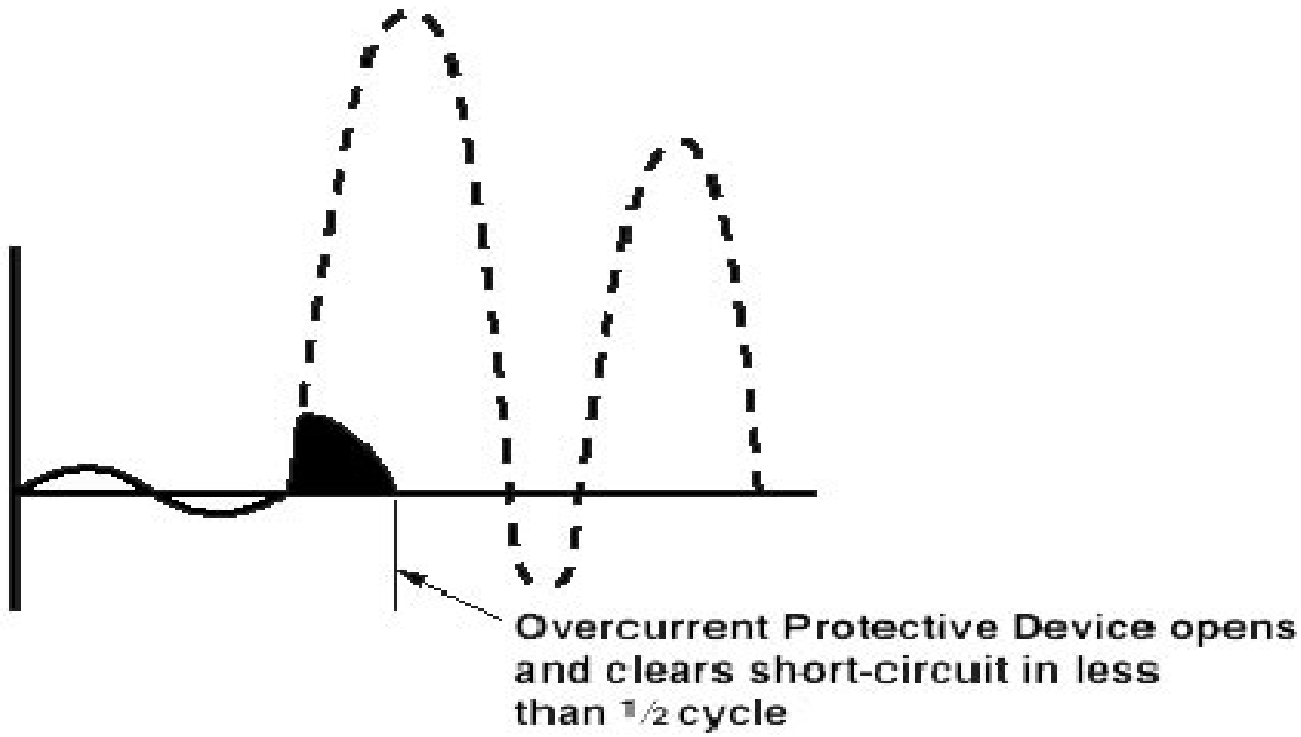
NEC® 110.10 Component Protection

- Current limiting devices are more expensive, but can reduce arc-flash durations and energies



ACTION OF CURRENT-LIMITING OVERCURRENT PROTECTIVE DEVICE

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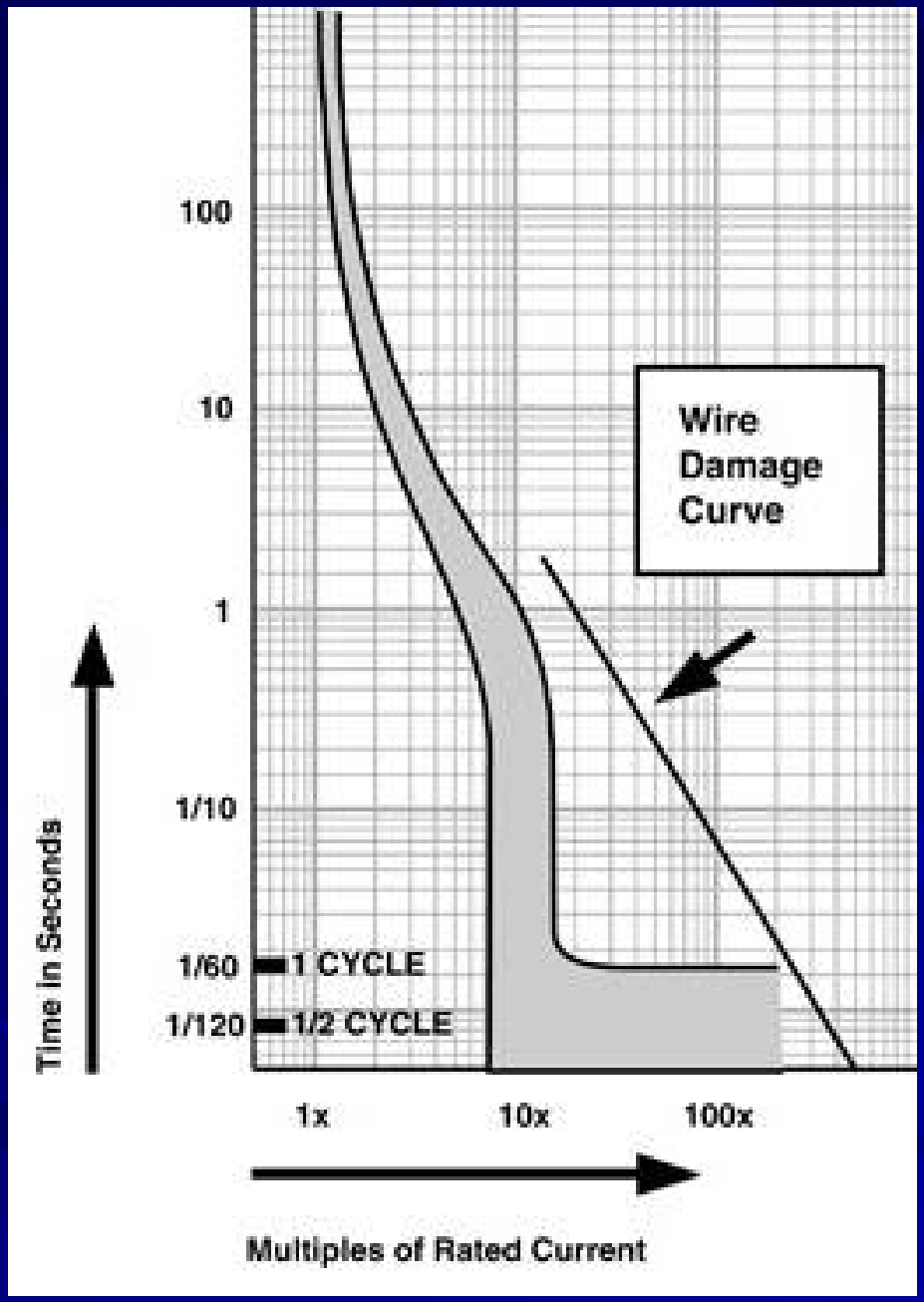


Typical Trip Curve

- Note logarithmic axes
- Fault current on X-axis determines trip time on Y-axis
- Width of curve reflects manufacturing variances
- Lower fault currents can sometimes deliver more total energy into an arc flash because of how long it takes to clear.

Typical Trip Times

- Circuit Breakers
  - 0.1 second or 6 cycles typical. Varies by Manufacturer and Current. See Trip Curves.
- Current Limiting Fuses
  - Generally one-half of a line cycle.
  - Classes RK1, J, T and L are best.
- Yard Transformers:
  - Consult with FESS (Joe Pathiyil) for specific location trip times

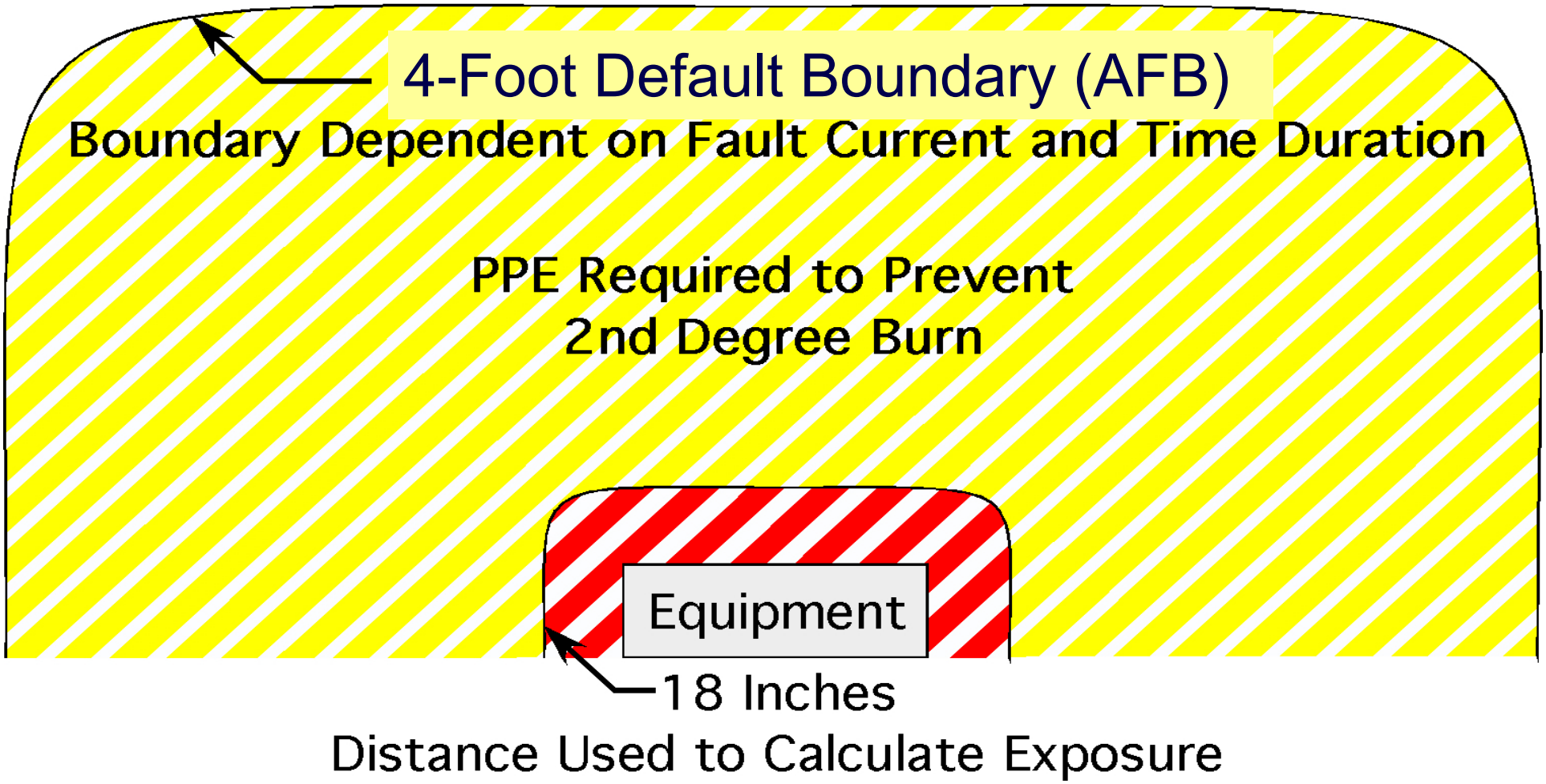
Arc Flash Boundary

- NFPA 70E 130.3 (A):
  D FPB = (2.65 X MVA bf X t)1/2

2000 KVA with t = 0.1	2.4 Feet
1500 KVA with t = 0.1	2.1 Feet
750 KVA with t = 0.1	1.5 Feet
500 KVA with t = 0.1	1.9 Feet
75 KVA with t = 0.05	0.4 Feet
45 KVA with t = 0.05	0.3 feet

- Fermilab's Default Arc Flash Boundary for systems 600 volts or less is 4 feet (1.2 meters)

Arc Flash Boundary (AFB)



Other Factors to Consider

- Longer and smaller conductors also serve to limit the available short circuit current due to the natural resistance of the wire
- Short Circuit Currents for Utilization Equipment are Most Always Less than those of the Sourcing Panelboard
- Exposure depends on distance to incident energy. 18 Inches is a typical value used for work done at less than 600 volts.
- “Open” or apply the “Box Factor.”

Flash Hazard Analysis

- The Arc Flash Risk Assessment determines the Arc Flash Boundary and the protective clothing and other PPE required
  - Refer to NFPA 70E Article 130.5 beginning on page 23
- Requires knowledge of
  - Fault current
  - Duration of the fault current
  - Location of potential arc-flash and
  - Worker body position

Likelihood of an arc-flash occurring - 1

- No likelihood of occurrence regardless of condition of maintenance, [Table 130.5(C)]:
  - Reading a panel meter, including operating a phase selector switch
  - Performing thermographic or non-contact observations while outside of the RAB
  - Work on control circuits at less than 125 VAC with no power circuits exposed
  - Examination of cables without moving them
  - Insertion, servicing, or removal of single cells or battery units in an open rack

Condition of Maintenance

- Normal Operating Condition means [130.2(A)(4)]:
  - The equipment is properly installed
  - The equipment is properly maintained
  - The equipment is used in accordance with listing and labeling and manufacturer's instructions
  - The equipment doors are closed and secured
  - All equipment covers are in place and secured
  - There is no evidence of impending failure

Likelihood of an arc-flash occurring - 2

- No likelihood of occurrence if equipment is in normal operating condition [Table 130.5(C)]:
  - Operation of a circuit breaker, switch, contactor, or motor starter
  - Opening and closing covers on wireways, junction boxes and cables trays that do not expose bare, energized conductors
  - Opening a panelboard door that only exposes dead-front circuit breakers or fuses
  - Voltage testing on single cells or battery units
  - Removal of insulating battery terminal covers

Likelihood of an arc-flash occurring - 3

- All other work on electrical equipment that has not been proven to be de-energized shall be considered to have a likelihood of an arc-flash event occurring, and “additional protective measures” (appropriate arc-flash PPE shall be used
  - If equipment is not in a Normal Operating Condition, the “additional protective measures” may need to exceed guidance from arc-flash calculations or the Fermilab interim guidance.

Arc-flash protective clothing & PPE

- Clothing and some other arc-flash PPE (like face shields) are categorized according to how much arc-flash energy they can stop. (Arc rating, ATPV, E_{BT})
  - Arc-flash PPE Category 1: Up to 4 cal/cm2
  - Arc-flash PPE Category 2: Up to 8 cal/cm2
  - Arc-flash PPE Category 3: Up to 25 cal/cm2
  - Arc-flash PPE Category 4: Up to 40 cal/cm2

Table 130.7(C)(15)(c)

Table 130.7(C)(15)(c) Personal Protective Equipment (PPE)

Arc Flash PPE Category	PPE
1	**Arc-Rated Clothing, Minimum Arc Rating of 4 cal/cm[2] (16.75 J/cm[2])[a]**
	Arc-rated long-sleeve shirt and pants or arc-rated coveralls
	Arc-rated face shield[b] or arc flash suit hood
	Arc-rated coat, parka, rainwear, or hard hat liner (AN)
	Protective Equipment
	Hard hat
	Safety glasses or safety goggles (SR)
	Hearing protection (ear canal inserts)[c]
	Heavy duty leather gloves[d]
	Leather footwear (AN)
2	**Arc-Rated Clothing, Minimum Arc Rating of 8 cal/cm[2] (33.5 J/cm[2])[a]**
	Arc-rated long-sleeve shirt and pants or arc-rated coveralls
	Arc-rated flash suit hood or arc-rated face shield[b] and arc-rated balaclava
	Arc-rated jacket, parka, rainwear, or hard hat liner (AN)
	Protective Equipment
	Hard hat
	Safety glasses or safety goggles (SR)
	Hearing protection (ear canal inserts)[c]
	Heavy duty leather gloves[d]
	Leather footwear
3	**Arc-Rated Clothing Selected so That the System Arc Rating Meets the Required Minimum Arc Rating of 25 cal/cm[2] (104.7 J/cm[2])[a]**
	Arc-rated long-sleeve shirt (AR)
	Arc-rated pants (AR)
	Arc-rated coveralls (AR)
	Arc-rated arc flash suit jacket (AR)
	Arc-rated arc flash suit pants (AR)
	Arc-rated arc flash suit hood
	Arc-rated gloves[d]
	Arc-rated jacket, parka, rainwear, or hard hat liner (AN)
	Protective Equipment
	Hard hat
	Safety glasses or safety goggles (SR)
	Hearing protection (ear canal inserts)[c]
	Leather footwear
4	**Arc-Rated Clothing Selected so That the System Arc Rating Meets the Required Minimum Arc Rating of 40 cal/cm[2] (167.5 J/cm[2])[a]**
	Arc-rated long-sleeve shirt (AR)
	Arc-rated pants (AR)
	Arc-rated coveralls (AR)
	Arc-rated arc flash suit jacket (AR)
	Arc-rated arc flash suit pants (AR)
	Arc-rated arc flash suit hood
	Arc-rated gloves[d]
	Arc-rated jacket, parka, rainwear, or hard hat liner (AN)
	Protective Equipment
	Hard hat
	Safety glasses or safety goggles (SR)
	Hearing protection (ear canal inserts)[c]
	Leather footwear

AN: As needed (optional). AR: As required. SR: Selection required.

[a]Arc rating as defined in Article 100.

[b]Face shields are to have wrap-around guarding to protect not only the face but also the forehead, ears, and neck, or, alternatively, an arc-rated arc flash suit hood is required to be worn.

[c]Ear canal inserts of hearing protection shall be used in lieu of or in addition to ear canal inserts provided when worn under an arc-rated arc flash suit hood.

[d]If rubber insulating gloves with leather protectors are used, additional heavy duty arc-rated gloves are not required. The combination of rubber insulating gloves with leather protectors satisfies the arc flash protection requirement.

Arc-flash protective clothing & PPE

- Changes from previous NFPA 70E versions include renaming “Hazard Risk Category” (HRC) to “Arc Flash PPE Category”
- Former HRC 0 and HRC 2* were removed
- Actually HRC 2 was removed and “2*” requirements are now call just “2”
- Fermilab has retained the use of “PPE Category 0” as a reminder to avoid meltable synthetic fabrics and short sleeves or pant legs, and to wear safety glasses, hearing protection, and leather gloves.

Arc-flash protective clothing & PPE

- Requirements from Table 130.7(C)(15)(c) and Fermilab's Category 0 are summarized in a ESS Simplified table, shown in the next slide

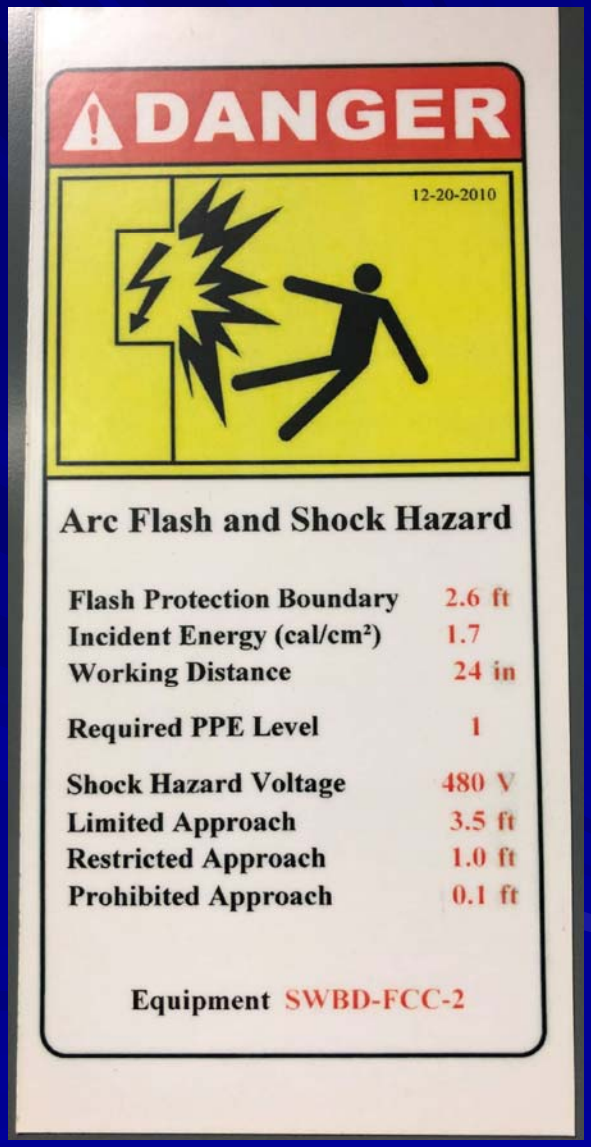
Arc-Flash PPE Categories - Required Clothing - Required PPE
Fermilab Summary for NFPA 70E, 2018 Edition [Based on Table 130.7(C)(15)(c).]

Calculated Exposure from Prospective Arc-Flash	PPE Category	Minimum Required Arc-rating	Clothing Requirements	Additional PPE
Zero up to 1.2 cal/cm^2	0*	NA	Long Sleeve Cotton Shirt and Pants	Safety Glasses required, Hearing Protection and Leather Gloves recommended
More than 1.2 and up to 4 cal/cm^2	1	4 cal/cm^2	FR Coverall**	Hard Hat, Safety Glasses, Arc-rated Face Shield, Hearing Protection, Leather Gloves, Leather Work Shoes
More than 4 and up to 8 cal/cm^2	2	8 cal/cm^2	Cotton Clothing Under FR Coverall**	Hard Hat, Safety Glasses, Flash Suit Hood, Hearing Protection, Leather Gloves, Leather Work Shoes
More than 8 and up to 25 cal/cm^2	3	25 cal/cm^2	Cotton Clothing Under FR Coveralls* plus Multilayer Flash Suit Jacket & Pants	Hard Hat, FR Hard Hat Liner, Safety Glasses, Flash Suit Hood, Hearing Protection, Arc-Rated Gloves, Leather Work Shoes
More than 25 and up tp 40 cal/cm^2	4	40 cal/cm^2	Cotton Clothing Under FR Coverall* plus Multilayer Flash Suit Jacket & Pants	Hard Hat, FR Hard Hat Liner, Safety Glasses, Flash Suit Hood, Hearing Protection, Arc-Rated Gloves, Leather Work Shoes

*Fermilab policy ** Coverall Rated at 8 cal/cm^2 Available from Fermilab Stockroom

Which PPE Category should I use?

- Where arc-flash calculations have been performed, follow guidance on equipment electrical hazard labels (example at right) or identified during work planning and hazard analysis process for equipment in harsher environmental locations



Which PPE Category should I use?

- Where equipment-specific PPE requirements have not been developed, NFPA 70E and Fermilab have tables based on equipment type and nominal voltage that provide conservative PPE categories for typical arc-flash hazard level
  - Table notes define the maximum fault current and clearing time for which the table is valid.

Table 130.7 (C)(15((a)

- Table entries are limited to equipment typically found in AC power distribution systems
- Table assumes equipment has not been proven to be de-energized and work is done within the Arc Flash Boundary
  - Includes Testing to Verify De-Energization
- No correlation with Table 130.4(D)(a) shock protection boundaries

Table 130.7(C)(15)(a)

Table 130.7(C)(15)(a) Arc-Flash PPE Categories for Alternating Current (ac) Systems

Equipment	Arc Flash PPE Category	Arc-Flash Boundary
Panelboards or other equipment rated 240 volts and below Parameters: Maximum of 25 kA available fault current; maximum of 0.03 sec (2 cycle) fault clearing time; minimum working distance 455 mm (18 in.)		455 mm (18 in.)
Panelboards or other equipment rated greater than 240 volts and up to 600 volts Parameters: Maximum of 25 kA available fault current; maximum of 0.03 sec (2 cycle) fault clearing time; minimum working distance 455 mm (18 in.)	2	900 mm (3 ft)
600-volt class motor control centers (MCCs) Parameters: Maximum of 65 kA available fault current; maximum of 0.03 sec (2 cycle) fault clearing time; minimum working distance 455 mm (18 in.)	2	1.5 m (5 ft)
600-volt class motor control centers (MCCs) Parameters: Maximum of 42 kA available fault current; maximum of 0.33 sec (20 cycles) fault clearing time; minimum working distance 455 mm (18 in.)	4	4.3 m (14 ft)
600-volt class switchgear (with power circuit breakers or fused switches) and 600-volt class switchboards Parameters: Maximum of 35 kA available fault current; maximum of up to 0.5 sec (30 cycles) fault clearing time; minimum working distance 455 mm (18 in.)	4	6 m (20 ft)
Other 600-volt class (277 volts through 600 volts, nominal) equipment Parameters: Maximum of 65 kA available fault current; maximum of 0.03 sec (2 cycles) fault clearing time; minimum working distance 455 mm (18 in.)	2	1.5 m (5 ft)
NEMA E2 (fused contactor) motor starters, 2.3 kV through 7.2 kV Parameters: Maximum of 25 kA available fault current; maximum of up to 0.24 sec (15 cycles) fault clearing time; minimum working distance 910 mm (36 in.)	4	12 m (40 ft)
Metal-clad switchgear, 1 kV through 15 kV Parameters: Maximum of 25 kA available fault current; maximum of up to 0.24 sec (15 cycles) fault clearing time; minimum working distance 910 mm (36 in.)	4	12 m (40 ft)
Arc-resistant switchgear 1 kV through 15 kV [for clearing times of less than 0.5 sec (30 cycles) with available fault current not to exceed the arc-resistant rating of the equipment], and metal-enclosed interrupter switchgear, fused or unfused of arc-resistant type construction, 1 kV through 15 kV	N/A (doors closed)	N/A (doors closed)
Parameters: Maximum of 25 kA available fault current; maximum of up to 0.24 sec (15 cycles) fault clearing time; minimum working distance 910 mm (36 in.)	4 (doors open)	12 m (40 ft)
Other equipment 1 kV through 15 kV Parameters: Maximum of 25 kA available fault current; maximum of up to 0.24 sec (15 cycles) fault clearing time; minimum working distance 910 mm (36 in.)	4	12 m (40 ft)

Note: For equipment rated 600 volts and below, protected by upstream current-limiting fuses or current-limiting circuit breakers sized at 200 amperes or less, the arc-flash PPE category can be established by one category less than the below arc flash PPE category 1.

Informational Note to Table 130.7(C)(15)(a): The following are typical fault clearing times for certain protective devices:

(1) 0.5 cycle fault clearing time is typical for current limiting fuses when the fault current is within the current limiting range.

(2) 1.5 cycle fault clearing time is typical for molded case circuit breakers rated less than 1000 volts with a instantaneous trip integral device operating trip.

(3) 2.0 cycle fault clearing time is typical for insulated case circuit breakers rated less than 1000 volts with a instantaneous trip integral device operating trip.

(4) 5.0 cycle fault clearing time is typical for relay operated circuit breakers rated 1 kV to 38 kV when the relay operates in the instantaneous range (i.e., zone one protection).

(5) 20 cycle arc clearing time is typical for low-voltage fuses and insulated case circuit breakers with a short time fault clearing delay for motor inrush.

(6) 30 cycle fault clearing time is typical for low-voltage fuses and insulated case circuit breakers with a short time fault clearing delay without instantaneous trip.

Informational Note No. 1: See Table 1 in NFPA 70E-2004, *Guide for Performing Arc Flash Hazard Calculations*, for further information regarding Notes 1 through 6.

Informational Note No. 2: An example of a standard that provides information for arc-resistant switchgear referenced in Table 130.7(C)(15)(a) is IEEE C37.20.7, *Guide for Testing Metal-Enclosed Switchgear Rated 1 kV to 38 kV for Internal Arcing Faults*.

Which PPE Category should I use?

- The Fermilab ESS Simplified Guidance has two tables for work on AC electrical systems and utilization equipment.
  - Both include Arc-flash Category 0
  - The first table closely parallels Table 130.7(C)(15)(a), addressing electrical distribution equipment.
  - The second table provides guidance for work on electrical utilization equipment that is still not found in NFPA 70E

Simplified Guidance for Electrical Work on Fermilab AC POWER DISTRIBUTION Equipment

Diagnostic Work Including LOTO Voltage Testing Unless Otherwise Noted, Plus Some Additional Operations

Equipment	Voltage	Rated Full Load Current	PPE Category	Conditions or Qualifications
Primary Panelboards SWBD DHP	480/277 VAC	More than 1,200 Amps	4	Primary Transformer Larger than 1000 KVA (Assuming More Than 25,000 ISC Available with Fault Clearing Time >2 Cycles) Take Advantage of Installed Panelboard Meter for LOTO Verification if Present.
Motor Control Centers MCC	480 VAC	Typical 600 Amps and Above	4 or 2	Category 2 permitted only if overcurrent protective device will clear fault in under two line cycles (0.03 s). Take Advantage of Installed Central Monitoring Unit for LOTO Verification if Present
Primary or Secondary Panelboards DHP PHP LP	480/277 VAC	400 to 1,200 Amps	2	Proximity to Transformer Power Source Presumed
Operating 13.8 KV Disconnects with Doors Closed	13.8 KV	NA	2	Booster Brentford or RF Anode Power Supplies are Examples
Secondary Panelboards PHP LP	480/277 VAC	100 to 225 Amps	2	More Than 200 Feet from Panelboard Sourcing Power
Work in Lighting Panelboards (LP) including LOTO Verification	480/277 VAC	100 Amps	2	More Than 100 Feet from Secondary Panelboard Sourcing Power
Work in Utility Panelboards Including LOTO Verification	120/208 VAC 120/240 VAC	Below 350 Amps	1	Requirement Direct from NFPA 70E 130.7(C)(15)(a). Applies if overcurrent protective device will clear fault in under two line cycles (0.03 s).
Operating Circuit Breakers and Disconnect Switches with Covers On or Closed	480/277 VAC	NA	0	Equipment must be in Normal condition as defined by NFPA 70E Table 130.5(C)
	120/208 VAC 120/240 VAC	NA	0	Equipment must be in Normal condition as defined by NFPA 70E Table 130.5(C)

This Simplified Table for AC Power Distribution Equipment Has Been Approved by the Electrical Safety Subcommittee, based on the 2018 Edition of NFPA 70E
If Stated Conditions or Qualifications Are Not Met or the Circumstances of the Work Activity Appear Unique, Refer to NFPA 70E Table 130.7(C)(15)(a) or Consult with Your D/S Electrical Coordinator.

Simplified Guidance for Electrical Work on Fermilab AC UTILIZATION Equipment

Diagnostic Work Including LOTO Voltage Testing Unless Otherwise Noted

Equipment	Voltage	Sourcing Branch CB	PPE Category	Conditions or Qualifications
Power Supplies	480 VAC	Various	Can Range from 1 to 3	Ask Your Department for an Assessment. Take Advantage of Installed Panel Meters for LOTO Verification.
Various Equipment	480 VAC or 480/277 VAC	100 to Less than 400 Amps	2	Distance from Primary Panelboards and Feed Conductors Limit Available Fault Currents
Various Equipment	480 VAC or 480/277 VAC	Less Than 100 Amps	1	Distance from Primary Panelboards and Feed Conductors Limit Available Fault Currents
Sump Pump Controllers Motor Controllers HVAC Equipment	480 VAC	60 Amps and Below	1	Distance from Primary Panelboards and Feed Conductors Limit Available Fault Currents
Ballasts and Light Fixtures	277 VAC	30 Amps and Below	1	Typical Lighting Ballast
Power Supplies	208 VAC	350 Amps and Below	0	Equipment and branch circuit overcurrent protective device(s) must be in Normal condition as defined by NFPA 70E Table 130.5(C)
Various Equipment	120/208 VAC	350 Amps and Below	0	Equipment and branch circuit overcurrent protective device(s) must be in Normal condition as defined by NFPA 70E Table 130.5(C)
Various Equipment	120 VAC	30 Amps and Below	0	Equipment and branch circuit overcurrent protective device must be in Normal condition as defined by NFPA 70E Table 130.5(C)

This Simplified Table for AC Utilization Equipment Has Been Approved by the Electrical Safety Subcommittee, based on the 2018 Edition of NFPA 70E
If Stated Conditions or Qualifications Are Not Met or the Circumstances of the Work Activity Appear Unique, Consult with Your D/S Electrical Coordinator.

Which PPE Category should I use?

- A separate arc-flash PPE table for DC systems first appeared in the 2015 NFPA 70E. Fermilab has also prepared an ESS Simplified Guidance Table that closely follows the NFPA 70E table. These follow on the next two slides

Table 130.7(C)(15)(b)

Table 130.7(C)(15)(b) Arc-Flash PPE Categories for Direct Current (dc) Systems

Equipment	Arc-Flash PPE Category	Arc-Flash Boundary
Storage batteries, dc switchboards, and other dc supply sources Parameters: Circuit ≤ 250 V and less than or equal to 600 V Maximum arcing duration and minimum working distance: 2 sec, 455 mm (18 in.)		
Available fault current less than 4 kA	2	990 mm (39 in)
Available fault current greater than or equal to 4 kA and less than 7 kA	2	1.2 m (4 ft)
Available fault current greater than or equal to 7 kA and less than 15 kA	3	1.8 m (6 ft)
Storage batteries, dc switchboards, and other dc supply sources Parameters: Circuit ≤ 250 V and less than or equal to 600 V Maximum arcing duration and minimum working distance: 2 sec, 305 mm (12 in.)		
Available fault current less than 4 kA	2	900 mm (35 in)
Available fault current greater than or equal to 4 kA and less than 8 kA	2	1.2 m (4 ft)
Available fault current greater than or equal to 8 kA and less than 7 kA	3	1.8 m (6 ft)
Available fault current greater than or equal to 7 kA and less than 10 kA	4	2.5 m (8 ft)

Notes

(1) Arc-flash hazards need not be expected to be exposed to electrolyte and meet both of the following conditions:

(a) Be enclosed in electrolyte proof material

Informational Note: ASTM F1296, *Standard Guide for Evaluating Chemical Protective Clothing*, contains information on how to evaluate apparel for protection from electrolyte.

(b) Be arc-rated

Informational Note: ASTM F1891, *Standard Specification for Arc and Flame Resistant Rainwear*, contains information on evaluating arc-rated apparel.

(2) A protective device is assumed. If there is no overcurrent protective device (OPD) or if the fault clearing time is not known, if the fault clearing time is unknown or is less than 2 seconds, an incident energy analysis could provide a more representative result.

Informational Note No. 1: When determining arc-flash current, the resistance of cables and other impedances in the circuit should be included. Arc-flash system modeling is the best method for determining the worst-case short-circuit current at the point of the arc. Battery cell short-circuit current can be obtained from the battery manufacturer. See Informative Annex D.5 for the basis for table values and alternative methods to determine incident energy. Modeling should be used with good engineering judgment.

Informational Note No. 2: The methods for estimating the dc arc-flash incident energy were used to determine the categories for this table based on typical incident energy calculations. Open air dc arc-flash tests were used for most battery systems and other dc power systems are in open air or in enclosures. If the specific task is within an enclosure, it would be prudent to consider additional PPE protection beyond the value shown in this table. Research with dc arc-flash has shown a multiplier of as much as 3x for arc-in-a-box (305 mm × 305 mm × 305 mm (12 in. × 12 in. × 12 in.)) cubic enclosures. Open air modeling judgment is necessary when evaluating the specific conditions of the equipment and task to be performed, including the dimensions of the enclosure and the working distance involved.

(New Table) Simplified Guidance for Electrical Work on Fermilab DIRECT CURRENT Equipment

Diagnostic Work Including LOTO Voltage Testing Unless Otherwise Noted

Equipment	Voltage	Fault Current	PPE Category	Arc-Flash Boundary	Conditions or Qualifications
DS Batteries, Switchboards, or other sources exceeding limits on voltage, current, or both	> 600	Various	Varies	Varies	Also applies to arc durations over 2 seconds or working distance under 18 inches. Ask Your Department for an Assessment.
DS Batteries, Switchboards, or other sources	251 - 600	7 - 10 kA	4	8 Feet	Maximum arc duration of 2 seconds and working distace of not less than 18 inches
DS Batteries, Switchboards, or other sources	251 - 600	3 - 7 kA	3	6 Feet	Maximum arc duration of 2 seconds and working distace of not less than 18 inches
DS Batteries, Switchboards, or other sources	251 - 600	1.5 - 3 kA	2	4 Feet	Maximum arc duration of 2 seconds and working distace of not less than 18 inches
DS Batteries, Switchboards, or other sources	251 - 600	< 1.5 kA	2	3 Feet	Maximum arc duration of 2 seconds and working distace of not less than 18 inches
DS Batteries, Switchboards, or other sources	100 - 250	7 - 15 kA	3	6 Feet	Maximum arc duration of 2 seconds and working distace of not less than 18 inches
DS Batteries, Switchboards, or other sources	100 - 250	4 - 7 kA	2	4 Feet	Maximum arc duration of 2 seconds and working distace of not less than 18 inches
DS Batteries, Switchboards, or other sources	100 - 250	< 4 kA	2	3 Feet	Maximum arc duration of 2 seconds and working distace of not less than 18 inches

This Simplified Table for Direct Current Equipment Has Been Approved by the Electrical Safety Subcommittee, based on the 2018 Edition of NFPA 70E
If Stated Conditions or Qualifications Are Not Met or the Circumstances of the Work Activity Appear Unique, Refer to NFPA 70E Table 130.7(C)(15)(b) or Consult with Your D/S Electrical Coordinator.

PPE in Fermilab Stockroom

- Safety Glasses
- 8.2 cal/cm2 FR Coveralls
- 10 Cal Face Shields with Hard Hat
- 10 Cal Double-Layer Switching Hoods
- Replacement Face Shields
- Leather Gloves
- No Insulating Gloves
  (See ESH&Q Section)

General Comments About Arc-Flash PPE

- Always be Sure to Wear PPE that Satisfies the Minimum ATPV Required
- Shirts must be tucked in and wrist or neck openings buttoned or zipped up.
- Do NOT wear any non-FR clothing over your arc-flash PPE (non-melting OK underneath).
- OK to Wear Higher Rated Clothing and Face Shields, but Safety Can be Compromised
- Sometimes too much PPE or Duration of Use can Introduce New Hazards

Wear and Care of PPE

- Wear Non-melting clothing, including undergarments
- Avoid Scratching Eye Protection
- No Bleach or Fabric Softeners
- Wear Clothing Loose, rather than Tight
- Layering Increases Protection
- Dry is Better than Wet

- Coordinate shock and arc-flash PPE with PPE required to mitigate non-electrical hazards.

What are acceptable fabrics to wear?

- Avoid materials that will melt and stick to the skin while burning. If that sounds bad to you, its actually worse. DO NOT WEAR:
  - Nylon
  - Polyester
  - Spandex
  - Acrylic
  - Blends that include these fibers, e.g., polyester/cotton, wool/acrylic

What are acceptable fabrics to wear?

- Flammable but non-melting fabrics are permitted for Category 0 and underneath arc-rated clothing. Permitted fibers are:
  - Cotton
  - Wool
  - Plus linen, silk, and leather
  - Rayon is a permitted synthetic fiber, because it is made from wood cellulose, which burns (like paper) but does not melt
  - Meta-aramid (Nomex)
- Stitching and elastic may be meltable fibers

Establishing the electrical work area

- Physical barriers are required at the more distant of the AFB and LAB unless entrance to the area is controlled (e.g., locked room) and only one crew is working on a single task
  - Signage may also be required
  - Signs and barricades should be non-conductive
  - If signs and barricades may be ineffective at deterring unqualified workers, attendants mat be needed.
  - Mark RAB if there is a potential for confusion

Safe Work Practices

- Covered in Articles 130.4 - 130.6
  - Be Alert (fatigue, illness, medications, etc.)
  - Use Common Sense
  - No blind reaching. If view is obstructed, you cannot work on live parts. Sharp edges may cut your PPE
  - Illumination must be provided. The light-restricting properties of arc-flash face shields or hoods may require supplemental lighting.
  - Conductive articles (jewelry, clothing) shall not be worn

More Safe Work Practices

- Covered in Articles 130.4 - 130.6
  - Conductive objects shall be kept out of the RAB except parts being installed or removed
  - Block hinged doors and covers to prevent them from bumping workers
  - Place additional barriers and safeguards to prevent contact with energized parts when doing housekeeping in LAB

More Safe Work Practices

- Covered in Articles 130.4 - 130.6
  - Use only load-rated switches for opening or closing circuits unless all loads are removed, unless it is an emergency
  - Correct the cause of a blown fuse or circuit breaker trip before replacing or resetting it
  - Safety interlocks may only be bypassed by workers qualified to be in the RAB. They must have full control of the interlock, and return interlock to normal operation when work is completed.

Safe Work Practices (SWP)

- Plan for Emergencies
  - Part of daily work planning and Hazard Analysis
  - Know how to de-energize Quickly or
  - Be prepared to pull employee free with an Insulated Rescue Hook
  - Have the Means Available to Contact Emergency Personnel - Dial 3131
  - Know CPR & Where AED's are located
    - Contact your supervisor CPR for training
- See FESHM 9180 for additional SWPs

Electrical Hazard Analysis / Work Permit (From FESHM 9110 and 9120)

- See Provided Handout of the EHAWP
- Essentially a Hazard Analysis with Electrical Specifics
- Qualified Person in Charge (PIC)
- Person Performing Switching, unless same as or directly supervised by Person in Charge
- Used for both AC Power Distribution Equipment and Electrical Utilization Equipment
- Requirements for Shock and Arc-Flash Protection
- Establishes 4 Feet as the Default Arc Flash Boundary
- Available as a Word Document from the ES&H Section Web Site

Visually verify disconnect operation

- 120.5(3): Wherever possible, visually verify that all blades of the disconnecting devices are fully open or that drawout-type circuit breakers are withdrawn to the fully disconnected position.
- 120.5(3): Wherever possible means????
  - Wherever it is possible to visually confirm device operation without exposing the worker to additional hazards, e.g., do not open the door of a disconnect switch with line side still energized

Verification of De-Energization

- Most Important Step in LOTO
- Assume Energized
  - PPE, Voltage Rated Tools and Gloves
  - Establish Appropriate Boundaries
- Do not use Proximity Meters as your Primary Testing Tool (HV excepted)
- Test line-to-line, line-to-ground, and line-to-neutral if a neutral conductor is present.
- Know your Test Equipment is Working
  - Test Before and After Use

Test Before Touch (TBT)

- 120.4(B)(6)(3): The [LOTO] procedure shall establish the requirement to test before touching every exposed conductor or circuit part(s) within the defined boundary of the work area.
- 120.4(B)(6)(4): The [LOTO] procedure shall establish the requirement to retest for absence of voltage when circuit conditions change or when the job location has been left unattended.

Risks in Demolition Work

- Demolition presents different and often greater risks than construction work.
  - Decrepit and undocumented conditions are often present in complete facility removal
  - Selective demolition, where adjacent cables & equipment must remain operational, present hazards from misidentification, resulting in contact with energized cables and equipment
  - Removing conductors when the terminations are not in sight requires additional measures to identify them and confirm zero voltage

Subcontractors

- Contracts require compliance with NFPA 70E
- Time and Material Subcontractors
  - T&M Office will verify training
    - Make sure scope of work includes enough information for T&M Office to understand that training is expected
  - Make sure HA addresses electrical shock and arc- flash hazard mitigation
    - PPE, tools, and boundaries are identified
    - Emergency actions identified

Subcontractors

- Fixed Price Contract
  - Verify that workers are trained
    - Request training documentation
  - Verify the HA includes electrical shock and arc-flash hazard mitigation
    - PPE, tools, and boundaries are identified
    - Emergency actions identified

Where to get More Information

- ES&H Web Site Has Copies of Summary Guidance, the EHAWP, and ESS Determinations
- NFPA 70E and Handbook
- Electrical Safety Subcommittee
- Division/Section Electrical Coordinators
- Division Safety Officers
- Special Meetings

Electrical Coordinators

- Accelerator – Jim Ranson
- Computing – Mark Thomas
- ES&H – David Mertz
- Quality – David Mertz
- FESS – Joe Pathiyil
- WDRS – Joe Pathiyil
- ND & PPD – Steve Chappa, J. Dwight Featherston, Tim Martin
- Technical – Miguel Nunez

Electrical Safety Subcommittee

Member	Title	Term Expires
David Mertz	ES Subject Matter Expert, Chair	Indefinite
Michael Utes	PPD Subject Matter Expert, Deputy	10/1/2019
John Scott	Fermi Site Office - Observer	Indefinite
Trevor Butler	AD Subject Matter Expert	6/2/2020
Timothy Martin	PPD Subject Matter Expert	Indefinite
John Reid	AD Subject Matter Expert	Indefinite
Randal Wielgos	FE Subject Matter Expert	Indefinite
Dennis Barak	AD Representative	4/3/2020
Steve Chappa	PPD Representative	3/31/2021
Timothy Kasza	CCD Representative	10/1/2020
Miguel Nunez	APS-TD Representative	2/28/2021
Joseph Pathiyil	FE Representative	Indefinite
Mark Thomas	CCD Representative	5/31/2019

The LAST Slide

- Twenty-Two Question Test
- Open Book
- Self-Scoring
- Questions Entertained During and After the Test
- Comments and Evaluation