R&D Electrical Safety at SLAC

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A Brief History of Electrical Safety

- 1880 - first electrical codes (NEC and UL)
- 1945 - first DCE R&D labs
- 1960s - first studies on the effects of electricity
- 1960s - equipment ground implemented
- 1970 - OSHA
- 1970s - GFCIs added to NEC
- 1990 - "tiger teams"
- 1990s - DOE Electrical Safety Handbook started
- 1996 - ISM
- 1998 - DOE Electrical Safety Handbook released
- 2002 - arc fault interrupter in NEC

(NEC 2 pages)

(NEC 711 pages)
Outline

- Introduction
- Electrical Injury Mechanisms
- Electrical Hazard Classification
- SLAC Electrical Safety Program
- Discussion and Summary

Electrical hazards in the R&D laboratory are unique due to:

- the application of many unusual, hazardous forms of electrical energy,
  - voltage (mV to MV)
  - current (mA to MA)
  - waveform (DC, 60 Hz, MHz, GHz, pulsed)
  - stored energy (batteries, capacitors, inductors)

- the requirement to often interact with the system in various states of energization to
  - operate
  - design and build
  - test and observe
  - maintain and/or modify
  - de-energize and verify

- the uniqueness of the laboratory systems making standardization and code application difficult
- unlisted equipment

At home you are a user (operator) of listed (approved) equipment, in a facility (your home) that was inspected and approved by the local Authority Having Jurisdiction (the electrical inspector). You are largely protected by design and are do NOT need to be an electrical worker.
Examples

- The following photos illustrate some of the unique equipment used in a DOE R&D laboratory. These photos are from Los Alamos National Laboratory, but similar equipment is found at SLAC.

- This equipment illustrates the wide variety of electrical hazards found in R&D equipment.
Objectives

- review the types of injury that can result from electrical energy
- be able to classify electrical hazards in your work area
- be familiar with the SLAC Electrical Safety Program, specifically found in the ES&H Manual, Chapter 8
- understand the responsibilities for electrical safety, for each worker, and for other groups of workers
- understand qualification and training requirements
- know the approach to Integrated Safety Management for electrical hazards
- present Lessons Learned throughout the session

Who are you?

| physicists | supervisors | undergraduate students |
| technicans | visiting scientists | material scientists |
| chemists | designers | engineers |
| graduate students | managers |
Approaching Electrical Safety

1. Qualification and Training
2. Scoping the Work
3. Identifying the Electrical Hazard
   - Safe Design
   - Safe Work Practices

4. Evaluation and Improvement

Identifying the Electrical Hazard

1. Understanding the Electrical Injury
2. Classifying the Electrical Hazard
Physiology of electric shock

- What is electric shock?
- What does it do to the human body?
- What kinds of injury result?
- What factors affect the severity of a shock?
- What determines the current level in a shock?
- What to do in case of emergency.

Definitions # 1

- **direct electrical hazard**: A potential source of injury resulting from the flow of electrical current through a person (electrical shocks and burns).
- **indirect electrical hazard**: A potential source of injury resulting from electrical energy that is transformed into other forms of energy:
  - electromagnetic fields (including rf and magnetic fields)
  - light (including infrared, optical, and UV)
  - heat
  - energetic particles and components, electrical explosion
  - ionizing radiation (e.g., x-rays)
  - mechanical movement of electrically driven equipment
  - reflex action from electrical shock
  - fire, including toxic gases
What is Electric Shock?

The passage of electric current through the body from an external source.

Electric shock may be caused by:
- ac
- dc
- rf
- impulse currents.

What is an Electric Arc Blast?

An expanding "fireball" of hot gas, molten metal, and energetic parts that can cause severe burn injury.

Electrical Explosion
Electrical Burn Injury

- no Lockout/Tagout
- no verification
- no PPE

from an energized fluorescent light fixture

R&D Equipment Blows Up!
Injury to the body from electricity.

The Human Body is a Complex Electrical System

The body has elements of
- circuitry
- control
- feedback
- memory
- calculation
- motion
- sensing

It operates at mV and less than mA levels.
Medical Definitions

- burn - The damage received to skin or other tissue by excessive heat. Can be caused by the passage of large electric currents.
- duration - The length of the time interval during which a specified waveform or feature exists. For an electric shock it is the length of time that the victim is exposed to the shock.
- fibrillation - Also known as ventricular fibrillation. Failure of the heart to contract regularly resulting in an irregular often rapid contraction. Death will result if ventricular fibrillation is not stopped and normal contraction of the heart re-initiated.
- let-go-current - The level of current at which a person can release a live wire of his own free will. At currents above the let-go-current muscle contraction prevents voluntary release of the conductor.
- resuscitation - Reviving someone from unconsciousness. Sometimes used equivalently to CPR (Cardiopulmonary Resuscitation)
- shock - Sudden stimulation of nerves and contraction of muscles due to electric current passing through living tissue.

Medical Definitions

- burn
- duration
- fibrillation
- let-go-current
- resuscitation
- shock
Why are we susceptible to injury by electric shock?

During a shock, current:
(1) Interacts with the very small electrical signals that the body uses to control muscular action, and
(2) dissipates energy by resistive heating of body tissues.

The human body has little ability to withstand an electric shock because:
(1) the neural signals are very susceptible to disruption, and
(2) tissue is very sensitive to heat damage.

Electric current passing through the body causes muscle contraction.

Normal nerve impulses are very small electric signals travelling down the neural pathways to the muscle tissues.

An electric shock overrides normal nerve impulses and totally dominates muscle action. This is known as the reflex action.
Heat dissipation inside the body causes burns.

The chemical energy that creates body heat is distributed throughout various organs and muscle tissue and is equivalent to about 6.8 W.

During an electric shock, electrical energy is distributed along a specific pathway involving only a portion of the body, and can easily be 10,000 W/sec locally.

Ventricular Fibrillation

- Ventricular fibrillation occurs when the heart receives an electrical stimulus during the T-wave portion of its cycle. This is the beginning of the repolarization of the ventricular myocardium and the cells are very sensitive to stimulation (25% of the cycle).
- A brief shock (ac, dc, or impulse) is less likely to stimulate the heart.
- A few seconds of 60 Hz ac is the most dangerous.
- DC, impulse, and high frequency ac require considerably more current to cause fibrillation.
Three basic types of injury.

Three types of injury often need to be treated for serious electric shock:

- **Shock** to the nervous system, such as muscle contraction, breathing stoppage, and heart stoppage.

- **Burns** to tissue, especially dangerous if the tissue affected includes organs or bones.

- **Mechanical injury** from reflex action, such as being thrown, or falling.

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### Technical Terms - Parameters and Units

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit</th>
<th>Symbol</th>
<th>Typical Ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>V</td>
<td>Volt</td>
<td>V</td>
<td>mV, V, kW, MV</td>
</tr>
<tr>
<td>Current</td>
<td>I</td>
<td>Ampere</td>
<td>A</td>
<td>mA, A, kA, MA</td>
</tr>
<tr>
<td>Time</td>
<td>t</td>
<td>second</td>
<td>s</td>
<td>ns, µs, s, minutes, hours</td>
</tr>
<tr>
<td>Power</td>
<td>P</td>
<td>Watt</td>
<td>W</td>
<td>mW, W, kW, MW, GW, TW</td>
</tr>
<tr>
<td>Energy</td>
<td>E</td>
<td>Joule</td>
<td>J</td>
<td>MJ, J, kJ, MJ</td>
</tr>
<tr>
<td>Charge</td>
<td>Q</td>
<td>Coulomb</td>
<td>C</td>
<td>mC, C</td>
</tr>
<tr>
<td>Frequency</td>
<td>f</td>
<td>Hertz</td>
<td>Hz</td>
<td>Hz, kHz, MHz, GHz</td>
</tr>
<tr>
<td>Resistance</td>
<td>R</td>
<td>Ohm</td>
<td>Ω</td>
<td>mΩ, Ω, kΩ, MΩ</td>
</tr>
<tr>
<td>Capacitance</td>
<td>C</td>
<td>Farad</td>
<td>F</td>
<td>pF, nF, µF, mF, F</td>
</tr>
<tr>
<td>Inductance</td>
<td>L</td>
<td>Henry</td>
<td>H</td>
<td>mH, H</td>
</tr>
</tbody>
</table>

\[ p = \text{pico} = 10^{-12} \]
\[ n = \text{nano} = 10^{-9} \]
\[ µ = \text{micro} = 10^{-6} \]
\[ G = \text{giga} = 10^{9} \]
\[ m = \text{milli} = 10^{-3} \]
\[ k = \text{kilo} = 10^{3} \]
\[ M = \text{mega} = 10^{6} \]
\[ T = \text{tera} = 10^{12} \]
**Technical Terms - Important relations**

- **power** \( P = VI \)
- **energy** \( E = Pt \)
- **Ohm's Law** \( V = IR \)
- **frequency** \( Hz = \frac{cycles}{s} \)
- **Energy in a capacitor** \( E = \frac{1}{2} CV^2 \)
- **Energy in an inductor** \( E = \frac{1}{2} LI^2 \)

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**Technical Terms - Waveforms**

- **waveform** - the shape of a parameter (such as voltage or current), when displayed as a function of time.
- **alternating current (ac)** - a periodic current, the waveform value of which over a period is zero.
- **direct current (dc)** - usually indicates a constant, non-time-varying current or voltage. It may be positive or negative.
- **pulse** - The variation of a quantity having a normally constant value. An abrupt change in voltage or current, either positive or negative, which conveys information or transfers power to a circuit.
- **impulse** - A pulse that begins and ends within a short time interval. Although the time duration may be short, its high power imparts the current, voltage, and power can be very large.
- **transient** - A momentary surge in a signal or power line. It may produce false signals or triggering impulses and cause insulation of components breakdowns and failures or may result in a prime.
- **radio/frequency (rf)** - A special term for high frequency (megahertz to gigahertz) signals.
Electric shock can have many dangerous effects on the body.

- Muscle contraction, which can:
  - prevent release of the circuit
  - cause serious reflex action resulting in bodily injury
  - 10 mA

- Breathing stops due to:
  - paralysis of the chest muscles
  - nerve damage
  - 50 mA

- Heart malfunction:
  - fibrillation (very difficult to restore normal beating)
  - complete stoppage
  - 100 mA

- Internal burns cause tissue and bone damage due to heating.

- External burns due to the electrical explosion
  - 1 A
  - 250 V & 500 A

Factors affecting the severity of electric shock

- Current - determines muscle, cardiovascular, & brain response

- Voltage - determines skin breakdown (resistance), & current level

- Energy - determines total damage done

- Resistance - with voltage determines current and energy

- Current pathway - defines regions affected
Important Parameters for Electric Shock

\[ I = \frac{V}{R} \]

- Circuit
- Voltage
- Current
- Resistance
- Waveform
- Energy
- Duration

Determines Immediate Impact
Damage Done

NOTE: It is current and energy that directly determine injury.

Comparison of some shocks

<table>
<thead>
<tr>
<th>Form of electricity</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 Hz power</td>
<td>100 mA for 3 seconds - lethal</td>
</tr>
<tr>
<td>dc</td>
<td>500 mA for 3 seconds - lethal</td>
</tr>
<tr>
<td>carpet shock</td>
<td>10 A for 1 µs - harmless</td>
</tr>
<tr>
<td>1 MHz rf</td>
<td>200 mA for seconds - tolerable</td>
</tr>
</tbody>
</table>
Energy - does work, or destroys

How does electrical energy delivered quickly affect me?

<table>
<thead>
<tr>
<th>energy</th>
<th>example</th>
<th>result</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.01 J</td>
<td>a carpet shock</td>
<td>harmless</td>
</tr>
<tr>
<td>0.1 J</td>
<td>stored in the tube of a tv</td>
<td>reflex action</td>
</tr>
<tr>
<td>1 J</td>
<td>a 3 kV cap., size of a C-cell battery</td>
<td>hurts a lot!</td>
</tr>
<tr>
<td>10 J</td>
<td>in a microwave oven</td>
<td>will incapacitate you</td>
</tr>
<tr>
<td>100 J</td>
<td>delivered by a defibrillator</td>
<td>can stop and start heart</td>
</tr>
<tr>
<td>1000 J</td>
<td>energy storage caps, or a utility arc</td>
<td>blows off body parts</td>
</tr>
</tbody>
</table>
Some affects of current waveform on electric shock effects

- AC causes ventricular fibrillation and clamping of the muscles.
- AC sources often are on continuously, increasing the chance for prolonged exposure. Notice: penetration process a big concern
- DC can cause muscle clamping and/or stop the heart.
- RF immediately passes through the skin, and can shock and burn at much lower voltages; also, the burns are deeper.
- Pulsed power capacitive discharges usually involve very large currents, voltages, and energy.

Fibrillation Threshold as a Function of Duration of Shock for AC and DC

![Graph showing Fibrillation Threshold as a Function of Duration of Shock for AC and DC]
Impulse or capacitive discharge shock

Very little research has been done.

10 J has been chosen to be the threshold of dangerous energy by DOE (Jlab uses 5 J)

Over 50 J may be lethal.

Defibrillators use around 200 J.

A brief impulse discharge must occur during the T-wave to stimulate fibrillation and even then it must be a large current.

The most significant danger from capacitive discharge in the laboratory is from the large dissipated energy in a shock. Significant burn injury can result, especially to nerves.

DANGER - Electric Shock

- Electrocution can result from ac, dc, or impulse shock.
- Relatively little current is required for fatal shock.
- Many long-term and permanent effects can result from electric shock.
- Currents above the let-go threshold increase the chance for fatal shock.
- Untreated ventricular fibrillation over 5 minutes is usually fatal or seriously damaging.
- Wet skin or puncturing of the skin significantly lowers the contact resistance leading to an increase in current.
- The higher the voltage the higher the current.
Rescue and Resuscitation from Electric Shock

- If you witness or come upon an electric shock victim, you should perform the following (e.g., as a safety watch):
  - Disconnect the circuit safety
  - Call for help immediately
  - Rescue the victim from the circuit promptly and safely
  - Apply artificial respiration and CPR, if necessary
  - Continue resuscitation until victim revives or medical help arrives
  - Even if apparently recovered, the victim must receive medical attention
  - Report the accident

Classification of the Electrical Hazard

- Controls (engineering and administrative) are established according to the hazard class and risk.
- The hazard class is determined by:
  - the type of work: electrical or electronic, and
  - the combination of voltage and current
- The mode is determined by the nature of the work:
  - de-energized
  - energized with reduced safety and restricted manipulative operations
  - energized with manipulative operations
Electrical Hazard Classification

Classification of Power Sources

\[
P = I \times V
\]

\[
E = P \times t
\]
Approach to Electrical Hazard Classification

Determine power source
- AC - facility power (60 Hz)
  - no energy storage
- R&D power, (dc, energy storage)

Determine voltage
- < 50 V
  - < 75 kVA
  - > 75 kVA
- 50-300 V
  - > 75 kVA
  - > 300 V
- > 30 V
  - > 50 V
  - < 5 mA
  - < 10 J

Voltage, energy
- < 50 V
- > 50 V
- > 30 J-20 kJ
- > 20 kJ

Modes of Electrical Work

- Mode 1 - De-energized
  - external sources of electrical energy disconnected by some positive action (e.g., lockout/tagout)
  - all internal energy sources rendered safe

- Mode 2 - Diagnostics and Testing
  - some or all of the normal protective barriers removed
  - interlocks bypassed
  - measurements, diagnostics, testing, observation
  - no physical moving of conductors and parts near energized conductors

- Mode 3 - Energized
  - the physical movement of energized conductors and parts, or
  - moving parts that are near energized conductors
  - some or all of the normal protective barriers removed
Examples of Electrical Shock

• carpet shock
  - 20 kV, 10 A, 5 μs, 10 mJ, impulse
• car battery
  - 12 V, 500 A, 1 MJ, dc
• outlet
  - 120 V, 20 A, 60 Hz ac
• transmission line
  - 13 kV, 1000 A, 60 Hz ac

More Examples

• computer
  - 12 V, 5 A, dc
  - 120 V, 5 A, 60 Hz ac
• chemistry supply
  - 18 V, 400 A, dc
• photon detector HV supply
  - 5 kV, 1 mA, dc
• magnet supply
  - 5 V, 200 A, dc
• DC HV power supply
  - 20 kV, 1 A, 15 J, dc
Secondary Hazards of Electrical Equipment

• Fire
• X-rays (greater than 10 kV in vacuum)
• optical, UV and IR
• intense electromagnetic fields (dc to 300 GHz)

Important Acronyms

ac  alternating current
AHJ  Authority Having Jurisdiction
ANSI  American National Standards Institute
CFR  Code of Federal Regulations
CPR  Cardiopulmonary Resuscitation
dc  direct current
DOE  Department of Energy
GFCI  ground fault circuit interrupter
GFI  ground fault interrupter = GFCI
IEEE  Institute of Electrical and Electronic Engineers
ISM  Integrated Safety Management
## Important Acronyms - cont.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>NEC</td>
<td>National Electrical Code</td>
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<tr>
<td>NEMA</td>
<td>National Electric Manufacturer's Association</td>
</tr>
<tr>
<td>NESC</td>
<td>National Electrical Safety Code</td>
</tr>
<tr>
<td>NFPA</td>
<td>National Fire Protection Association</td>
</tr>
<tr>
<td>NRTL</td>
<td>Nationally Recognized Testing Laboratory</td>
</tr>
<tr>
<td>OJT</td>
<td>on-the-job training</td>
</tr>
<tr>
<td>OSHA</td>
<td>Occupation Safety and Health Administration</td>
</tr>
<tr>
<td>PPE</td>
<td>personal protective equipment</td>
</tr>
<tr>
<td>rf</td>
<td>radio frequency</td>
</tr>
<tr>
<td>R&amp;D</td>
<td>research and development</td>
</tr>
<tr>
<td>UL</td>
<td>Underwriters Laboratory</td>
</tr>
</tbody>
</table>

## Definitions #2

- **electrical power distribution** - The arrangement of feeders, transformer substations, electrical panelboards and circuit breakers that supply electrical power to end users.

- **electronic** - Pertaining to electrical circuits which use a variety of components (resistors, capacitors, conductors, etc.) to manipulate electrical signals and energy in a desired way. This does not include electrical power distribution, but does include controller and power supplies.

- **qualified person** - Someone recognized by SLAC management as being familiar with the construction and operation of the equipment in question and the hazards involved with the authorized work. Qualification for operating or servicing hazardous devices, systems, and facilities shall be documented by the responsible department head or designee.
Definitions #3

- **first-line protection** - The primary protective system provided to prevent physical contact with energized equipment. Covers, shielding and enclosures are examples of first-line protection.

- **backup protection** - A secondary, redundant, protective system designed to de-energize a device, system, or facility so as to permit safe physical contact by maintenance personnel. A backup protective system must be totally independent of the first-line protection and capable of functioning in the event of total failure of the first-line protective system.

Definitions #4

- **safety watch** - An individual whose sole task is to observe the worker and to quickly de-energize the equipment in case of an emergency and alert emergency personnel. This person must know when and how to de-energize the equipment. This person shall have current cardiopulmonary resuscitation (CPR) training.

- **working alone** - An individual is engaged in work without the presence or attention of another person.
Definitions #5

- **circuit breaker** - A device designed to open and close a circuit by nonautomatic means and to open the circuit automatically on a predetermined overcurrent without damage to itself when properly applied within its rating.

- **ground-fault circuit interrupter** - A device intended for the protection of personnel that functions to de-energize a circuit or portion thereof within an established period of time when a current to ground exceeds the values established for a Class A device (see UL 943).

- **arc-fault circuit interrupter** - A device intended to provide protection from the effects of arc faults by recognizing characteristics unique to arcing and by functioning to de-energize the circuit when an arc fault is detected.

Definitions #6

- **grounding** - A conducting connection, intentional or accidental, between an electrical circuit or equipment and the Earth - or some conducting body that serves as the Earth.

- **grounds, electrical** - Any designated conductor with adequate capacity to carry potential currents to earth. Designated conductors may be building columns or specifically designated ground-network cabling, rack, or chassis ground. Cold water pipes, walkways, and conduits shall not be relied upon as electrical grounds.

- **grounding point** - The high voltage contact point, such as the terminals of a capacitor, where the grounding hook is to make contact so as to release and dissipate a circuit's stored energy. Such a point shall be indicated by a yellow, circular marker.
Definitions #7 - some select definitions from the NEC

- **Authority Having Jurisdiction (AHJ)** - The organization, office, or individual responsible for approving equipment, materials, an installation, or a procedure.

- **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.

- **Listed** - Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that the equipment, material, or services either meets appropriate designated standards or has been tested and found suitable for a specified purpose.

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SLAC Electrical Safety Program

1 Policy
2 Responsibilities
3 Hazards
4 Qualified and Authorized Personnel
5 Training
6 Standards
7 General Requirements for Equipment Safety
8 Safety Requirements for Commonly Used Electrical Equipment
9 Safety Requirements for On-site Electrical Equipment
10 Safe Work Practices

SLAC ESH Manual, Chapter 8, August 2002
Ch. 1 - Electrical Safety Policy

- SLAC complies with OSHA regulations, the NEC, and other established safety codes.
- This program provides the SLAC community with the minimum knowledge of safety and recommended practices.
- Chapter 8 of the ESH Manual is insufficient and other formal study, training, and experience may be required to be qualified.

Ch. 2 - Responsibilities

- Electrical Safety Committee
- Environment, Safety, and Health Division
- Managers and Supervisors
- Personnel
- Safety Watch/Person
Responsibilities of Personnel

- Become acquainted with all potential electrical hazards in the area in which they work.
- Learn and follow the appropriate electrical standards, procedures, and hazard-control methods.
- Consult with appropriate supervisors (your own supervisor and the supervisor of the hazardous system) before undertaking a potentially hazardous electrical operation.
- Notify a supervisor of any condition, person, or behavior which poses a potential electrical hazard.

Responsibilities of Personnel - cont.

- Wear and use appropriate electrical personal protective equipment (PPE).
- Report immediately any electrical shock incident to the SLAC Medical Department and to the appropriate supervisor.
- Complete appropriate electrical safety and lock and tag training.
- Complete training in emergency response procedures, including cardiopulmonary resuscitation (CPR), if performing work on exposed electrical circuitry of more than 50 volts (AC or DC).
Responsibilities of Supervisors

- Be aware of all potentially hazardous electrical activities within their area of responsibility.
- Develop an attitude and awareness of electrical safety in the people they supervise and see that individual safety responsibilities are carried out.
- Ensure that the personnel they direct are knowledgeable and trained in the electrical tasks they are asked to perform.
- Maintain an electrically safety work environment and take corrective action for potentially hazardous operations or conditions.
- Ensure that safe conditions prevail in the area, and that area occupants are properly informed of electrical safety regulations and procedures.
- Ensure that all workers are properly protected by means such as instructions, signs, barriers, electrical personal protective equipment (PPE), and appropriate lock and tag devices.

Responsibilities of Supervisors - cont.

- Ensure that workers assigned to potentially hazardous electrical work are physically and mentally able to perform work.
- Assign a safety watch person when hazardous work is performed.
- Determine if two people are required for an energized work task by CSHA regulations.
- Provide necessary outage time frames so that maintenance personnel can provide periodic electrical maintenance and testing of personnel safety devices, such as electrical interlocks and grounding.
- Plan activities such that work may be performed in a de-energized state whenever possible.
Ch. 3 - Hazards

• covered earlier

Ch. 4 - Qualified and Authorized Personnel

• A qualified person has sufficient understanding of the equipment, device, system, or facility to positively control any hazards it presents.
• determined by the appropriate department head or designee.
• Only those persons who are qualified and authorized may install, fabricate, repair, test, calibrate, or modify electrical wiring, devices, systems, or equipment.
• qualification based on:
  • formal training
  • experience
  • on-the-job training
4.2 Qualifications for Working on Energized Components

- specific operations in which live work is anticipated
- features of the equipment including any specialized configuration
- location of energy-isolating devices
- techniques, tools and PPE used for the specific equipment
- relevant documents such as wiring diagrams, schematics, service manuals, design packages, and operating, testing and calibration procedures
- Systems’ energy control procedures, including energy-isolating devices, grounding and shorting procedures, and other energy control procedures.
- Recordkeeping and logging requirements.

How to be Qualified

- education (formal electrical coursework)
- training (assignment to an electrical training plan)
- experience (on-the-job training and work experience, e.g., 4 years)
- varies for each specific job assignment
- authorized by safety responsible line management
Training Requirements for Qualified Electrical Workers

The degree of training is determined by the risk to the employee. Individuals who work on or near de-energized systems shall receive electrical safety training, but possible to a lesser extent than those who work on energized systems. Training for electrically qualified workers must include, but not limited to, the following:

- Relevant electrical safe-work practices, including lockout/tagout
- PPE, how to determine need, and how to properly use
- Ability to distinguish exposed energized parts from other parts
- Ability to determine nominal voltage, current, power and energy of exposed parts
- Minimum approach distances, flash boundaries, etc.
- CPR

Ch. 5 - Training

- CPR/First Aid
- Electrical Safety for Non-Electrical Workers
- Electrical Safety for R&D Equipment
  - R&D Electrical Safety (4 hrs)
  - Pulsed Power Safety (2 hrs)
  - RF and Microwave Safety (2 hrs)
  - Designing Safe Electrical Equipment (2 hrs)
  - Basics of R&D Grounding and Shielding (EMC/EMI) (2 hrs)
- Electrical Safety, Low and High Voltage
- Lock and Tag Awareness for Affected Employees
- Lock and Tag for the Control of Hazardous Energy

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Government Codes and Standards for Electrical Safety

- Title 29, Parts CFR 1910 and 1926
- NFPA 70 - NEC (National Electrical Code) 2002
- NFPA 70E - Standard for Electrical Safety Requirements for Employee Workplaces 2000
- ASTM, ANSI, and IEEE Standards
- NRTL Standards (e.g., UL)
- SLAC ES&H Manual, Chapter 8 - Electrical Safety
- Other SLAC documents, e.g. Stop-Work (Ch. 2), LO/TO

29 CFR Part 1910 - Occupational Safety and Health Standards

- Subpart I - Personal Protective Equipment
  - 1910.137 - Electrical Protective Equipment
- Subpart J - General Environmental Controls
  - 1910.147 - The control of hazardous energy (lockout/tagout)
- Subpart R - Special Industries
  - 1910.269 - Electric Power Generation, Transmission, and Distribution
- Subpart S - Electrical
  - General
    - 1910.301
  - Design Safety Standards for Electrical Systems
    - 1910.302 - 309
  - Safety-Related Work Practices
    - 1910.331 - 335
  - Definitions
    - 1910.309

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Ch. 7 - General Requirements for Equipment Safety

7.1 Equipment Acceptability
   - NRTL listed and labeled equipment
   - Custom made equipment

7.2 Equipment Safety Practices

7.3 Design and Installation

7.4 Documentation

7.5 Enclosures

7.6 Clearance Around Electrical Equipment

Ch. 8 - Safety Requirements for Commonly Used Electrical Equipment

8.1 Flexible Cords

8.2 Extension Cords

8.3 Power Strips

8.4 Test Benches
Ch. 9 - Safety Requirements for On-site Electrical Equipment

9.1 Ground Fault Circuit Interrupters
9.2 Electrical Cables
9.3 Power Supplies
9.4 Capacitors
9.5 Inductors and Magnets
9.6 Control and Instrumentation
9.7 Anti-Restart Device

Ch. 10 - Safe Work Practices

10.1 General Safety Rules
10.2 Emergency Preparedness
10.3 Safe Energized Work
10.4 Working in Wet Areas and Near Standing Water
10.5 Lock and Tag Procedures
10.6 Resetting Circuit Breakers
10.7 Access to Substations
10.8 Safety Watch Person
10.9 Hi-pot Testing
10.10 Accelerator and Detector Areas
10.11 Two Person Rule

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Integrated Safety Management - for Electrical Hazards

Step 1 - Scope of Electrical Work
Step 2 - Electrical Hazard Assessment
Step 3 - Hazard Mitigation
Step 4 - Safe Electrical Work, General Requirements
Step 5 - Electrical Safety Improvement Process

ISM Step 2 - Electrical Hazard Assessment

• Classify the hazard based on the potential for injury, use the Safety Requirements in Tables 8-2 and 8-3 in the ES&H Manual.
• Determine the Mode of Electrical Work
  • De-energized
  • Energized
• Determine the safe work practice needed, including
  • Qualification requirements
  • PPE
  • Procedures
  • Documentation
  • Alone, 2nd person, or safety watch
Step 3 - Hazard Mitigation

- Hierarchy of Controls
  1. De-energize the circuit, and verify
  2. Engineering controls
     barriers, insulation, interlocks
  3. Administrative controls
     work control, warning signs, access control
     training, SOPs, OSRs, TOSRs, design reviews
  4. Personal Protective Equipment (PPE)
     safety glasses, protective gloves
- Safe-process and documentation approval
- Work authorization

Step 4 - Safe Electrical Work, General Requirements

- Qualified workers
- The 100% rule
- De-energized electrical work
- Working on or near energized electrical equipment
- Two person rule
- Safety watch
  - Personal protective equipment
**Basic Electrical Safety Principles**

- Use only properly grounded or double-insulated equipment
- Don't open enclosures of energized electrical equipment
- Don't attempt to service or repair equipment unless you are trained and authorized to do so.
- Avoid any use of electrical equipment under wet conditions
- Don't use damaged power cords or equipment.
- Minimize your use of extension cord and avoid "Daisy Chains" of cords.
- Understand the importance of and respect lockout and tagout of electrical systems.
- Purchase NRTL listed equipment if possible.

**Safety Measures for Preventing Accidents**

- Ensure that the work is properly planned
  - Identify needed
    - worker skills
    - parts and tools
    - scheduling and access
    - documentation
  - Develop the right engineering and administrative controls to protect the workers
- Personal protective clothing and equipment
- Elevated work (≥ 4 feet above the floor)
- Excavation, digging, floor/ceiling penetrations, and demolition
Additional safety practices:

- Maintain an up-to-date set of documentation for safe operation, maintenance, and testing for work on hazardous equipment.
- Remove clothing and jewelry that might increase the danger of working on electrical or electronic equipment.
- Use protective equipment appropriate to the task.
- Use lockout/tagout procedures whenever appropriate.
- Exclude from hazardous work anyone who appears to be fatigued, ill, emotionally disturbed, or whose performance is otherwise impaired.
- When in doubt, stop and reassess the safety of the situation.

Additional safety practices - cont.

- Conduct training sessions and drills periodically to help prevent accidents and to train people to respond effectively if an accident does occur.
- Preserve ground continuity during operation and testing when appropriate.
- Use appropriate tools with intact insulation
- Use GFCI whenever required or recommended.
- Recognize that equipment combining high voltage (> 10 KV) and vacuum has the potential of becoming a source of x-rays. Be sure that such systems have been reviewed.
General Design Considerations for Equipment

- cable strain-relief
- lighting
- emergency lighting
- flammable and toxic material control
- covers and enclosures
- overload and/or short circuit protection
- conductor overcurrent protection
- power
- rating
- emergency-off switch
- non-standard usage.

An example of an in-house built piece of equipment

- The following example illustrates the dangers created when we build our own equipment, or purchase unlisted equipment from outside sources.
Waste Drum heater

Uniformly heats a waste drum for WIPP shipment to measure hydrogen production, manufactured by another DOE site.

Plug wired incorrectly with wrong cable

- White used for hot
- Red used for neutral
- Black used for ground

Cable was listed BUT for electronic power in cable tray use, not as a power cord for cord connected equipment.
white wired to neutral
black to ground
red to hot
wire nuts, loose wires
Some of the problems

- poor grounds, shock hazard
- heaters could be plugged into wall outlet, runaway
- reversed polarity, neutral fused and switched
- heaters always powered
- no on/off switch, only plug
- poor control labels
- poor shock protection on wiring

Shock and fire hazards!!
THE END

- Thank you for your time.
- Please ask questions now