# Electrical Arc Flash Safety and Risk Management In Healthcare Facilities

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# What is an Arc Flash?

**NFPA 70E says an arc flash hazard is:**

**A dangerous condition associated with the possible release of energy caused by an electric arc**

NFPA 70E 2009 article 100 - Definitions

***A hazard beyond shock and electrocution***

# Two Types of Major Electrical Faults Can Occur

- **Bolted faults**
  - Low impedance and high current
  - Energy is contained by the conductor (bus or cable)
  - Cleared quickly by circuit breakers or fuses
  - Arcing is confined within the circuit breaker or fuse
  - Usually no damage to equipment
  - Relatively low safety risk to personnel

- **Arcing faults**
  - High impedance (air) results in lower current
  - Persist longer and propagate
  - High release of heat and blast energy
  - Are very destructive and dangerous to personnel

# Causes of Bolted and Arcing Faults

- What causes these types of faults?
  - Bolted faults (low impedance and high current)
    - Commonly caused by
      - Improper connections after maintenance
      - Installation errors
  - Arcing faults (high impedance, lower current)
    - Commonly caused by
      - Careless cover or device removal
      - Foreign object (tool) dropped into equipment
      - Misalignment of moving contacts (parts failure)
      - Dirt contamination or dielectric breakdown
      - Entry of foreign body (rodent, snake, squirrel)

# Incident Energy

**The amount of energy impressed on a surface, a certain distance from the source, generated during an electrical arc event.**

**Incident energy is measured in calories/cm$^2$ or Joules/cm$^2$.**

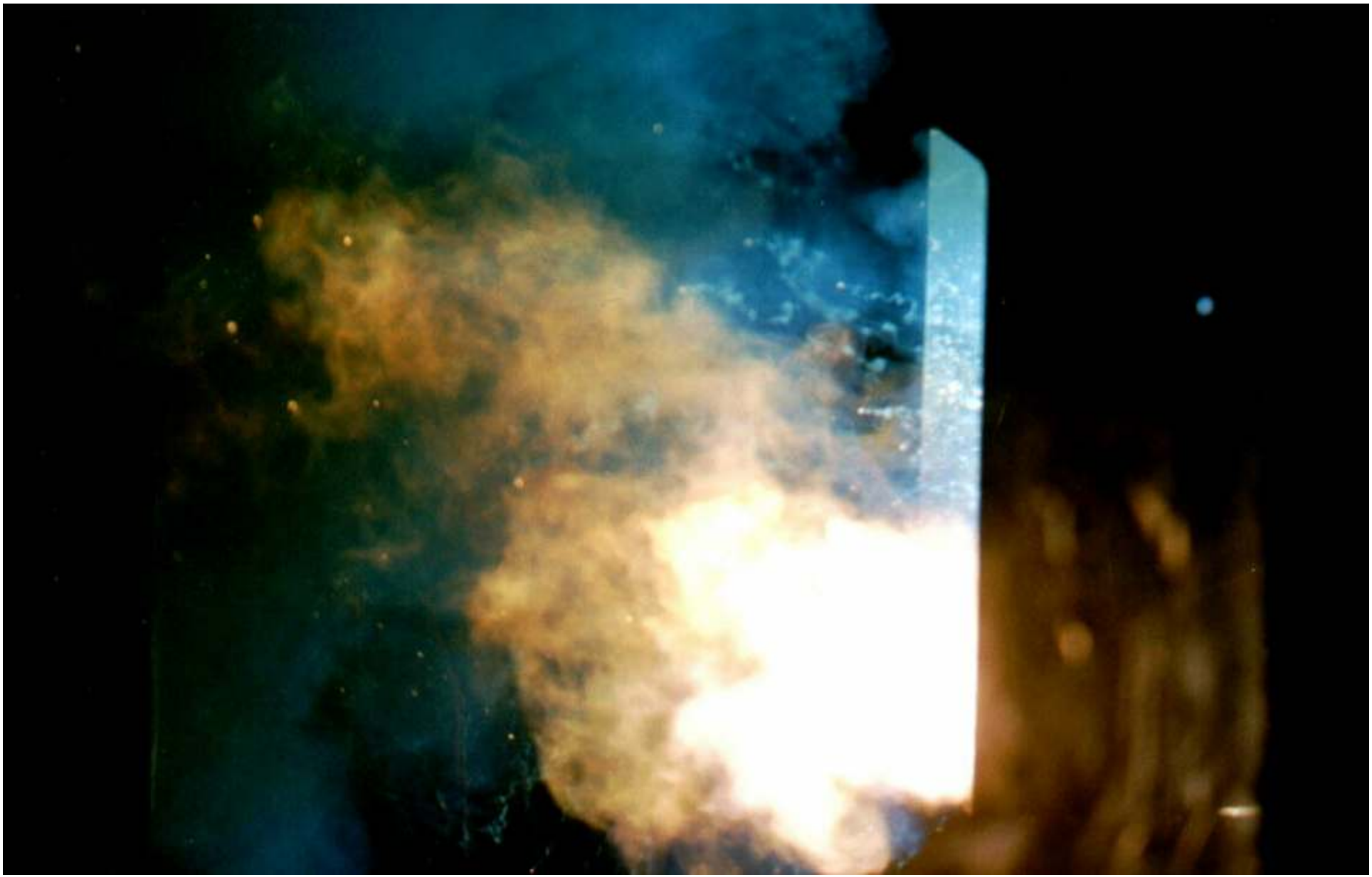
**The incident energy defines the PPE category required**

**NFPA 70E 2009 Article 100 - definitions**

# Bolted and Arcing Fault Characteristics

- Arcing fault incident energy released is:
  - Greater at higher available fault current levels (neglecting the action of an over-current protective device)
  - Reduced by dynamic impedance (air)
  - And increased by the time duration of the arc
- The most controllable factor in reducing the incident energy is time
- Current flow in a 480V arcing fault is approximately half that of the bolted fault current (impedance of air)
- Fuses or circuit breakers are the first line of defense in reducing arcing fault incident energy
- Calculating arc fault incident energy is a very complex engineering task

# What a 480 volt  Arcing Fault Looks Like



# Electrical Arc Facts

- Arc is electric current passing through air
  - Shock potential from potential contact with arc
- Temperature of arc plasma center often reaches 35,000 Degrees Fahrenheit
  - Radiated heat burns
- Pressure wave generated from arc
  - Impact to hearing, etc (sound levels can exceed160 dB)
  - Gaseous copper is 67,000 times its solid volume
  - Molten metal expelled from equipment at high speed (~700 MPH)
  - Extreme pressures (thousands of pounds per square foot).
- Arc fault results from something wrong or out of place

# Some Arc Flash Injury Statistics

**Five to ten arc flash explosions occur in electrical equipment every day in the United States, according to statistics compiled by Cap-Schell, Inc., a Chicago-based research and consulting firm that specializes in preventing workplace injuries and deaths.**

**Injuries from arc flash events range from minor injuries to third degree burns and potential death due to the energy released.**

**Other injuries include blindness, hearing loss, nerve damage, and cardiac arrest.**

**The average cost of medical treatment for survivors of serious arc flash injuries is $ 1,500,000**

**Total costs including litigation will typically be $8M - $10M**

# Results of an Arc Flash

- Other non-human consequences
  - Downtime
  - Lost revenue
  - Loss of product
  - Equipment damage
  - Regulatory impact
  - OSHA citation and fines

# Electrical Safety

## Goal:

**Electrical installations that are free from occurrences**

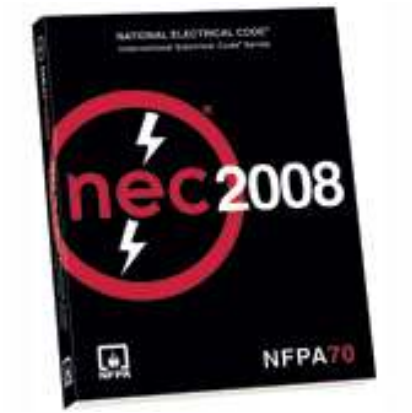
### Hazards:

- **Shock**
- **Electrocution**
- **Arc flash and arc blast**

# What's Changing in the Industry?

- Attention to arc flash – costs and prevention
- Impact to large manufacturers drove attention to arc flash hazards
- Recognition of unsafe work practices: energized work
- Changes to NEC &  NFPA 70E
- New IEEE 1584 Standard for Arc Flash Hazard Calculations
- Enforcement by OSHA

# Applicable Documents




**NFPA70 (NEC)**

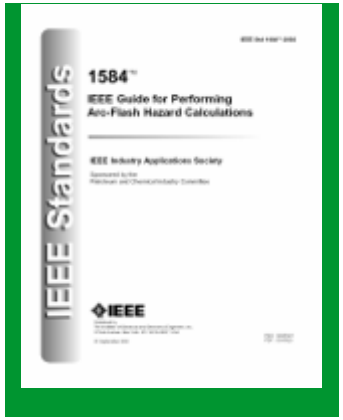
**Governs Electrical Installations**


**NFPA70E-2009**

**Governs Employee Workplace Safety**


**OSHA 29 CFR Part 1910**

**OSHA Standards (Iowa Shown)**




**IEEE 1584 -2002**

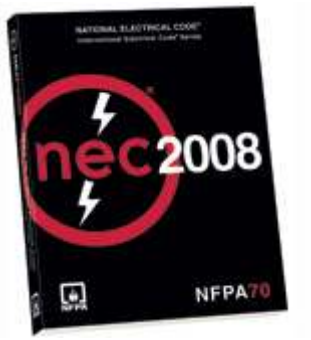
**Guide for Performing Arc Flash Hazard Calculations**

# New Requirements on Facilities

- NFPA 70E and NEC state that facilities must provide:
  - **Safety program with defined responsibilities**
  - **Analysis for arc flash hazard degree**
  - **Training for workers**
  - **Personal protective equipment (clothing) for workers**
  - **Tools for safe work**
  - **Warning labels on equipment**

***Result: Facilities must take steps to comply.***

# Requirements: 2008 NEC




110.16: “Electrical equipment, such as switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers, that are in other than dwelling occupancies, and are likely to require examination, adjustment, servicing, or maintenance while energized shall be field marked to warn qualified persons of potential electric arc flash hazards. The marking shall be located so as to be clearly visible to qualified persons before examination, adjustment, servicing, or maintenance of the equipment.

***Warning for awareness, to prepare for future work***

***Field marked - not marked by manufacturer***

***No mention of values - only warning of hazard***

***References NFPA 70E, ANSI Z535.4***

# Example Equipment Label

## New Equipment Square D Label

# DANGER

**HAZARD OF ELECTRIC SHOCK, EXPLOSION, OR ARC FLASH**

- Apply appropriate personal protective equipment (PPE) and follow safe electrical work practices. See NFPA 70E

- This equipment must only be installed and serviced by qualified electrical personnel.
- Turn off all power supplying this equipment before working on or inside equipment.
- Always use a properly rated voltage sensing device to confirm power is off.
- Replace all devices, doors and covers before turning on power to this equipment.

**Failure to follow these instructions will result in death or serious injury.**

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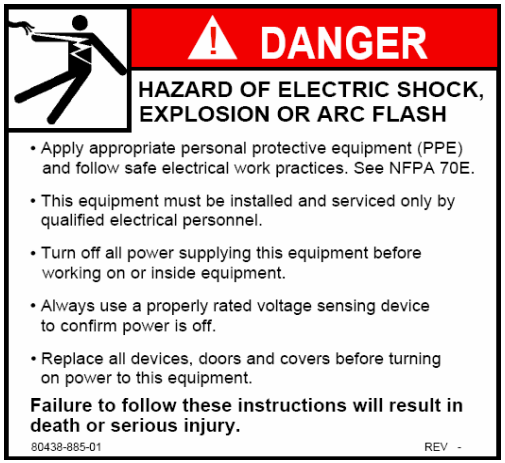
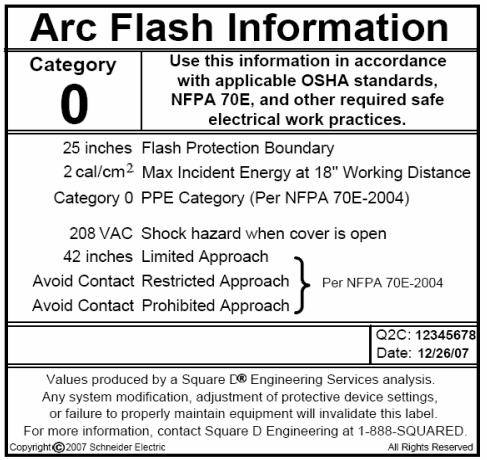
# Examples - Arc Flash Labels with Data Values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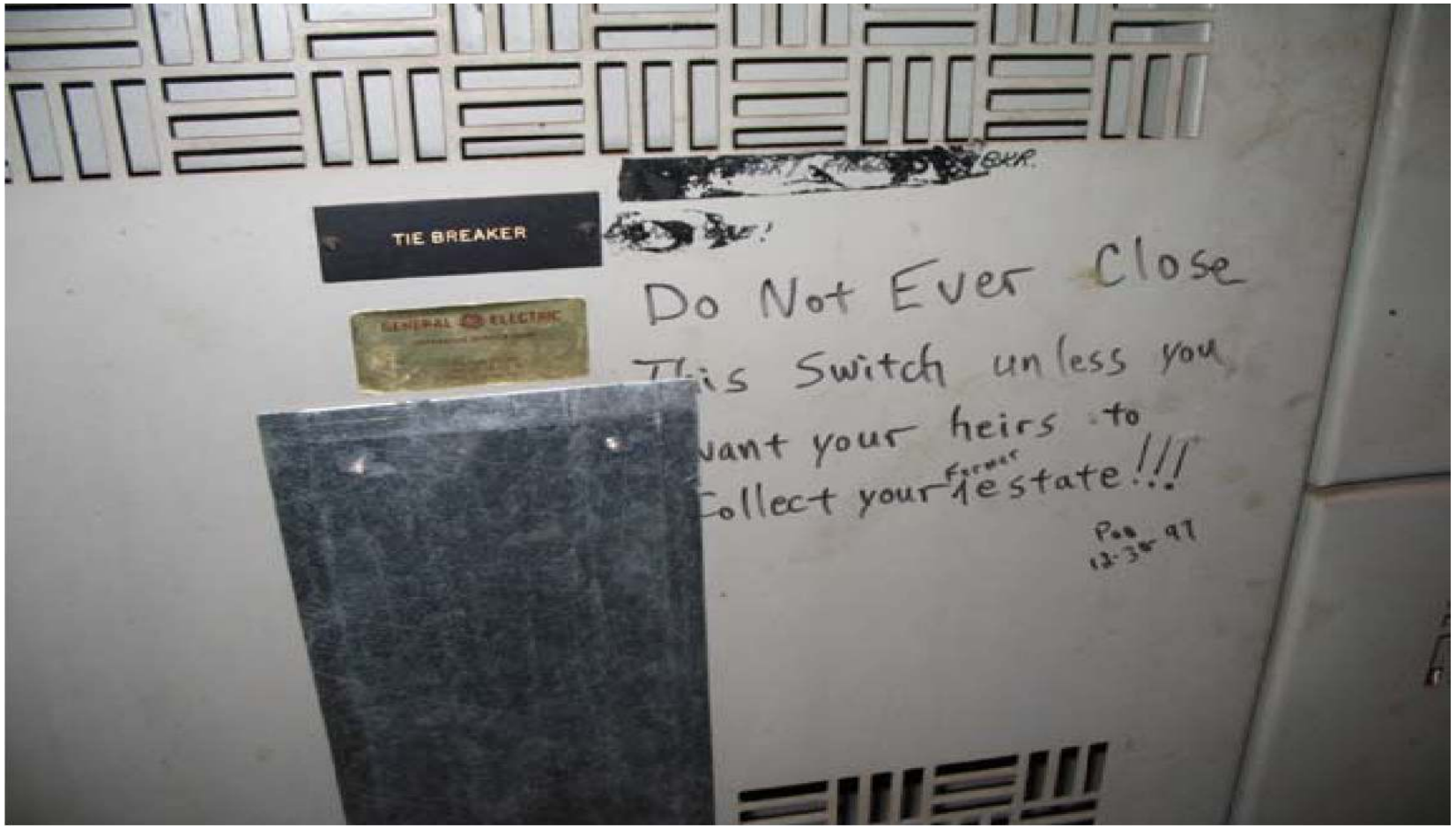
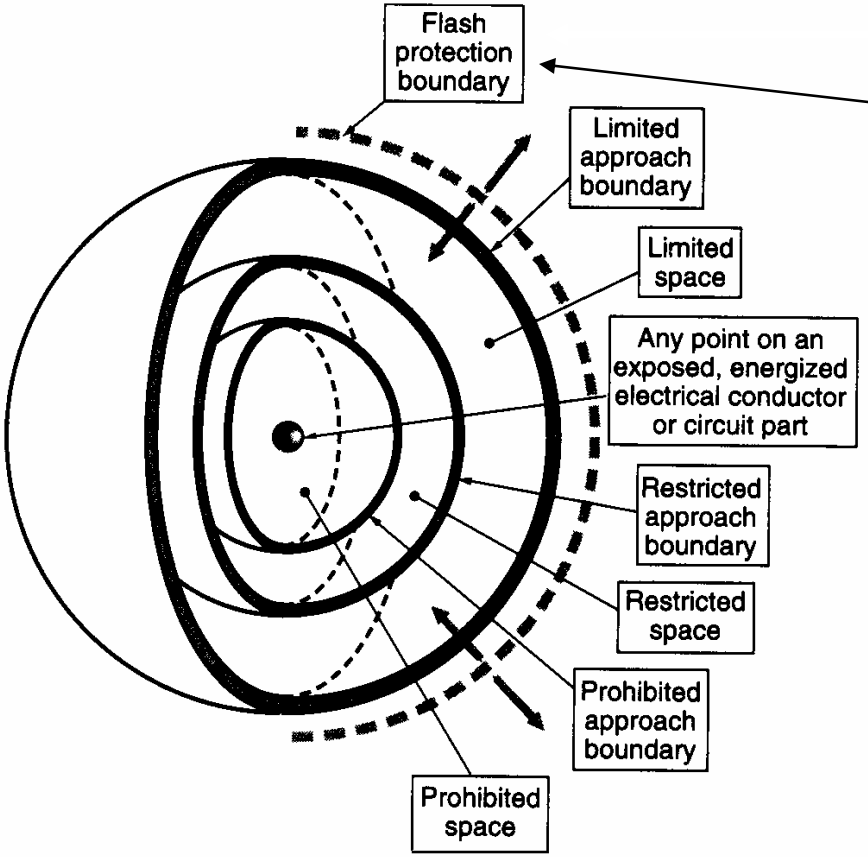
# Importance of Proper Hazard Warning Labels

- **What is a “failure to adequately warn”?**
- **ANSI Z535.4, UL 969, and ISO standards**
- **OSHA always cites to the most current labeling standards (ANSI Z535.4)**
- **The standards define the colors, symbols, materials and wording used on labels**
- **Labels should be designed to accommodate standards changes**
- **From a risk exposure and safety standpoint, proper labeling is very important**

# Inadequate Labeling Example



# Limits of Approach



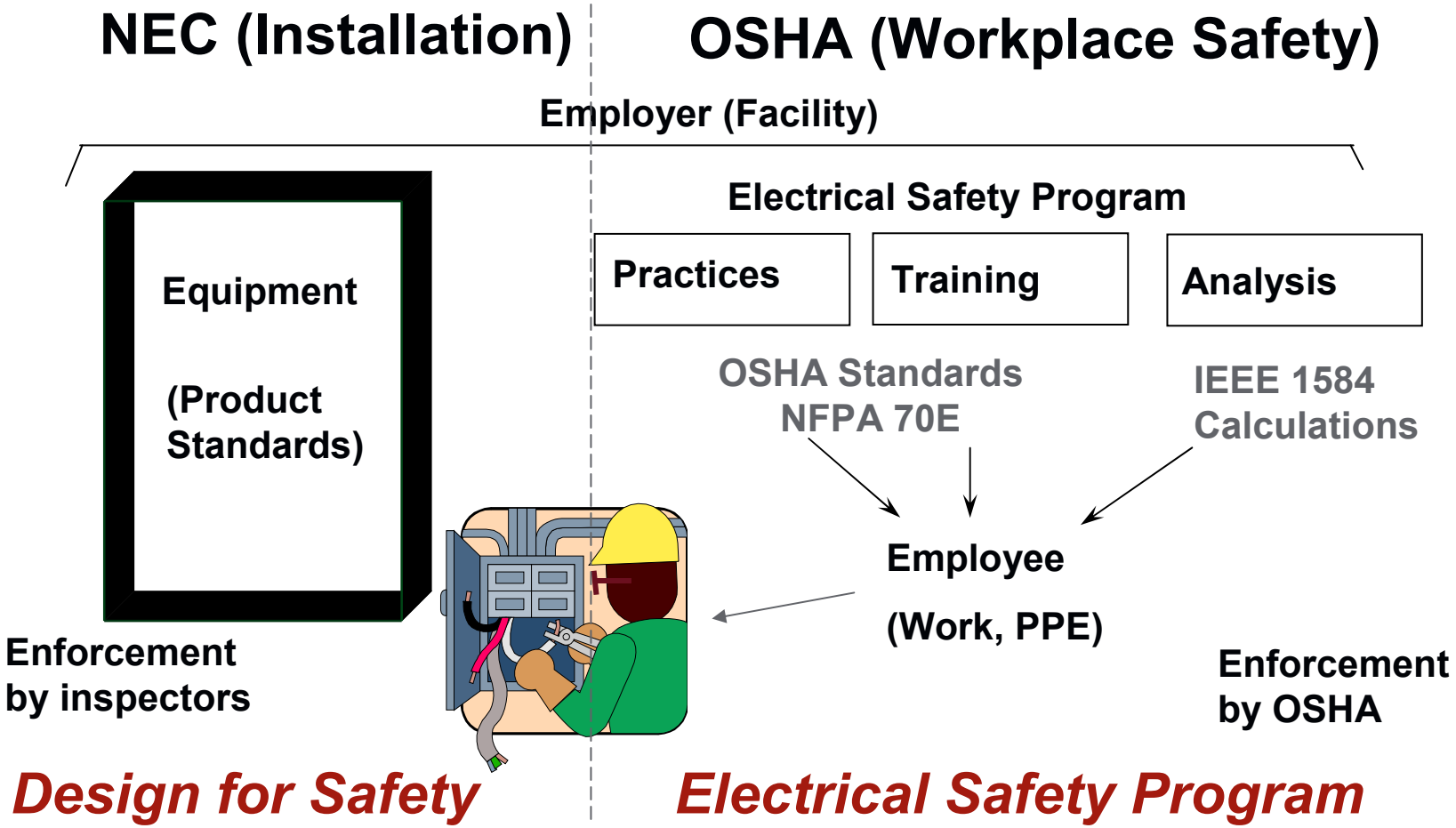

## Flash protection boundary

**An approach limit at a distance from exposed live parts within which a person could receive a second degree burn if an electric arc flash were to occur. (NFPA 70E 2004)**

***It is generally accepted that a second degree burn results from exposure of incident energy of 1.2 cal/cm$^2$***

**NFPA 70E 2009 Annex C, Fig. C.1.2.4**

# Safety System for Work on or Near Electrical Equipment



# Responsibilities for Safety Compliance

- **Employer shall provide practices**
- **Employer shall provide training**
- **Employee shall implement practices**

**The responsibilities as defined in the codes and standards**

# Who is a “Qualified Person” ?

**NFPA 70E and the National Electrical Code (NEC) define a qualified person as:**

**“One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved”**

**Training on the hazards is required by definition**

NFPA 70E 2009 Article 100 - definitions

# OSHA 29 CFR 1910.333

**"Safety related work practices shall be employed to prevent electric shock or other injuries resulting from either direct or indirect electrical contacts when work is performed near or on equipment of circuits which are or may be energized"**

***OSHA cites NFPA 70E for compliance requirements***

# OSHA 29 CFR 1910.333

**"Live parts to which an employee may be exposed shall be de-energized before the employee works on or near them, unless the employer can demonstrate that de-energizing introduces additional or increased hazards or is infeasible due to equipment design or operational limitations."**

***The fundamental requirement is to de-energize!***

***Whenever you allow work to be done energized, you take a risk.***

# Work Involving Electrical Hazards

**Justification for Work** (NFPA 70E 2009 article 130.1 (A)

**Energized electrical conductors and circuit parts to which an employee might be exposed shall be put into an electrically safe work condition before an employee works within the Limited Approach Boundary of those conductors or parts.**

**(1) Greater Hazard. Energized work shall be permitted where the employer can demonstrate that de-energizing introduces additional or increased hazards.**

**(2) Infeasibility. Energized work shall be permitted where the employer can demonstrate that the task to be performed is infeasible in a de-energized state due to equipment design or operational limitations.**

**(3) Less than 50 volts. Energized electrical conductors and circuit parts that operate at less than 50 volts to ground shall not be required to be de-energized…**

# OSHA 29 CFR 1910.335

## Personal Protective Equipment

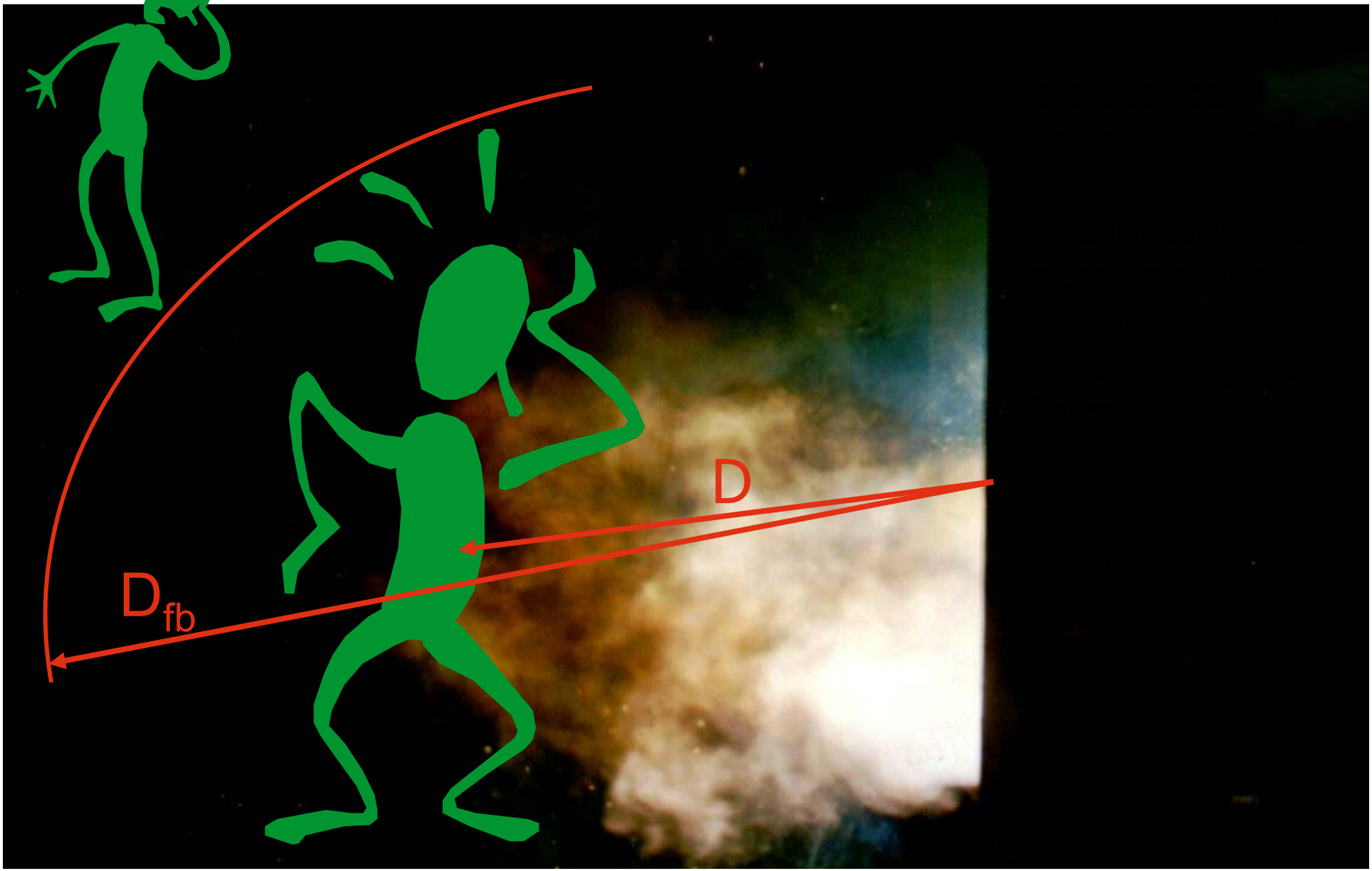
**"Employees working in areas where there are potential electrical hazards shall be provided with, and shall use, electrical protective equipment that is appropriate for the specific parts of the body to be protected and for the work to be performed."**

***Notice that OSHA does not specifically mention calculations or NFPA 70E. However, since NFPA 70E is a recognized, published standard available to the industry, OSHA will always cite using requirements of NFPA 70E.***

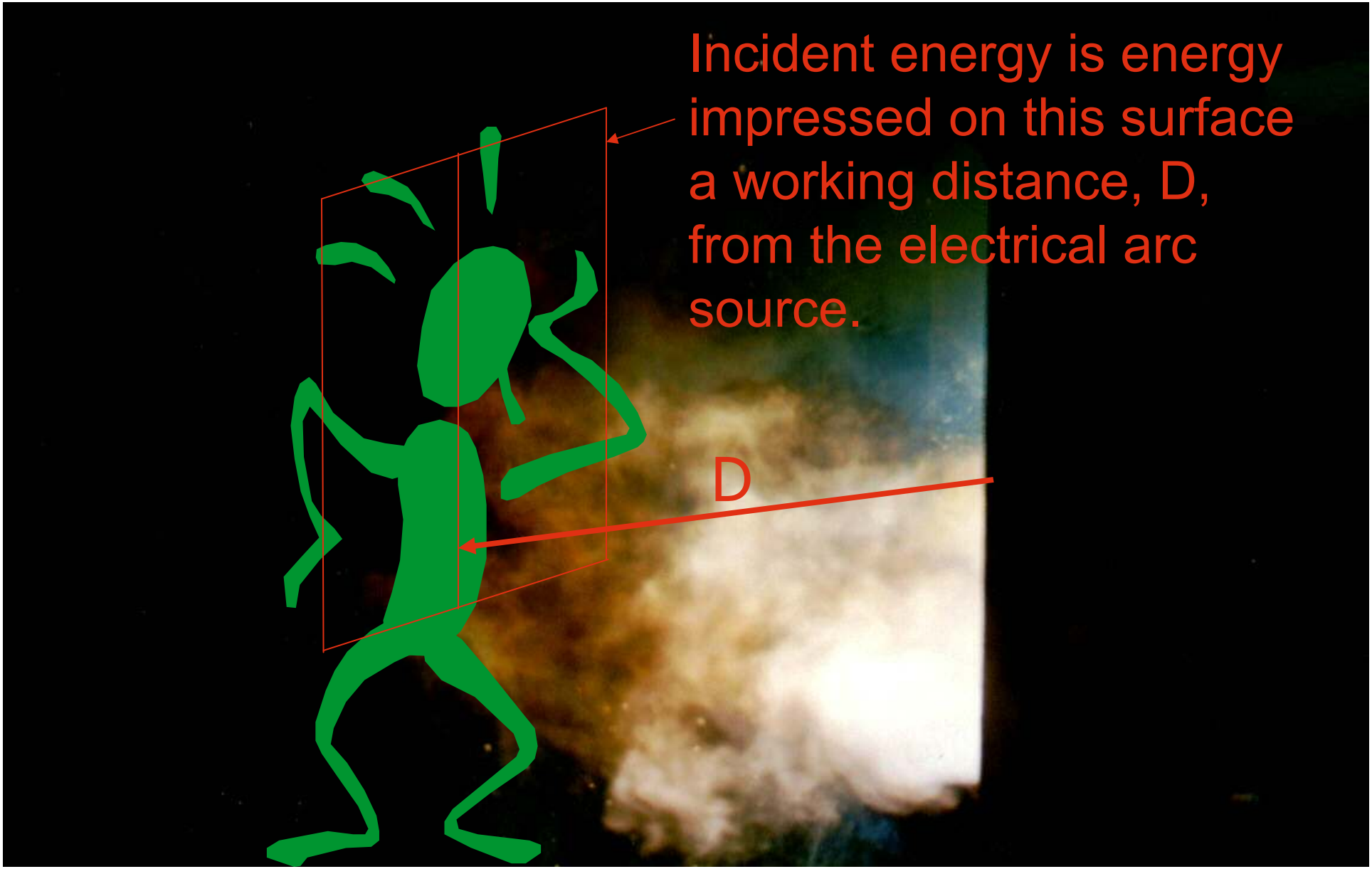
# Condition of Existing Equipment is Critical

- **Device operating time is critical to reducing arc flash incident energy**
- **The arc flash analysis assumes that existing devices will operate on their original OEM time current curve**
- **The arc flash analysis software uses the device's original OEM trip curve and settings to perform arc flash hazard calculations**
- **For existing devices (circuit breakers) that are not in good condition, the opening times can vary considerably from the original trip curve**
- **In some cases, poorly maintained devices will not open for any reason**
- **The incident energy during an arc flash event will become unpredictable**
- **Maintenance and condition of the existing devices becomes a very important factor, when calculating arc flash hazard potential**

# Flash Protection Boundary



# Incident Energy



# Determine PPE Hazard Risk Category

| Category | Cal/cm$^2$ | Clothing Description |
|---|---|---|
| 0 | N/A | Untreated cotton, wool, rayon or silk, or blends of these materials with a fabric weight of at least 4.5 oz/yd$^2$ |
| 1 | 4 | Arc Rated FR shirt & FR pants or coverall |
| 2 | 8 | Arc Rated FR shirt & FR pants or coverall |
| 3 | 25 | Arc rated FR shirt & pants or coverall, and arc flash suit selected so that the system arc rating meets the required minimum. |
| 4 | 40 | Arc rated FR shirt & pants or coverall, and arc flash suit selected so that the system arc rating meets the required minimum. |

**Note that melt-able fabrics and other similar synthetics are never permitted**

**Source: NFPA 70E 2009**

# Other Requirements for PPE

- Hard hat, safety glasses, hearing protection (canal inserts), leather gloves and leather work shoes are required for most protective clothing classes. Refer to NFPA 70E 2009 Article 130 for clothing system details
- Face shields with a minimum arc rating of 4 for Hazard / Risk category 1, or 8 for Hazard / Risk category 2, with wrap around guarding to protect not only the face, but also the forehead, ears and neck, are required. (Alternately, an arc-rated arc flash suit hood may be used.
- For Hazard / Risk category 2*, a sock hood (balaclava) with a minimum rating of 8 is required, in addition to the wraparound face shield.

# Does Working at 100 cal/cm$^2$ Make Sense?

- No PPE class in NFPA 70E beyond 40 cal/cm$^2$ - 70E does not intend for work to be performed at locations with such high AFIE
- Above these levels, arc blast may be as significant a concern as the arc flash
- Research & experience shows that burn injuries are not the only concern
  - **Hearing damage**
  - **Internal injuries (collapsed lung, concussion)**
  - **Shrapnel**
- 100 cal/cm2 PPE is rated for high heat levels, but is not a suit of armor!
- Exception:  placing equipment in electrically safe condition

# PPE Examples

**Category 2 PPE**

**Category 4 PPE**

# Methods of Determining Incident Energy and Hazard Risk Category

- IEEE 1584
  - Hand calculations (not recommended)
  - Shortcut calculations
  - Calculations using spreadsheet
  - Calculations by consulting engineers
- Tables in NFPA 70E
- Schneider / Square D consulting services
- Published values from manufacturers tests
- Commercial software

# NFPA 70E Table (example)

**Note: Tables are a convenient way to know the hazard if calculations have not been done. However, data in tables tends to be conservative**

| Task | Hazard/Risk Category | V-rated gloves | V-rated tools |
|---|---|---|---|
| 240 V Panelboard<br>Work on energized electrical<br>Conductors and circuit parts | 1 | Y | Y |
| 600 V Panelboard<br>Work on energized electrical<br>Conductors and circuit parts<br>parts | 2* | Y | Y |

*** - a double-layer switching hood or wraparound face shield and hearing protection are required for this task in addition to other Category 2 requirements**

**Take care to follow footnotes when using the tables**

**NFPA 70E 2004, Table 130.7(C)(9)**

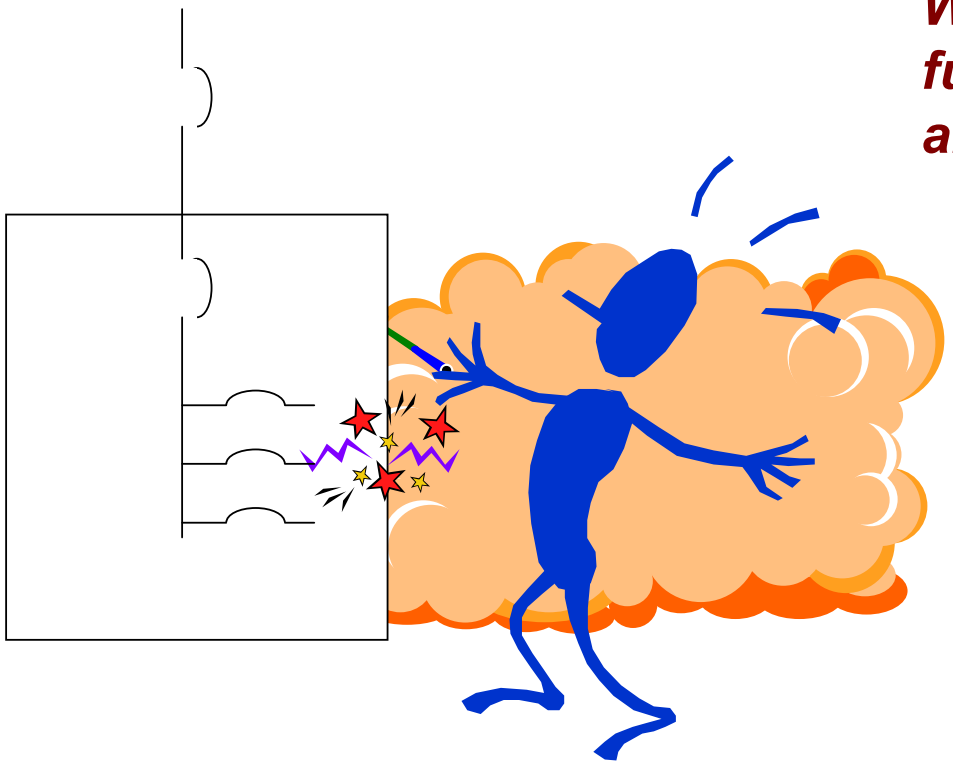
# Sample NFPA 70E Table

NFPA70E 2009 Table 130.7(C)(9) - (Partial)

| 600 V Class Switchgear(with power circuit breakers or fused switches) Note 4 | Hazard Risk/ Category | V-rated Gloves | V-Rated Tools |
|---|---|---|---|
| Perform infrared thermography and other non-contact inspections Outside the restricted approach boundary | 2 | N | N |
| 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 electrical conductors and circuit parts parts, including voltage testing | 2* | Y | Y |
| Work on control circuits with energized electrical conductors and Circuit parts 120 V or below, exposed | 0 | Y | Y |
| Work on control circuits with energized electrical conductors and circuit parts >120 V, exposed | 2* | Y | Y |
| Insertion or removal (racking) of CBs from cubicles, doors open or closed | 4 | N | N |
| Application of safety grounds, after voltage test | 2* | Y | N |
| Removal of bolted covers (to expose bare, energized electrical Conductors and circuit parts) | 4 | Y | N |
| Opening hinged covers (to expose bare, energized electrical Conductors and circuit parts) | 2 | N | N |

**Note 4. Maximum of 35kA short circuit current available, maximum of up to .5 sec (30 cycle) fault clearing time**

# Overcurrent Protection and Arc Flash Analysis



***Why is a circuit breaker or fuse always considered in arc flash analysis?***

**1. The circuit breaker or fuse clears the circuit to stop the arcing.**

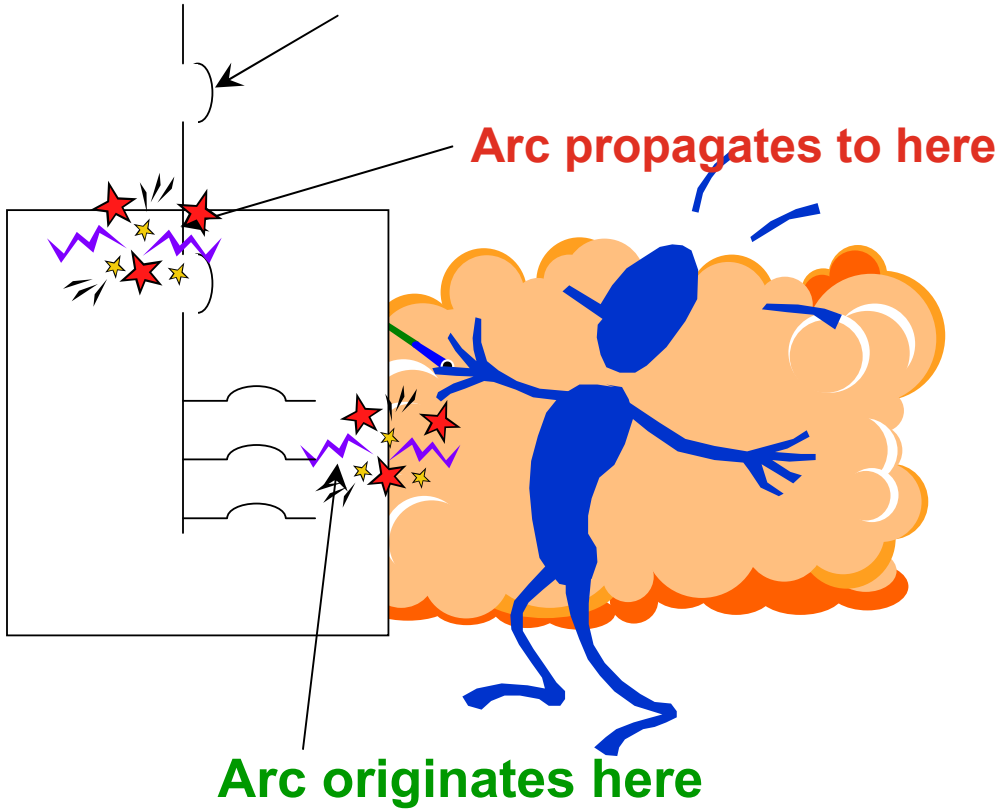
**2. It determines how fast the circuit is cleared.**

energy = volts x amps x <u>time</u>

faster clearing time = lower energy

# Which device clears the arcing fault?

**Arc may propagate to the supply side of all devices in the same enclosure**



# Arc Flash Hazard Analysis

**An arc flash hazard analysis shall determine the Arc Flash Protection Boundary and the personal protective equipment that people within the Arc Flash Protection Boundary shall use.**

**The Arc Flash Hazard Analysis shall:**

- **Be updated when a major modification or renovation takes place**
- **Be reviewed periodically, not to exceed every five years**
- **Take into consideration the design of the overcurrent protective device, including it's condition of maintenance**

**Desired output for each equipment studied:**

- **Flash protection boundary distance**
- **Incident energy**
- **Hazard / risk category for PPE selection**

NFA 70E 2009 article 130.3

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# Buying an Arc Flash Hazard Analysis

- Many vendors offer this service
- The process / scope of work (and pricing) varies widely
- Most facilities do not understand how to properly specify an arc flash analysis (and this is critical)
- Sometimes a bad arc flash analysis is worse than none at all
- Square D Engineering Services has established the “gold standard” for arc flash analysis
- Ask us for our guide specification, which details the proper process and the qualifications required
- We see many examples of companies who bought the lowest priced study, and later regretted that choice
- There should be no compromise where employee safety and legal liability are at risk

# IEEE 1584-2002

- Provides new methods for calculation of arc flash energy and flash protection boundaries
- Empirically derived model based on extensive testing and statistical analysis of results
- Requires input from short circuit and coordination analysis
- Considers equipment type, bus gap, voltage class, grounding, motor contribution, short circuit current, clearing characteristics, etc.
- The most accurate method available today to model arc flash incident energy
- Does not replace NFPA 70E or OSHA guidelines
- Recommends display of calculated incident energy values on equipment where an arc-flash hazard exists
- Encourages safety by design

# IEEE Arc Flash Calculation Procedure

Step 1 - **Collect system and installation data**

Step 2 - **Determine all system modes of operation**

Step 3 - **Determine bolted fault currents -**

Step 4 - **Determine arc fault currents**

Step 5 - **Protective device characteristics and arc duration -**

Step 6 - **Document system voltages and classes of equipment**

Step 7 - **Select working distances**

Step 8 - **Determine incident energy of all equipment**

Step 9 - **Determine flash protection boundary for all equipment**

# Once the Calculations are Done...

- Workers are required to wear appropriate Personal Protective Equipment (PPE)
- What workers wear depends upon the incident energy exposure level...
- And the specific task to be performed

# Electrical System Documentation

- Many facilities lack accurate electrical system documentation
  - **Accurate electrical single-line drawings**
  - **Accurate short circuit and coordination studies**
- Accurate one-line drawings are also critical for safety in performing lockout/tagout procedures
- The cost of an arc flash analysis is directly related to the accuracy of the one-line drawings
  - **Single-line drawings and other documentation must be reconstructed as part of the arc flash analysis**
- Once the arc flash analysis is completed, facilities should keep the documentation current
  - **When the system or conditions change, update the drawings and revalidate the arc flash hazard analysis**
- Having inaccurate documentation creates additional legal and safety risk.
  - **May be cited as causative factors in accident injury litigation**
  - **Keeping it up to date is required in NFPA 70E (Article 205.2)**

# Important Changes in NFPA 70E 2009

- Article 130.3 Exception Number 1– An arc flash hazard analysis shall not be required where all of the following conditions exist:
  - The circuit is rated 240 volts or less
  - The circuit is supplied by one transformer
  - The transformer supplying the circuit is rated less than 125 kVA
- Article 130.3 Exception Number 2 – The requirements of 130.7(C)(9), 130.7(C)(10), and 130.7(C)(11) shall be permitted to be used in lieu of a detailed incident energy analysis

  FPN Number 1 – Improper or inadequate maintenance can result in increased opening time of the overcurrent protective device, thus increasing the incident energy
- Article 130.3 (C) -- Equipment shall be field marked with a label containing the available incident energy or required level of PPE.

# Important Changes in NFPA 70E 2009

130.3 Arc Flash Hazard Analysis -- The arc flash hazard analysis shall be updated when a major modification or renovation takes place. It shall be reviewed periodically, not to exceed five years, to account for changes in the electrical distribution system that could affect the results of the arc flash hazard analysis.

- Article 130.3 (C) Effect of maintenance on arc flash protection boundary and personal protective equipment - Proper maintenance of overcurrent protective devices is required in order to successfully predict the degree of hazardous energy to which a worker may be exposed under arc flash conditions.

  Note: NFPA 70E cites NFPA 70B and equipment manufacturer's recommendations for proper maintenance requirements and intervals.

# Important Changes in NFPA 70E 2009

- Article 205.2 Single Line Diagram – A single line diagram where provided for the electrical system shall be maintained
- Article 205.3 General Maintenance Requirements – Overcurrent protective devices shall be maintained in accordance with the manufacturer's instructions or industry consensus standards
- Article 210.5 Protective Devices – Protective devices shall be maintained to adequately withstand or interrupt available fault current.
  - FPN: failure to properly maintain protective devices can have an adverse effect on the arc flash hazard analysis incident energy values

# Recent history of OSHA Enforcement Actions

- The U.S political administration clearly affects Department of Labor (OSHA) directives and enforcement actions
  - During the Bush administration OSHA enforcement activities were reduced approximately 80% from the prior administration
  - With the end of the Bush administration in 2008, the head of OSHA (Edwin G. Foulkes) returned to his private legal practice, defending companies against OSHA enforcement actions
- The Obama administration appointed Hilda Solis to head the Department of Labor. Solis was confirmed in February 2009
- Jordan Barab was appointed by Solis as deputy assistant secretary of OSHA in April 2009
- Barab will have acting responsibility as Assistant Secretary of OSHA until a permanent appointment is made when he will assume the role of Deputy Assistant Secretary
- Dr. David Michaels has been confirmed as permanent OSHA head, replacing Jordan Barab in that capacity..

# There's a New Sheriff in Town

- Hilda Solis and Jordan Barab spoke in late June 2009 to 3,300 members of the ASSE (American Society of Safety Engineers) in San Antonio on OSHA enforcement. Some highlights of that meeting…
  - Solis – "OSHA is back in the enforcement business"
  - Focus on voluntary (VPP) programs will be highly scrutinized
  - More than 150 new inspectors will be hired in 2009 (adding to the current staff of 2,500)
  - Enforcement budget will increase by10% to $22.5M
  - Number of annual inspections will increase from 38,000 nationwide to perhaps 44,000
  - More enforcement, less voluntary protection focus
  - Penalties will be higher for violations
  - OSHA will be more aggressive with standards and policing / enforcement than at any time in the last 20 years
  - Solis - "As long as I am Secretary of Labor the department will go after anyone who puts worker lives needlessly at risk."
  - Barab - "Economic hardship is no excuse for taking short cuts with safety and health"

# In the First Six Months of the New OSHA Administration

- More than $1.1 million in penalties against Milk Specialties Co. in Whitehall, Wis.
- $500,000 to be paid by Tyson Foods
- More than $255,000 in fines against a New Hampshire firearms manufacturer
- $217,000 in fines against Delek Refining
- More than $141,000 in fines against Hess Corp
- $105,000 in proposed penalties against an Orlando manufacturer
- A Petrolia, Pa., chemical company fined more than $121,000
- $273,000 in fines against a Jamestown, N.Y., employer
- $148,000 against Miranda Roofing for fall hazards
- an El Paso, Texas, construction contractor fined $106,200 for alleged workplace safety violations.

- Hilda Solis stated “the Department of Labor is back in the enforcement business. We are serious, very serious.”

# What it Means to Our Customers

- OSHA will be very aggressive on electrical workplace safety violations
- Most of the 2,500 Compliance Officers have been trained on NFPA 70E, and many carry copies of that standard during “walkaround” inspections. Some are referring customers to me for help.
- Threats of increased enforcement will result in more emphasis on the compliance requirements of NFPA 70E
- Many of our customers will need help with compliance – and we are best suited to help them with the solution

# Summary

- Arc Flash is a significant electrical safety concern
- Industry standards are in place to address the issue
  - Require selection and use of PPE based on Flash Hazard analysis
  - But PPE is to be a last line of defense!

- System design considerations can reduce the potential exposure to arc flash
  - #1 goal: No energized work
  - #2 goal: If work must be done energized, at least let it be done on a system where the hazard level has been reduced

See NFPA 70E 2009 Annex O – Safety Related Design Requirements - for recommendations on designing for safety