

# Electrical Codes and Standards for R&D

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# Topics

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- I. Existing Codes and Standards for Electrical Safety
- II. Application of existing standards to R&D
- III. New electrical codes and standards for R&D

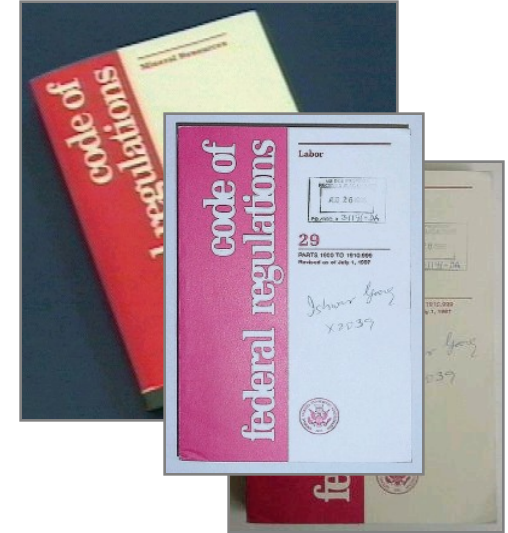
# Government and National Codes and Standards for Electrical Safety

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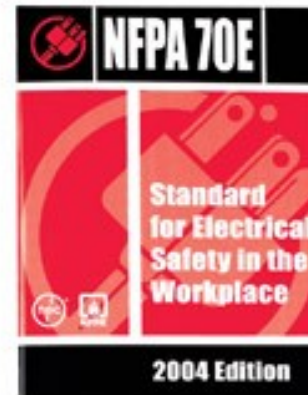
- OSHA - Title 29, Parts CFR 1910 and 1926
- NEC - National Electrical Code (2008)
- NFPA 70E - Standard for Electrical Safety in the Workplace (2004)
- DOE Electrical Safety Handbook - 2004 (guidance only)
- ASTM, ANSI, and IEEE Standards
- NRTL Standards (e.g., UL)

# National Electrical Standards

- OSHA - Code of Federal Regulations
- NEC (National Electrical Code)  
Standard for the safe installation of electrical wiring & equipment
- NFPA (National Fire Protection Association) 70E, Standard for Electrical Safety in the Workplace



QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.



# Code of Federal Regulations (including OSHA)

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10 CFR 851 - Worker Safety and Health Program (DOE Rule)

29 CFR 1904 - Recording and Reporting Occupational Injuries and Illnesses

29 CFR 1910 - Occupational Safety and Health Standards

Subpart I - 1910.137 - Personal Protective Equipment

Subpart J - 1910.147 - Control of Hazardous Energy (Lockout/Tagout)

Subpart R - 1910.269 - Electric Power Generation, Trans., and Distribution

Subpart S - Electrical

1910.301 - General

1910.302 - 308 - Design Standards for Electrical Systems

1910.331 - 335 - Safety-Related Work Practices

1910.339 - Definitions

29 CFR 1926 - Safety and Health Regulations for Construction

Subpart K - Electrical

Subpart V - Power Transmission and Distribution

# 1910 Subpart S - Electrical

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301 - Introduction

302 - 308 Design safety standards for utilization systems

302 - Electric Utilization Systems

303 - General Requirements

304 - Wiring design and protection

305 - Wiring methods, components, and equipment for general use

306 - Specific purpose equipment and installations

307 - Hazardous (classified) locations

308 - Special systems

331 - 335 Electrical safety work practices

331 - Scope

332 - Training

333 - Selection and use of work practices

334 - Use of equipment

335 - Safeguards for personnel protection

361 - 380 reserved for safety-related maintenance requirements

381 - 398 reserved for safety requirements for special equipment

399 - Definitions applicable to this subpart

# NFPA 70 - The National Electrical Code

2008 Edition - 822 pages

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- 1 - General
- 2 - Wiring and Protection
- 3 - Wiring Methods and Materials
- 4 - Equipment for General Use
- 5 - Special Occupancies
- 6 - Special Equipment
- 7 - Special Conditions
- 8 - Communications Systems

# NFPA 70E - Standard for Electrical Safety in the Workplace

April 2004 - 133 pages

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- Tailored to fulfill OSHA's responsibilities, that is fully consistent with the NEC
- Deals with Electrical Safety for personnel

# NFPA 70E

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- Introduction (Scope and Definitions)
- Chapter 1 - Safety-Related Work Practices
- Chapter 2 - Safety-Related Maintenance Requirements
- Chapter 3 - Safety Requirements for Special Equipment
- Chapter 4 - Installation Safety Requirements

# NFPA 70E - Chapter 1 - Safety-Related Work Practices

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100 - Definitions

110 - General Requirements for Electrical Safety-Related Work Practices

120 - Establishing an Electrically Safe Work Condition

130 - Working On or Near Live Parts

# Other Standards and Codes

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## National Fire Protection Association (NFPA)

- 70 - National Electrical Code
- 70E - Electrical Safety in the Workplace
- 70B - Electrical Equipment Maintenance
- 77 - Static Electricity
- 79 - Electrical Standard for Industrial Machinery
- 780 - Lightning Protection

## Institute of Electrical and Electronic Engineers (IEEE)

- IEEE/ANSI C2 - National Electrical Safety Code
- IEEE 80, 142, 524A, 1048, 1100 - various grounding
- IEEE 142 - Electrostatic Discharge
- IEEE/ANSI C95.1 - Exposure to Electromagnetic Fields
- IEEE 1584 - Guide for Performing Arc-Flash Hazard Calculations

# Other Standards and Codes

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## Underwriters Laboratories (UL)

- UL 45 - Portable Electric Tools
- UL 508 - Industrial Control Equipment
- UL 508A - Industrial Control Panels
- UL 698, 877, 886 - Equipment in Hazardous Locations
- UL 3101 - Electrical Equipment for Laboratory Use
- UL 1244 - Measuring and Testing Equipment

## American National Standards Institute (ANSI)

- Z535.1 - For Safety Color Code
- Z535.2 - For Environmental and Facility Safety Signs
- Z535.3 - Criteria for Safety Symbols
- Z535.4 - For Product Safety Signs and Labels
- Z535.5 - Safety Tags and Barricade Tapes (for Temporary Hazards)

## National Electrical Manufacturers Association (NEMA)

- 280 - Ground Fault Circuit Interrupters

# DOE Electrical Safety Handbook

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- 1 - Introduction
- 2 - General Requirements
- 3 - Electrical Preventative Maintenance
- 4 - Grounding
- 5 - Special Occupancies
- 6 - Specific Equipment
- 7 - Work in Excess of 600 Volts
- 8 - Temporary Wiring
- 9 - Enclosed Electrical/Electronic Equipment
- 10 - Research and Development
- 11 - Excavations

# Electrical Safety Requirements in the CFR 851 Final Rule

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## Codes and Standards

- 29 CFR 1910 Subpart S
- 29 CFR 1910.268 Telecommunications
- 29 CFR 1910.269 Electric Power Generation, Transmission, and Distribution
- 26 CFR 1926 Subparts K Electrical
- 26 CFR 1926 V Power Transmission and Distribution
- NFPA 70 National Electrical Code
- NFPA 70E Standard for Electrical Safety in the Workplace
- 10 CFR 851 Appendix A Part 10

## II. How does NFPA 70 and 70E apply to R&D?

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- What is applicable?
- How can it be misused?

# NFPA 70 and 70E

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- Scope - installation of electrical conductors, equipment, etc. for
  - buildings
  - parking lots
  - connections to supply
  - office buildings
  - homes

# NEC General requirements

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- working clearance - to protect the worker while working on energized equipment.
  - to allow for adequate room to work
  - to allow emergency egress
- no unused openings - to prevent shock or arc flash escape to operators
- equipment grounding - to protect buildings and people
  - to allow overcurrent protection to work
  - to keep voltage of enclosure low, and provide a fault path
- listing
  - to prevent failure leading to facility and equipment damage
  - to prevent electric shock
  - to fail safe
- installation requirements
  - to prevent overload, overcurrent, fire

# NEC Chapters 2, 3

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- facility power installations
  - service
  - feeders
  - overcurrent protection
  - branch circuits
- wiring methods
  - for 60 Hz continuous power delivery

# NEC Ch. 4 - Equipment for General Use

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- flexible cords and cables
- receptacles
- panelboards
- control panels
- luminaires
- appliances
- space heating equipment
- motors
- AC
- transformers
- capacitors - not in equipment, Article 460
- reactors - very limited, Article 470
- storage batteries, Article 480
- equipment over 600 V
  - switchgear, boilers, etc.

# NEC Ch. 5 - Special Occupancies

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- hazardous locations
- health care
- theaters
- carnivals
- motion picture
- agricultural
- RVs
- floating buildings

Does NOT cover accelerators, laser systems, capacitor banks, etc.

# NEC Ch. 6 - Special Equipment

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- induction and dielectric heating
- X-ray equipment
- electroplating

Industrial equipment

# DC in the NEC

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- only mentioned in Article 250-VIII
- for dc power distribution in facilities

# applicability of NFPA 70E

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- LOTO - YES, but meant for facility work by electricians
- Table 130.2(C) - Approach Boundaries to Live Parts for Shock Protection - YES, but need DC table
- Table 130.7(C)(9)(a) Hazard/Risk Category Classifications - Insufficient
  - tasks, some facility tasks are done by R&D (breakers)
  - none others are listed
- Calculations of flash boundary - not applicable to dc, capacitors and rf

# Approach Boundaries from NFPA 70E

**Table 130.2(C) Approach Boundaries to Live Parts for Shock Protection. (All dimensions are distance from live part to employee.)**

| (1)<br>Nominal System Voltage<br>Range, Phase to Phase | (2)<br>Limited Approach Boundary <sup>1</sup><br>Exposed Movable<br>Conductor | (3)<br>Exposed Fixed<br>Circuit Part | (4)<br>Restricted Approach<br>Boundary <sup>1</sup> ; Includes<br>Inadvertent Movement<br>Adder | (5)<br>Prohibited Approach<br>Boundary <sup>1</sup> |
|--|---|--------------------------------------|---|---|
| Less than 50   | Not specified   | Not specified                        | Not specified   | Not specified                                       |
| 50 to 300  | 3.05 m (10 ft 0 in.)  | 1.07 m (3 ft 6 in.)                  | Avoid contact   | Avoid contact                                       |
| 301 to 750   | 3.05 m (10 ft 0 in.)  | 1.07 m (3 ft 6 in.)                  | 304.8 mm (1 ft 0 in.)   | 25.4 mm (0 ft 1 in.)                                |
| 751 to 15 kV   | 3.05 m (10 ft 0 in.)  | 1.53 m (5 ft 0 in.)                  | 660.4 mm (2 ft 2 in.)   | 177.8 mm (0 ft 7 in.)                               |
| 15.1 kV to 36 kV                                       | 3.05 m (10 ft 0 in.)  | 1.83 m (6 ft 0 in.)                  | 787.4 mm (2 ft 7 in.)   | 254 mm (0 ft 10 in.)                                |
| 36.1 kV to 46 kV                                       | 3.05 m (10 ft 0 in.)  | 2.44 m (8 ft 0 in.)                  | 838.2 mm (2 ft 9 in.)   | 431.8 mm (1 ft 5 in.)                               |
| 46.1 kV to 72.5 kV                                     | 3.05 m (10 ft 0 in.)  | 2.44 m (8 ft 0 in.)                  | 965.2 mm (3 ft 2 in.)   | 635 mm (2 ft 1 in.)                                 |
| 72.6 kV to 121 kV                                      | 3.25 m (10 ft 8 in.)  | 2.44 m (8 ft 0 in.)                  | 991 mm (3 ft 3 in.)   | 812.8 mm (2 ft 8 in.)                               |
| 138 kV to 145 kV                                       | 3.36 m (11 ft 0 in.)  | 3.05 m (10 ft 0 in.)                 | 1.093 m (3 ft 7 in.)  | 939.8 mm (3 ft 1 in.)                               |
| 161 kV to 169 kV                                       | 3.56 m (11 ft 8 in.)  | 3.56 m (11 ft 8 in.)                 | 1.22 m (4 ft 0 in.)   | 1.07 m (3 ft 6 in.)                                 |
| 230 kV to 242 kV                                       | 3.97 m (13 ft 0 in.)  | 3.97 m (13 ft 0 in.)                 | 1.6 m (5 ft 3 in.)  | 1.45 m (4 ft 9 in.)                                 |
| 345 kV to 362 kV                                       | 4.68 m (15 ft 4 in.)  | 4.68 m (15 ft 4 in.)                 | 2.59 m (8 ft 6 in.)   | 2.44 m (8 ft 0 in.)                                 |
| 500 kV to 550 kV                                       | 5.8 m (19 ft 0 in.)   | 5.8 m (19 ft 0 in.)                  | 3.43 m (11 ft 3 in.)  | 3.28 m (10 ft 9 in.)                                |
| 765 kV to 800 kV                                       | 7.24 m (23 ft 9 in.)  | 7.24 m (23 ft 9 in.)                 | 4.55 m (14 ft 11 in.)   | 4.4 m (14 ft 5 in.)                                 |

Note: For Flash Protection Boundary, see 130.3(A).

<sup>1</sup>See definition in Article 100 and text in 130.2(D)(2) and Annex C for elaboration.

# Example Energies in power arcs

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| Bus voltage | Short Circuit Current | Power  | Clearing Time of Fault | Energy in Arc | Typical Arc Flash Boundary |
|-------------|-----------------------|--------|------------------------|---------------|----------------------------|
| 120 V       | 3,000 A               | 460 kW | 0.1 s                  | 50 kJ         |                            |
| 240 V       | 10,000 A              | 2.4 MW | 0.1 s                  | 0.2 MJ        |                            |
| 480 V       | 15,000 A              | 7.2 MW | 0.1 s                  | 0.7 MJ        | 1 m                        |
| 4160 V      | 25,000 A              | 104 MW | 0.1 s                  | 10 MJ         | 2.2 m                      |
| 13.8 kV     | 31,000 A              | 430 MW | 0.1 s                  | 400 MJ        | 4 m                        |

Note: Clearing time can be reduced by fast acting fuses

# Example Energies in Capacitor arcs

| Type                 | Voltage   | Energy | Arc Flash Boundary |
|----------------------|-----------|--------|--------------------|
| Cathode Ray Tube     | 40,000 V  | 0.1 J  | 0.6 mm             |
| High Pot Tester      | 60,000 V  | 0.1 J  | 0.6 mm             |
| Microwave Oven       | 4,000 V   | 10 J   | 0.7 cm             |
| High Power Laser     | 10,000 V  | 1000 J | 7 cm               |
| X-ray Source         | 100,000 V | 10 J   | 0.7 cm             |
| Energy storage Cap   | 60,000 V  | 200 kJ | 1 m                |
| Large Capacitor Bank | 60,000 V  | 1 MJ   | 2 m                |

Note: most of these are well within the Prohibited Approach Boundary

# Types of Electrical Equipment

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- 60 Hz power distribution
- dc power supplies
- capacitors
- inductors
- batteries
- pulsed systems
- rf systems ( $> 3000$  Hz)

NOTE: NFPA 70 and 70E clearly applies to 60 Hz power distribution, but does not immediately apply to other forms of electrical energy

# Examples of “troublesome” application of 70 and 70E to R&D

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- Cable Trays (NEC)
  - fill requirements
  - cables need to be tray rated
  - mixing power and control cables in the same tray
  - cable trays covered
- Personnel Safety Grounds (70E)
  - Require testing every 2 - 3 years
- PPE (70E)
  - applying arc flash boundaries and PPE to dc and capacitors
- Unlisted electrical equipment
  - how to apply UL type equipment approval to systems
  - middle of the night “modifications”
- Applying NEC grounding requirements to R&D systems

# More examples

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- Require training for
  - use of any PPE
  - RF work environment
  - specialized hazards
- Energy Control (OSHA and 70E)
  - trying to apply a “red lock” process to everything
  - one person/one lock rule
  - questions capture key control methods
- Accelerator beamlines
  - exposed leads (e.g., magnet)
  - sprinkler systems
  - emergency egress (50 ft rule)
  - signage
- Using 70E Task tables to determine PPE
- Arc flash PPE in mixed hazard environments (radiation, confined space)

# Application of NEC and NFPA 70E to R&D - Summary

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- Except for the fundamental principles for protecting the facility and personnel, which **MUST** be interpreted and adapted to R&D, there are very few requirements that can be immediately and directly applied to R&D equipment and safe work practices.

# III. New electrical codes and standards for R&D

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- Recent accomplishments
- Suggested Areas of Focus

# Recent accomplishments

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- Held 4 Workshops on R&D Electrical Safety (2004 - 2007)
- New chapters for DOE Electrical Safety Handbook
  - electrical hazard classification
  - unlisted electrical equipment approval
- Influenced CFR 851, DOE Worker Safety and Health Rule
- Proposal to NFPA 70E on R&D work environments
- Established ISA Standards Committee

# High-Power Research and Development Electrical Systems Standards ISA Committee

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## Scope

Develop standards and to maintain, clarify, update, and provide guidance on existing standards for research and development (R&D) involving high-power electrical systems including power supplies, radio frequency power systems, energy storage, and pulse forming networks, and their associated control, monitoring, data acquisition, and protection systems.

# High-Power Research and Development Electrical Systems Standards

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## Purpose

This committee is organized to be the focal point in the High-Power R&D Electrical Systems Community for documenting through standards publications: criteria, standards, practices, and procedures related to high power electrical systems, and the associated control, monitoring, safety, and protection systems for national and international research programs in accelerators, pulsed power applications, and high power lasers.

# Electrical Safety Requirements in the Final CFR 851 Rule

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## Two Requirements

- Electrical Safety Program
- Comply with Codes and Standards

## Quotes from 851

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- “Contractors must implement a comprehensive electrical safety program appropriate for the activities at their site. This program must meet the applicable electrical safety codes and standards referenced in 851.23”

## New Article in 2009 NFPA 70E

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- **“Addition of Article 350, Safety-Related Work Requirements: Research and Development Laboratories:** This new article provides information for minimizing exposure to electrical hazards in research and development laboratories, which may use equipment uniquely designed and constructed for discovering new concepts or developing a method to use a new discovery.”, Ray Jones

# 2005 Workshop Brainstorm – Electrical Safety Topics

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- Interlocks / Permissive Control
- Shielding (Rated) and Barriers (Stops Contact)
- Grounding
- Ground hooks
- Controls
  - Access Control
  - Remote Controls
  - PLC Controls
  - PC Controls
- Stored Energy Electrical Safety (Safeing of System)
  - Capacitor Safety
  - Inductor and Flywheel Safety
  - Battery
- Results of Stored Energy
  - RF Safety
  - X-Rays
  - Laser (EN 61010)
  - Ionizing Radiation
  - Magnet Fields
- Testing Systems
- Confusion between Shielding and Barriers
- Engineered Zero Energy Verification / Indication
- Rack Design and Layout
- Indication for Power Dumps

# Suggested Areas of Focus

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- Application of Shock and Arc Flash Protection to DC power supplies, batteries, capacitors and inductors
- Personnel Safety Grounds (Ground hooks)
  - Design, testing and maintenance
  - OJT and PPE
- Cable Trays in R&D (especially signal and control cable trays)
- Control of Hazardous Energy, including access control
- System AHJ approval
- RF Safety (signage, training, measurement, control)
- Mixed hazard environments (electrical, rf, radiological, confined space, respirators, chemical, explosive, etc.)
- Consistent and universal electrical training for R&D workers
- Remote methods of safing systems, to achieve the Electrically Safe Work Condition without worker exposure

# Goals

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- Brainstorm - what areas do we need to focus for national consistency
- Design standards, guidelines
- Safe work practices
- Training

## Suggested venues

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- DOE Electrical Safety Handbook
- EFCOG Electrical Safety Task Group
- Accelerator Safety Guidelines
- ISA Standards Committee
- NFPA 70E (2012)
- Center of Excellence for Electrical Safety website
  
- Consistency across the complex!

# Conclusions

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- We must develop standards and guidelines for electrical safety in R&D