Electrical Codes and Standards for R&D

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August 7, 2007

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Topics

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

Lloyd Gordon

- R&D background - pulsed power, plasma physics, HV
- Division Electrical Safety Officer, LANSCE - 4 years
- Currently LANL Chief Electrical Safety Officer
- Vice-chair, National Electrical Safety Task Group
- lectured, trained, consulted at
  - Argonne, Brookhaven, Jefferson, SLAC, SNS, LANL, SSC, LLNL, etc.
- co-chair - ISA Standards Committee for High Power….
- chaired 4 workshops on R&D Electrical Safety

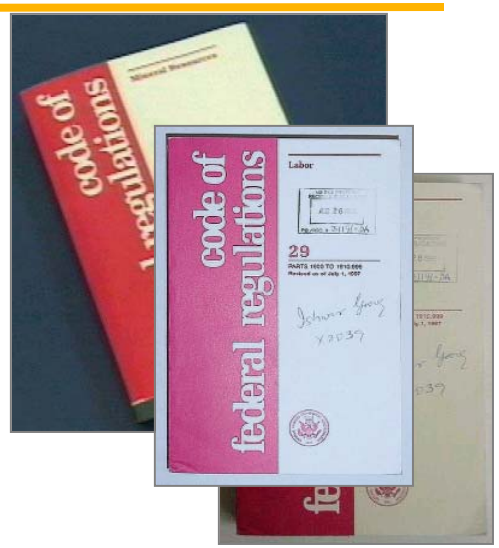
Government and National Codes and Standards for Electrical Safety

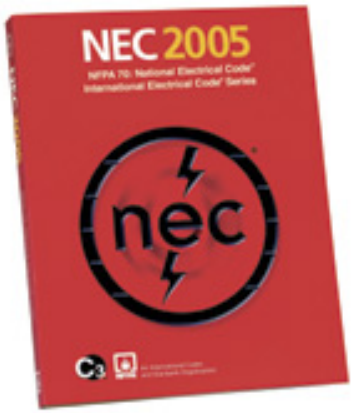
- OSHA - Title 29, Parts CFR 1910 and 1926
- NEC - National Electrical Code (2005)
- NFPA 70E - Standard for Electrical Safety in the Workplace (2004)
- DOE Electrical Safety Handbook - 2004 (guidance only)
- ASTM, ANSI, and IEEE Standards
- NRTL Standards (e.g., UL)

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





Code of Federal Regulations (including OSHA)

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 Distribribution
- 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

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

Subpart S was just revised

NFPA 70 - The National Electrical Code

2005 Edition - 772 pages

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

2008 NEC will be released in September 2007

NEC 70 - National Electrical Code

- Adopted by the National Fire Protections Associations (NFPA) and approved by the American National Standards Institute (ANSI)
- Advisory for the practical safeguarding of persons and property from the hazards arising from the use of electricity
- Not a design specification nor an instruction manual; the NEC stresses installation and maintenance of electrical systems to protect the users and public
- Extensive reference on installing electrical conductors and equipment within or on public and private buildings

NFPA 70E - Standard for Electrical Safety in the Workplace

April 2004 - 133 pages

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

2009 NFPA 70E will be released sometime in 2008
~ 200 changes out of 530 proposals
new R&D section

NFPA 70E

- 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

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

NFPA 70E - Chapter 2 - Safety-Related Maintenance Requirements

200 - Introduction

205 - General Maintenance Requirements

210 - Substation, Switchgear Assemblies, Switchboards, Panelboards, Motor Control Centers, and Disconnect Switches

215 - Premises Wiring

220 - Controller Equipment

225 - Fuses and Circuit Breakers

230 - Rotating Equipment

235 - Hazardous (Classified) Locations

240 - Batteries and Battery Rooms

245 - Portable Electric Tools and Equipments

250 - Personal Safety and Protective Equipment

NFPA 70E - Chapter 3 - Safety Requirements for Special Equipment

300 - Introduction

310 - Safety-Related Work Practices for Electrolytic Cells

320 - Safety Requirements Related to Batteries and Battery Rooms

330 - Safety Related Work Practices for Use of Lasers

340 - Safety Related Work Practices: Power Electronic Equipment

NFPA 70E - Chapter 4 - Installation Safety Requirements

400 - General Requirements for Electrical Installations

410 - Wiring Design and Protection

420 - Wiring Methods, Components, and Equipment for General Use

430 - Specific Purpose Equipment and Installations

440 - Hazardous (Classified) Locations

450 - Special Systems

NFPA 70E - Anneces

- Annex A - Referenced Publications
- Annex B - Informational References
- Annex C - Limits of Approach
- Annex D - Sample Calculation of Flash Protection Boundary
- Annex E - Electrical Safety Program
- Annex F - Hazard/Risk Evaluation Procedure
- Annex G - Sample Lockout/Tagout Procedure
- Annex H - Simplified, Two-Category, Flame-Resistant (FR) Clothing System
- Annex I - Job Briefing and Planning Checklist
- Annex J - Energized Electrical Work Permit
- Annex K - General Categories of Electrical Hazards
- Annex L - Typical Application of Safeguards ion the Cell Line Working Zone
- Annex M - Cross-Reference Table

Other Standards and Codes

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

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

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

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?

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

NFPA 70 and 70E

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

NEC General requirements

- 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

Principles can be applied to R&D

NEC Chapters 2, 3

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

NEC Ch. 4 - Equipment for General Use

- 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

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

Does NOT cover accelerators!

NEC Ch. 6 - Special Equipment

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

Industrial equipment

DC in the NEC

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

applicability of NFPA 70E

- 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 and R&D

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)	(2) Limited Approach Boundary[1]	(3)	(4)	(5)
Nominal System Voltage Range, Phase to Phase	Exposed Movable Conductor	Exposed Fixed Circuit Part	Restricted Approach Boundary[1]; Includes Inadvertent Movement Adder	Prohibited Approach Boundary[1]
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).
[1]See definition in Article 100 and text in 130.2(D)(2) and Annex C for elaboration.

NFPA 70E, Table 130.2(C)

Example Energies in power arcs

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

- 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

- 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

- 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

- 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

- Recent accomplishments
- Suggested Areas of Focus

Recent accomplishments

- 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

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

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

Two Requirements

- Electrical Safety Program
- Comply with Codes and Standards

Quotes from 851

- “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”

2005 Brainstorm – Electrical Safety Topics

- 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

- Application of Shock and Arc Flash Protection to DC, capacitors and inductors
- Personnel Safety Grounds (Ground hooks)
  - testing and maintenance
  - OJT and PPE
- Cable Trays
- Control of Hazardous Energy, including access control
- System approval
- RF Safety (signage, training, measurement, control)
- Mixed hazard environments
- Consistent and universal electrical training

Goals

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

Suggested venues

- DOE Electrical Safety Handbook
- National Electrical Safety Task Group
- Accelerator Safety Guidelines
- ISA Standards Committee
- NFPA 70E (2012)
- Center of Excellence for Electrical Safety

- Consistency across the complex!

Conclusions

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

Center of Excellence for Electrical Safety

- Recently established to support Electrical Safety Across the complex

Background

- Over the past decades site electrical safety programs have evolved separately. Although the elements based on national codes (e.g., NEC, NESC, NFPA 70E) may be common, other elements have evolved somewhat independently.
- Key elements that vary from site to site include:
  - structure of AHJ (e.g., Electrical Safety Committee, ESOs)
  - electrical hazard classification
  - unlisted electrical equipment approval
  - training
  - management of subcontractors
  - electrical incident investigation and reporting
  - R&D safe work practices
  - program assessments

The goal of consistency

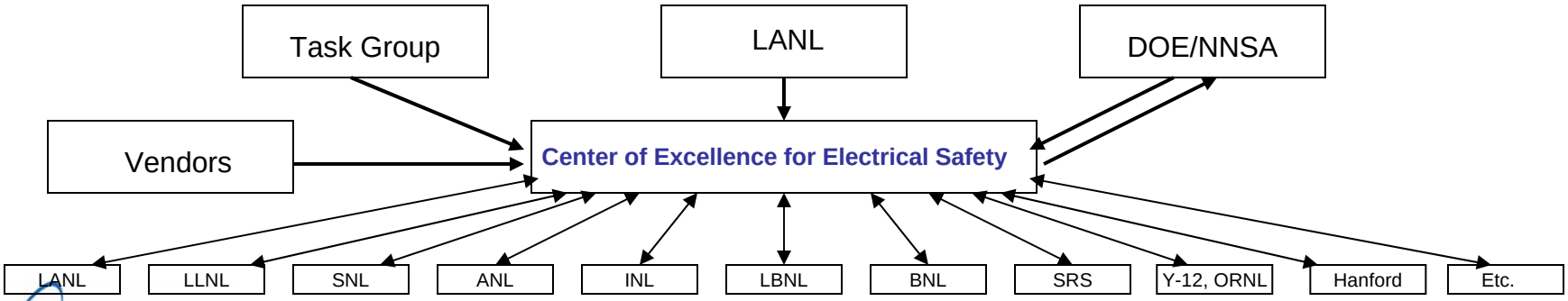
- Consistency across the complex is important to:
  - Minimize resources needed for program development
    - Don’t keep reinventing the same wheel
  - Share best practices and common issues
  - Improve safety across the complex
  - Aid in program assessment
  - Have a robust and defendable program for CFR 851, Electrical section
- Special areas needing focus for consistency are:
  - R&D electrical safety
  - Subcontractor work
  - Implementation of NFPA 70E

Efforts towards consistency

- Annual Electrical Safety Meeting (for over 15 years)
  - held in Las Vegas
  - focused on facility issues
- DOE Electrical Safety Handbook
  - 1998, revised 2004
- R&D Electrical Safety Meeting/Workshop
  - 2004, 2005, 2006
  - 100 participants from 28 sites and site offices
  - major contributions in last two years
- EFCOG Electrical Safety Improvement Project
- New National Standards submissions
- Electrical Safety Task Group
- Center of Excellence for Electrical Safety

Center of Excellence for Electrical Safety

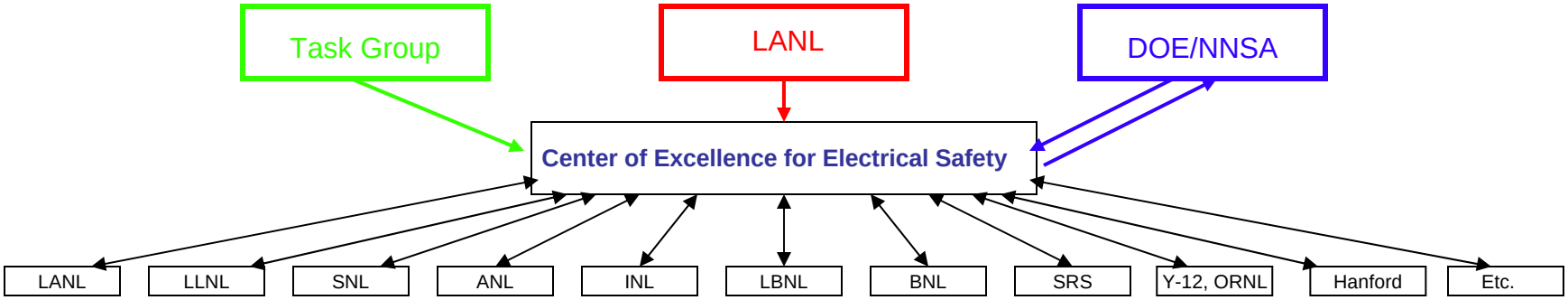
- Work under technical guidance of EFCOG ISM/OSH Electrical Safety Task Group
- Solicit input from all sites, through the Task Group and through direct contact
  - Gather best practices
  - Collect training resources
  - Determine site needs



Individual site Electrical Safety Programs

Organization of Center

- EFCOG ISM/OSH Electrical Safety Task Group Technical Guidance
- LANL Steward
- DOE/NNSA Sponsorship



Center gathers from and provides to site programs

Center Provides to the DOE complex:

- Resources
- Leadership
- Training
- Research

Resources

- Library
  - Texts, articles
  - Codes and standards
  - Videos
  - Training materials
  - DOE electrical safety archives
- Equipment
  - PPE
  - Below surface detection equipment
  - Meters and other verification instruments
  - New technologies for protection of electrical workers
- Laboratories
  - For the use of below surface detection tools
  - Demonstration of PPE and verification instruments
  - Unlisted electrical equipment inspection and approval
- Personnel
  - SMEs to answer questions for other sites

Leadership

- Draws upon national Electrical Safety Task Group
- Annual R&D Electrical Safety Meeting/Workshops
- Involvement and leadership in all EFCOG Electrical Safety Improvement Projects groups
- Members and/or participants in ISA, IEEE, and NFPA committees
- Provide expertise in (from all sites):
  - Event analysis and severity ranking
  - R&D Electrical Safety training
  - Electrical Hazard Classification
  - Managing R&D Electrical Hazards
  - Unlisted Electrical Equipment Approval
  - Subcontractor management

Training

- Provide modules in R&D Electrical Safety Training
- Provide modules and leadership in AHJ Training
- Hands-on training for:
  - Use of PPE
  - Use of detection technologies
  - Hazardous energy control
  - Unlisted electrical equipment inspection and approval
  - Methods for safing R&D equipment (capacitors, magnets, etc.)

Research (for the future!)

- Determine hazards of pulsed and dc arcs
- Test PPE for use around pulsed and dc arcs
- Measure voltage gradients for conductors in contact with water
- Develop standards for Personnel Safety Devices (e.g., ground hooks)

Goals for FY 2007

- Develop Charter, establish relationship with Electrical Safety Task Group
- Develop Website for Center, accessible to complex
- Develop and cultivate communications with all partners, including vendors of electrical safety products
- Provide training materials developed through Electrical Safety Improvement Project and gathered from sites, to complex
- Support Annual Electrical Safety Meeting

Summary

- The Center of Excellence for Electrical Safety:
  - support the national EFCOG ISM/OSH Electrical Safety Task Group
  - gather best practices from other sites, especially in subcontractor electrical safety and management
  - work closely with National Training Center, and other Centers
  - serve as a centralized resource to the complex
  - promote cooperation and communication across the complex
  - aim towards consistency across the complex
  - a great asset to all sites