ELECTRICAL SAFETY MANUAL

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Revision History

Revision	Date Published	Summary
Initial	July 2015	Initial edition – implementation of NFPA 70E-2012, *Standard for Electrical Safety in the Workplace*, and DOE-HDBK-1092-2013, *Electrical Safety Handbook*. Additional material from IEEE Std 3007.3-2012, *Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems*.

1 Introduction

1.1 Purpose

1.1.1 The purpose of this Electrical Safety Manual is to establish Berkeley Lab site-specific electrical safe work practices that meet regulatory requirements and match the types of hazards found on site.

1.1.2 The electrical safe work practices prescribed in this manual are mandatory, unless specifically indicated as a recommended practice.

1.2 Scope

1.2.1 This manual establishes electrical safe work practices for both Qualified Electrical Workers (QEWs) and Non-QEWs.

1.2.2 It includes work on facilities distribution and premises wiring, and commercial and R&D type equipment.

1.2.3 Institutional requirements for the overall Electrical Safety Program are found in Chapter 8, *Electrical Safety Program* and are not repeated in this manual. These include:

a. Scope and structure of the overall Electrical Safety Program

b. Roles and responsibilities, including Electrical Safety Officers and Electrical Safety Advocates

c. Electrical Authority Having Jurisdiction (AHJ)

d. Training and qualification requirements

e. Emergency response to an electrical shock incident

f. Electrical incident severity score calculation

g. Subcontractor requirements

1.3 Regulatory Drivers

1.3.1 DOE 10 CFR 851, *Worker Safety and Health Program*

1.3.2 NFPA 70, *National Electrical Code (NEC)*, 2011 edition

1.3.3 NFPA 70E, *Standard for Electrical Safety in the Workplace,* 2012 edition

1.3.4 OSHA 29 CFR 1910.7, *Definition and requirements for a nationally recognized testing laboratory*

1.3.5 OSHA 29 CFR 1910.132, *Personal Protective Equipment*

1.3.6 OSHA 29 CFR 1910.137, *Electrical protective devices*

1.3.7 OSHA 29 CFR 1910 Subpart S (.301-.399), *Electrical (General Industry)*

1.3.8 OSHA 29 CFR 1926 Subpart K (.400-.449), *Electrical (Construction)*

1.3.9 OSHA 29 CFR 1910.269, *Electric Power Generation, Transmission, and Distribution*

1.4 Format

1.4.1 The Electrical Safety Manual is divided into three Parts:

a. Part I: Electrical Hazards

b. Part II: Electrical Safe Work Practices

c. Part III: Acronyms, Definitions and Appendices

1.4.2 While most of this manual is written for people with an electrical background, Section 5, *General Electrical Safety for All Persons*, is written with the non-QEW in mind. Should the reader require help in understanding any part of this manual, contact an Electrical Safety Advocate, an Electrical Safety Officer, or the EHS Electrical Safety Group for assistance. You can also direct any questions to electricalsafety@lbl.gov.

1.4.3 For more information, including field guides and other useful tools for implementing this manual, go to http://electricalsafety.lbl.gov.

PART I – ELECTRICAL HAZARDS

2 Electrical Hazards

2.1 Scope

2.1.1 There are numerous injury mechanisms from exposure of a worker to electrical energy. This section, extracted from the DOE Electrical Safety Handbook, briefly presents the various types of electrical hazards, injuries that can result from those hazards, and a classification system with thresholds to trigger various controls.

2.2 Electrical Shock

2.2.1 Electricity is one of the most commonly encountered hazards in any facility. Under normal conditions, safety features (engineering controls) built into electrical equipment protect workers from shock. Shock is the flow of electrical current through any portion of the worker's body from an external source. Accidents can occur in which contact with electricity results in serious injury or death.

2.2.2 Most electrical systems establish a voltage reference point by connecting a portion of the system to an earth ground. Because these systems use conductors that have electrical potential (voltage) with respect to ground, a shock hazard exists for workers who are in contact with the earth and exposed to the conductors. If a person comes in contact with an energized (ungrounded) conductor, while also in contact with a grounded object, an alternate path to ground is formed in which current passes through his or her body.

2.2.3 The effects of electric current on the human body depend on many variables, including the:

a. Amount of current

b. Waveform of the current (e.g., DC, 60 Hz AC, RF, impulse)

c. Current's pathway through the body (determined by contact location and internal body chemistry)

d. Duration of shock

e. Energy deposited into the body

2.2.4 The amount of current passing through the body depends on:

a. Voltage driving the current through the body

b. Circuit characteristics (impedance, stored electrical energy)

c. Frequency of the current

d. Contact resistance and internal resistance of the body

e. Environmental conditions affecting the body's contact resistance

Condition	Resistance (Ohms)	
	Dry	Wet
Finger touch	40,000 to 1,000,000	4,000 to 15,000
Hand holding wire	15,000 to 50,000	3,000 to 6,000
Finger-thumb grasp	10,000 to 30,000	2,000 to 5,000
Hand holding pliers	5,000 to 10,000	1,000 to 3,000
Palm touch	3,000 to 8,000	1,000 to 2,000
Hand around 1.5 in pipe or drill handle	1,000 to 3,000	500 to 1,500
Two hands around 1.5 in pipe	500 to 1,500	250 to 750
Hand immersed	-	200 to 500
Foot immersed	-	100 to 300
Human body, internal, excluding skin ohms	200 to 1,000	

Table 2.2.4a – Human resistance values for various skin-contact conditions[1]

Material	Resistance (Ohms)
Rubber gloves or soles	>20,000,000
Dry concrete above grade	1,000,000 to 5,000,000
Dry concrete on grade	200,000 to 1,000,000

[1] Source: IEEE Std 3007.3-2012 Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems

Leather sole, dry, including foot	100,000 to 500,000
Leather sole, damp, including foot	5,000 to 20,000
Wet concrete on grade	1,000 to 5,000

Table 2.2.4b – Resistance values for 130 cm^2 areas of various materials[2]

2.2.5 The heart and brain are the parts of the body most vulnerable to electric shock. Some research shows that fatal ventricular fibrillation (disruption of the heart's rhythmic pumping action) can be initiated by a current flow of as little as 70 milliamperes (mA). Without immediate emergency resuscitation, electrical shock may cause a fatality from direct paralysis of the respiratory system, disruption of rhythmic pumping action, or immediate heart stoppage. Severe injuries, such as deep internal burns, can occur, even if the current does not pass through vital organs or the central nervous system. Specific values for hazardous voltages and for hazardous current flow through the body are not completely reliable because of physiological differences between people.

Current (60 Hz)	Physiological phenomena	Feeling or lethality
<1.0 mA	None	Imperceptible
1.0 mA	Perception threshold	-
0.5 mA – 2.0 mA	-	Mild sensation
1.0 mA – 4.0 mA	-	Painful sensation
6.0 mA – 22 mA	Paralysis threshold of arms	Cannot release hand grip. If no grip, victim may be thrown clear. (May progress to higher current and be fatal.)
18 mA – 30 mA	Respiratory paralysis	Stoppage of breathing (frequently fatal).
90 mA	Fibrillation threshold, 0.5% (greater than or equal to 3 sec exposure)	Heart action discoordinated (probably fatal).

[2] Source: IEEE Std 3007.3-2012 Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems

250 mA	Fibrillation threshold, 99.5% (greater than or equal to 3 sec exposure)	Heart action discoordinated (probably fatal).
4 A	Heart paralysis threshold (no fibrillation)	Heart stops for duration of current passage. For short shocks, heart may restart on interruption of current (usually not fatal from heart dysfunction).
> 5 A	Tissue burning	Not fatal unless vital organs are burned.

Table 2.2.5 – Current Range and Effect on a 150 lbs. Person[3]

2.2.6 There are five principal electrical waveforms of interest that cause various responses to electrical shock:

a. Alternating current (AC) power frequencies

b. Direct current (DC)

c. Sub radio frequencies (sub RF) 1 Hz – 5 kHz

d. Radio frequencies (RF) 5 kHz – 100 MHz

e. Impulse shock (such as from a capacitor circuit)

2.2.7 AC Response:

a. The most dangerous are AC power frequencies, typically 60 hertz (Hz). Exposure to current at these frequencies causes ventricular fibrillation at the lowest thresholds and causes severe contraction of the muscles with a possible no-let-go response.

[3] Source: IEEE Std 3007.3-2012 Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems

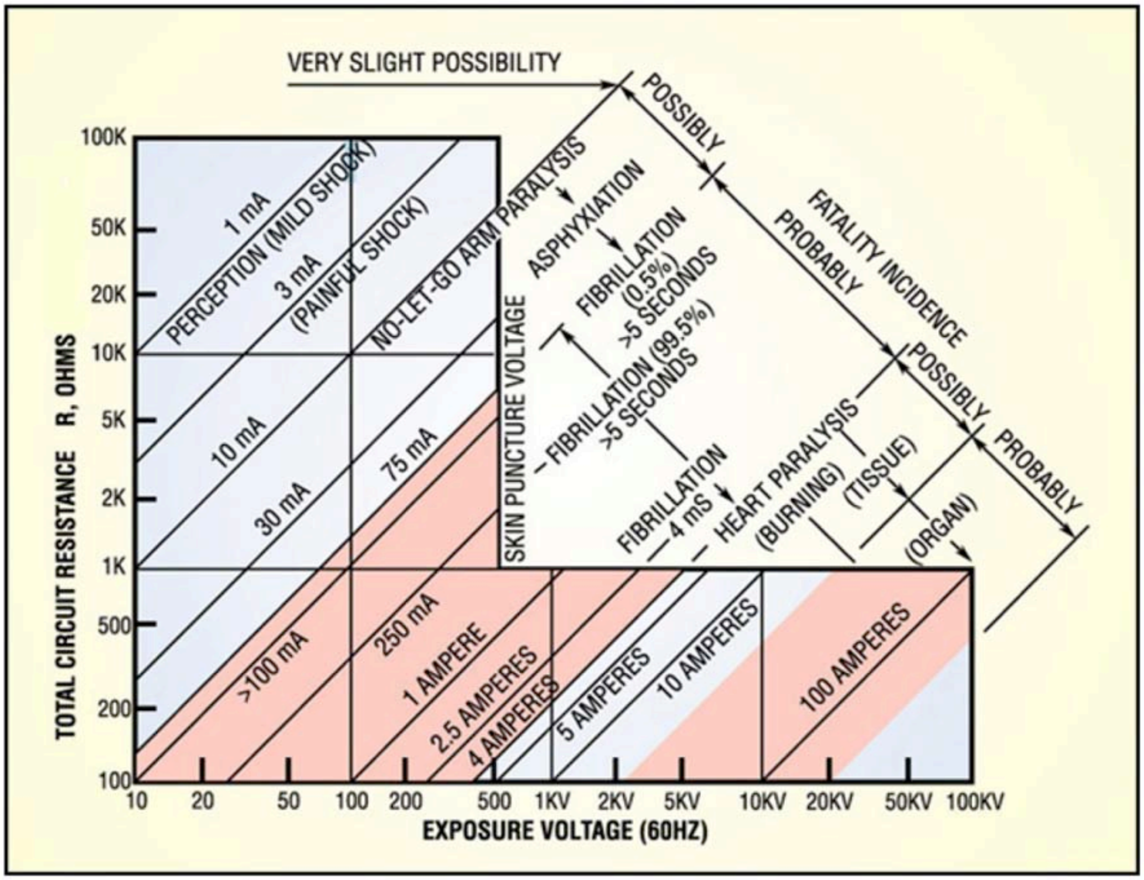


Fig 2.2.7 – Combined physiological response to the effects of resistance and voltage[4]

b. Radiofrequency waveforms (5 kilohertz (kHz) to 100 megahertz (MHz)) have decreasing neurological effects with increasing frequency, but energy deposited results in tissue burning.

2.2.8 DC Response:

a. Exposure to DC electric currents can also cause a muscle response at first contact and when releasing, as well as heart fatigue and failure at high enough current levels.

2.2.9 Body Resistance:

a. The resistance of the body is much less if the skin is punctured by a shock above the skin breakdown threshold (400 to 500 V). This allows higher current flow through the body, resulting in more damage. The amount and duration of current flow determines the severity of the reflex action, the amount of damage to the heart, and neurological and other tissue.

[4] Source: IEEE Std 3007.3-2012 Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems

2.2.10 Reflex action:

a. Reflex action occurs when electric current causes a violent contraction of the muscles. Such contraction can result in violent recoil, resulting in falling from heights, recoiling into a nearby hazard, or violent muscle contractions resulting in broken bones, torn ligaments, or dislocated joints. Reflex action is enhanced by high-voltage shock as the energy can be delivered more quickly from higher instantaneous currents.

2.2.11 Let-Go Threshold:

a. The so called no-let-go response occurs when continuous shock current keeps the muscles violently contracting such that the victim is clutching the conductor without any ability to release. This only happens with AC waveforms.

2.2.12 Shock Thresholds:

a. Because of the effects of the waveform on the body's response, the thresholds for acceptable shock vary, depending on the form of the electricity. Acceptable means that below these thresholds there is no injury, and above these thresholds there could be injury.

b. The thresholds are listed in Table 2.2.12 (and repeated in Table 6.2.3) and are found embedded in the hazard classification charts in Sections 3.3-3.8. The threshold values are based on available research and theoretical data. The hazard class values reflect the consensus agreement of a task group that developed the process, based on the collective knowledge and experience. The values should not be considered absolute, but guidance when applying effective hazard analysis to a particular task.

Source	**Includes**	**Thresholds**	**Hazard Classes (see section 3)**
AC	50-60 Hz nominal	≥ 50 V and ≥ 5 mA	1.2, 1.3, 1.4, 1.5
DC	All	≥ 100 V and ≥ 40 mA	2.2c, 2.2d, 2.3, 2.4
Capacitors	All	≥ 100 V and ≥ 1 J, or ≥ 400 V and ≥ 0.25 J	3.2b, 3.2c, 3.3b, 3.3c, 3.3d, 3.4b, 3.4c
Batteries	Lead-Acid and Lithium Ion	≥ 100 V	Could be in any Class, 4.0, 4.1, 4.2, 4.3

Source	Includes	Thresholds	Hazard Classes (see section 3)
Sub-RF	1 Hz to 3 kHz (excluding 50-60 Hz nominal)	≥ 50 V and ≥ 5 mA	6.2a, 6.2b, 6.2c, 6.3, 6.4
RF	3 kHz to 100 MHz	A function of frequency	5.2a, 5.2b

Table 2.2.12 – Thresholds for defining shock hazards

c. Table notes:

- It is possible for a worker to be exposed to more than one shock hazard at any given location (e.g. multiple types of sources).
- There may be other electrical hazards below the above shock thresholds (e.g., a thermal burn hazard-see Table 2.3.5).
- Injuries may result from startle reactions due to contact with energized components, even though the source energy is too low to do physical damage, such as high-voltage/low-current circuits (e.g., Classes 2.1d and 3.1d).
- Shock and burn hazards from induced and contact RF currents become negligible above 100 MHz (but radiated hazards still exist).

2.3 Electrical Burn

2.3.1 Burns suffered in electrical accidents are of three basic types – electrical current burns, arc burns, and thermal contact burns. The cause of each type of burn is different, and prevention necessitates different controls.

2.3.2 Electrical Current Burns

a. In electrical current burns, tissue damage (whether skin-level or internal) occurs because the body is unable to dissipate the heat from the current flow.

b. Typically, electrical current burns are slow to heal. Such electrical burns result from shock currents, and thus adhering to the shock current thresholds in Table 2.2.12 should prevent electrical current burns.

2.3.3 Arc Flash Burns

a. Arc flash burns are caused by electric arcs and are similar to heat burns from high-temperature sources. Temperatures generated by electric arcs can melt nearby material, vaporize metal in close vicinity, and burn flesh and ignite clothing at distances of several meters, depending on the energy deposited into the arc. The arc can be a stable low-voltage arc, such as in an arc welder, or a short-circuit arc at higher voltage, resulting in an arc flash and/or arc blast. Such an expanding arc can ignite clothing and/or cause severe burns at a distance from inches to feet.

b. There are four types of arc flash:
   - Arc in open air: this type of arc is mostly infrared radiation as opposed to plasma and typically occurs on power lines in front of the worker. The gases are expanding in relatively all directions equally at once like a sphere. These gases can ignite clothing and cause skin burns as can the infrared radiation. This is the least invasive arc but the most easily measured. It is used in all ASTM test setups to test arc-rated materials.
   - Arc in a box: This type is much more dangerous than an arc in open air. With an arc in a box, all of the energy is concentrated in a focused path—usually straight out the doors where you will be standing. This is typical of nearly all arc flash events in industrial electrical equipment (MCC's, panelboards, switchgear, meter sockets, etc.)
   - Arc plasma convective flow: a sustained arc flash event can be driven by the magnetic forces on the plasma cloud, forcing it to travel to the busbar tips, in a direction away from the power source. At the tips it forcefully ejects plasma in a convective flow. This flow can be highly directional, and can also be redirected by bouncing off metal surfaces. The resulting convective flow can lead to very high thermal concentration of the incident energy at a farther distance as opposed to the uniform spread calculated in the arc in open air and the arc in a box scenarios. While the result can exceed the rating of arc flash PPE, it can also be countered by proper body positioning.
   - High voltage skin surface tracking arc: a high voltage shock event can sometimes lead to a tracking arc, where the current flows along the surface or just above the skin instead of through the body. In this case there is no metal plasma effect, just the thermal infrared burn from the arc itself. However, this type of arc can propagate underneath the arc flash PPE and ignite flammable undergarments, leading to very serious whole body burns.

c. The arc flash boundary is defined to characterize the distance at which this injury mechanism is severe. Hazard classes that include arc flash hazards are shown in Table 2.3.3. The current values are the short circuit available currents, or fault currents. The threshold values are based on available research and theoretical data. The hazard class values reflect the consensus agreement of the task group that developed the process based on the collective knowledge and experience. The values should not be considered absolute, but, rather as guidance when applying effective hazard analysis to a particular task.

Source	Includes	Thresholds	Hazard Classes (see section 3)
60 Hz power	60 Hz	<250 V and the transformer supplying the circuit is rated >125 kVA <250 V and the circuit is supplied by more than one transformer ≥ 250 V	1.2, 1.3, 1.4, 1.5
Sub-RF	1–3 kHz	≥ 250 V and ≥ 500 A	6.4
DC	All	≥ 100 V and ≥ 500 A	2.4
Capacitors	All	≥ 100 V and ≥ 10 kJ	3.4b, 3.4d
Batteries	All	≥ 100 V and ≥ 500 A	4.3
RF	NA	NA	

Table 2.3.3 – Thresholds for defining arc flash hazards

2.3.4 Arc Blast Hazards

d. A rapid delivery of electrical energy into an arc can cause additional hazards not covered by arc flash hazards. The acoustical shock wave, or arc blast pressure wave, can burst eardrums at lower levels and can cause cardiac arrest at high enough levels.

e. In addition, high currents (> 100 kA) can cause strong magnetic forces on current-carrying conductors, which can lead to equipment destruction, or the whipping of conductors. Such arc blast hazards are of particular concern in high-energy facility power circuits (Classes 1.3d, 1.4, and 1.5) and large capacitor banks (Class 3.4d).

2.3.5 Thermal Contact Burns

a. Thermal contact burns are those that occur when skin comes into contact with the hot surfaces of overheated electrical conductors, including conductive tools and jewelry. This injury results from close proximity to a high-current source with a conductive object.

b. Thermal burns can occur from low-voltage/high-current systems that do not present shock or arc flash hazards, and controls should be considered. The controls to prevent injury from shock and arc flash should also protect against thermal contact burn.

c. High-current hazard classes with thermal burn hazards are shown in Table 2.3.5. The threshold values are based on available research and theoretical data. The values are calculated to raise the temperature of the skin to a level that would cause a second-degree burn using the Stoll Curve at a time of two seconds. The hazard class values reflect the consensus agreement of the task group that developed the process based on the collective knowledge and experience. The values should not be considered absolute, but guidance when applying effective hazard analysis to a particular task.

Source	Includes	Thresholds	Hazard Classes (see section 3)
Sub-RF	1–3 kHz	<50 V and >1000 W	6.2a
DC	All	>100 V and >1000 W	2.2a, 2.2b
Capacitors	All	<100 V and >100 J	3.2a, 3.3a, 3.4a
Batteries	All	<100 V and >1000 W	4.2, 4.3
RF	NA	NA	NA

Table 2.3.5 – Thermal contact burn hazards, not included in shock and arc flash hazards

2.4 Delayed Effects

2.4.1 Damage to the internal tissues may not be apparent immediately after contact with electrical current. Delayed swelling and irritation of internal tissues are possible. In addition, imperceptible heart arrhythmia can progress to ventricular fibrillation.

2.4.2 In some cases, workers have died two to four hours after what appeared to be a mild electrical shock. Immediate medical attention may prevent death or minimize permanent injury. All electrical shocks should be reported immediately.

2.5 Battery Hazards

2.5.1 During maintenance or other work on batteries and battery banks, there are electrical and physical hazards that should be considered. In addition, when working near or on flooded lead-acid storage batteries additional chemical and explosion hazards should be considered.

2.5.2 The hazards associated with various types of batteries and battery banks include:

a. Electric shock;

b. Burns and shrapnel-related injuries from a short circuit;

c. Chemical burns from electrolyte spills or from battery surface contamination;

d. Fire or explosion due to hydrogen;

e. Physical injury from lifting or handling the cells; or

f. Fire from overheated electrical components.

2.6 Other Hazards

2.6.1 Low-Voltage Circuits

a. Low-voltage circuits, which are not hazardous themselves, are frequently used adjacent to hazardous circuits. A minor shock can cause a worker to rebound into the hazardous circuit.

b. Such an involuntary reaction may also result in bruises, bone fractures, and even death from collisions or falls. The hazard is due to the secondary effects of the reflex action.

2.6.2 Operating Electrical Disconnects

a. An arc may form when a short circuit occurs between two conductors of differing potential, or when two conductors carrying current are separated, such as a safety switch attempting to interrupt the current. If the current involved is high enough, the arc can cause injury, ignite flammable materials or initiate an explosion in combustible or explosive atmospheres.

b. Injury to personnel can result from the arc flash, or arc blast, resulting in severe burns to exposed skin, or ignition of clothing. Equipment or conductors that overheat, due to overload, may ignite flammable materials. Extremely high-energy arcs can cause an arc blast that sends shrapnel flying in all directions.

2.6.3 R&D Electrical Equipment

a. Analyzing electrical hazards associated with R&D equipment may present challenges beyond that associated with standard electrical distribution equipment. Some R&D equipment is custom designed and built and may need specific qualifications for workers that operate or maintain the equipment. An uncommon or unique design can be difficult to analyze for hazard identification.

b. Regardless, the hazard analysis should include shock, potential arc or thermal sources. Acoustic shock wave, pressure shock wave and shrapnel are potential hazards that should be considered as well. Once the hazards have been identified, a risk mitigation plan should be developed.

c. Personnel working on electrical equipment should be specifically qualified through training specific to the work to be done. The scope of such additional training depends on the hazards associated with the equipment.

3 Electrical Hazard Classification

3.1 Explanation of the electrical hazard classification structure

3.1.1 The electrical hazard classification charts cover eight broad categories: 50-60 Hz, DC, capacitors, batteries, Sub-RF, RF, inductors, and photovoltaic. Table 3.2 shows these eight major categories with a pointer to the figure where each category is broken into the individual classes. These classes, taken collectively, represent the electrical hazards found in electrical equipment.

3.1.2 All classes should be considered when identifying the hazards associated with any piece of electrical equipment. A single piece of equipment may have multiple electrical hazard classifications, and the combination of hazards must be addressed by appropriate safety-related work practices.

3.1.3 To aid hazard identification, each chart has cross-reference notes in the upper right hand corner. For example, the DC chart has cross-reference notes to capacitance, inductance, Sub-RF, battery, and 50-60 Hz hazard charts. Workers shall have a thorough understanding of the equipment they are analyzing for hazards. Consulting manuals and schematics and speaking with factory service representatives and electrical SMEs are ways to ensure that all of the hazards are fully understood and that all the pertinent classes are taken into account.

3.1.4 Some guidelines on use of the hazard classification charts are provided, below. They are general, and there may be exceptions to each one:

a. If these guidelines and the equipment are not understood, an SME should be consulted.

b. All equipment gets its power from 50-60 Hz (Classes 1.x) or batteries (Classes 4.x). Thus, all equipment starts with one of those classes.

c. Most small appliances, hand tools, and portable laboratory equipment plugs into Class 1.2. In general, if it can be carried, it most likely it uses 120 to 240 V.

d. Larger facility and laboratory equipment may use up to 480 V (Class 1.3). Often, if it is a large motor, or consumes significant power, it may be Class 1.3.

e. DC power supplies need to be evaluated for both DC (Class 2.x) and Capacitance (Class 3.x).

f. All UPSs have hazards in Classes 4.x as well as 1.x, since they usually are tied into facility power (input), and produce facility type power (output).

3.1.5 The colors used in each hazard Class box are organized in increasing hazard: blue, green, yellow, red, and maroon. Some general statements can be made about each color. There may be exceptions.

Light blue and white boxes are not hazard classes, but are decision points.

A blue Class (X.0) indicates no hazard, and no engineering or administrative controls are needed.

A green Class (X.1) indicates little to no hazards, few, or no, engineering or administrative controls are needed.

A yellow Class (X.2) indicates injury or death could occur by close proximity or contact; often the hazard is shock or contact burn. Engineering controls are necessary for operation (e.g., listing or equipment approval), and administrative controls are necessary for electrical work in this Class.

A red Class (X.3) indicates injury or death could occur by proximity or contact; often the hazard is shock, contact burn, or arc-flash burn; engineering controls are necessary for operation (e.g., listing or equipment approval), and administrative controls are necessary for electrical work in this Class.

Maroon Class (X.4 and X.5) is the highest level of risk; significant engineering and administrative controls are necessary to manage the hazard in these classes.

Gray, Class 3.1c, takes the user outside of electrical safety controls, as the primary hazard is chemical explosion.

3.1.6 Modes of work (for a description of Modes of work, see 6.4-6.7):

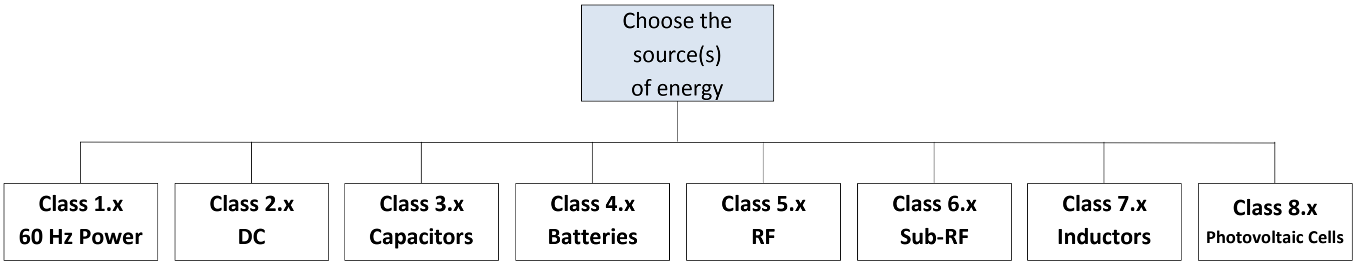
a. Mode 0 – Electrically Safe Work Condition

b. Mode 1 – Establishing an Electrically Safe Work Condition

c. Mode 2 – Energized Diagnostics (Testing & Troubleshooting)

d. Mode 3 – Energized Repair Work (EEWP)

3.2 Classification Matrix



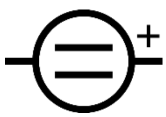
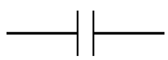
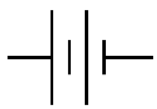
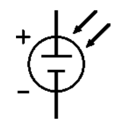
Class 1.x	Class 2.x	Class 3.x	Class 4.x	Class 5.x	Class 6.x	Class 7.x	Class 8.x
							
50-60 Hz Power	DC	Capacitors	Batteries	RF	Sub-RF	Inductors	Photovoltaic Cells
See Fig. 3.3	See Fig. 3.4	See Fig. 3.5.a-b	See Fig. 3.6	See Fig. 3.7	See Fig. 3.8	future updates	future updates

Table 3.2 – Complete Electrical Hazard Classification System Showing Eight Major Classes

3.3 Hazard Class 1.x, 50-60 Hz Nominal Power

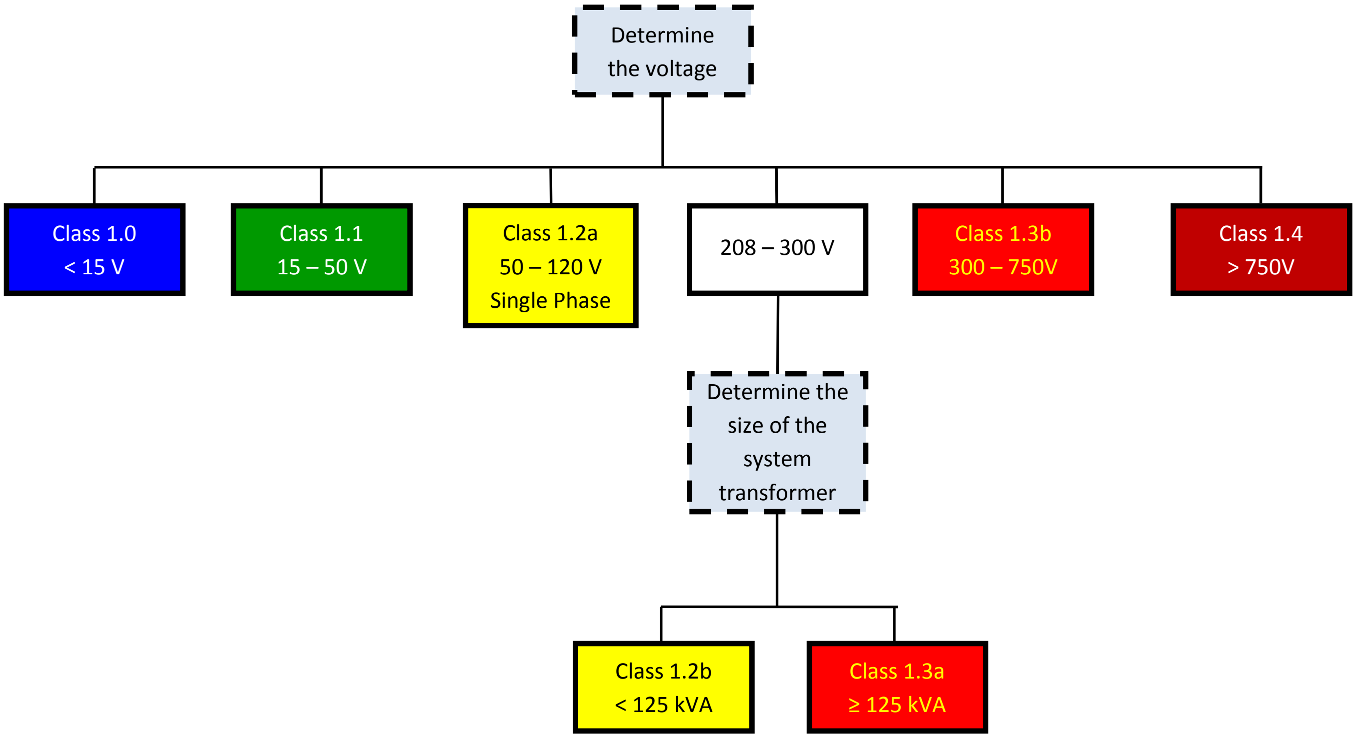


Fig. 3.3. Hazard Classes 1.x, for 50-60 Hz Nominal Power

Notes on use:

1. The voltage is the root mean square (rms) voltage.
2. For current limited 50-60 Hz circuits (≤5 mA), use hazard Class 6.x, Sub-RF.

Table 3.3. Control Table for Work in Hazard Classes 1.x, 50-60 Hz AC Nominal Power

Class	Mode	Two-Person	QEW Level	Work Control	PPE
1.0 <15 V	All	Alone	Non-QEW	None	None
1.1 15–50 V	All	Alone	Non-QEW	None	None
1.2a 50–120 V Single Phase	0	Alone	QEW 1	LOTO	None
	1	Alone		LOTO	Shock[2]
	2	Standby Person[1]		YES	
	3	Safety Watch		YES, EEWP	
1.2b 208–300 V 3-Phase <125 kVA	0	Alone	QEW 1	LOTO	None
	1	Alone		LOTO	Shock[2]
	2	Standby Person[1]		YES	
	3	Safety Watch		YES, EEWP	
1.3a 208–300 V ≥125 kVA	0	Alone	QEW 2	LOTO	None
	1	Standby Person		YES	Shock[2], Arc Flash[3]
	2	Safety Watch		YES	
	3	Safety Watch		YES, EEWP	
1.3b 300–750 V	0	Alone	QEW 2	LOTO	None
	1	Standby Person		LOTO	Shock[2], Arc Flash[3]
	2	Safety Watch		YES	
	3	Safety Watch		YES, EEWP	
1.4 >750 V	0	Alone	QEW 3	LOTO	None
	1	Standby Person		LOTO, ESWP	Shock[2], Arc Flash[3]
	2	Safety Watch		ESWP	
	3	Safety Watch		YES, EEWP	

[1] Mode 2 in Class 1.2 may be performed alone, if proper voltage rated gloves and leather protectors are worn.
[2] Determine PPE by performing a shock hazard analysis using methods covered in Section 7.1.
[3] Determine PPE by performing an arc flash hazard analysis using methods covered in Section 8.1.

3.4 Hazard Class 2.x, DC

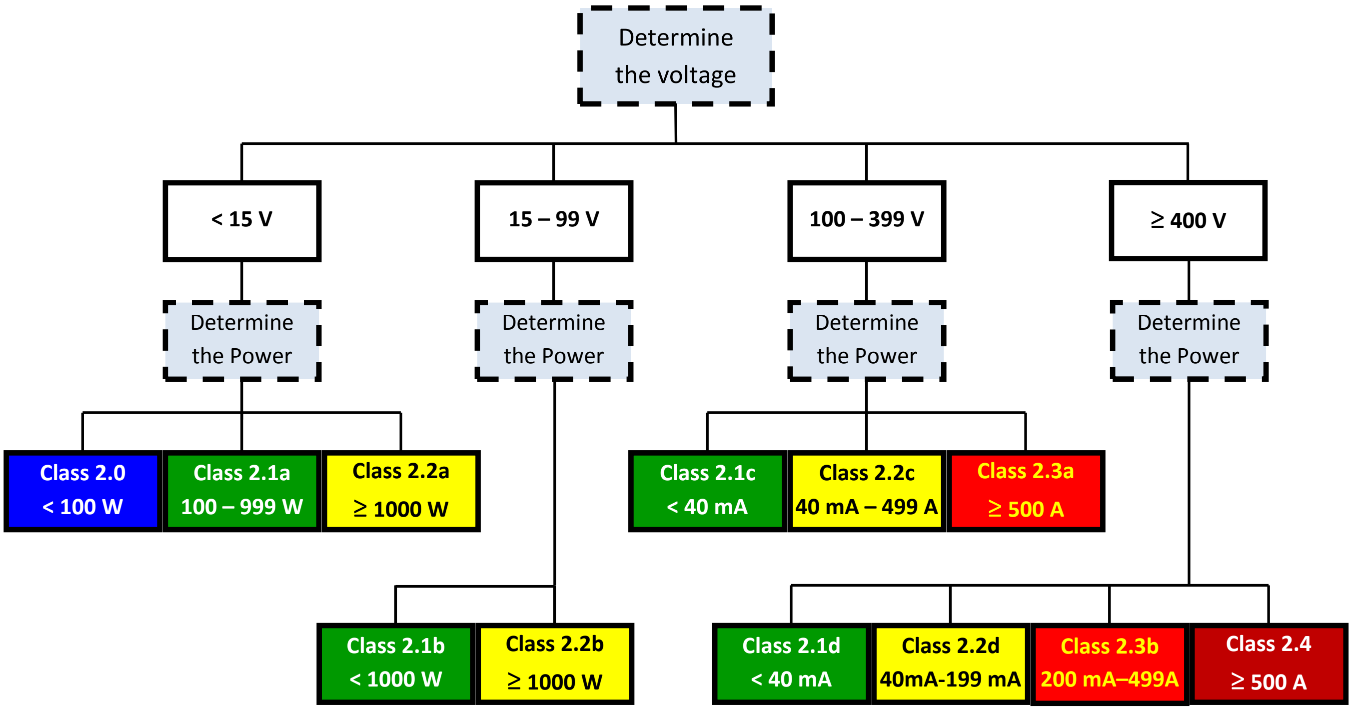


Fig. 3.4 Hazard Classes 2.x, DC

Notes on use:

1. The voltage is the DC voltage.
2. Power is available short-circuit power.
3. Current is available short-circuit current.
4. Most equipment supplying DC also needs to be evaluated for capacitance hazards in Class 3.x.

Table 3.4. Control Table for Work in Hazard Classes 2.x, DC

Class	Mode	Two-Person	QEW Level	Work Control	PPE
2.0 ≤15 V, ≤100 W	All	Alone	Non-QEW	None	None
2.1a,b,c,d ≤100 V, ≤1 kW or >100 V, ≤40 mA	All	Alone	Non-QEW	None	None
2.2a ≤15 V >1 kW	All	Alone	Non-QEW	None	None
2.2b 15–100 V >1 kW	All	Alone	Non-QEW	LOTO	None
		Alone		LOTO	Insulated tools, gloves
		Alone		NO	Insulated tools, gloves
		Alone		NO	Insulated tools, gloves
2.2c 100–400 V 40 mA–500 A	0	Alone	QEW 1	LOTO	None
	1	Alone		LOTO	Shock[1]
	2	Standby Person		YES	
	3[3]	Safety Watch		YES, EEWP	
2.2d >400 V 40–200 mA	0	Alone	QEW 1	LOTO	None
	1	Alone		LOTO	Shock[1]
	2	Standby Person		YES	
	3[3]	Safety Watch		YES, EEWP	
2.3a 100–400 V >500 A	0	Alone	QEW 1	LOTO	None
	1	Standby Person		LOTO	Shock[1], Arc Flash[2]
	2[3]	Safety Watch		YES	
	3[4]	Safety Watch		YES, EEWP	
2.3b >400 V 200 mA–500 A	0	Alone	QEW 2	LOTO	None
	1	Standby Person		LOTO	Shock[1], Arc Flash[2]
	2[3]	Safety Watch		YES	
	3[4]	Safety Watch		YES, EEWP	
2.4 >400 V >500 A	0	Alone	QEW 2	LOTO	None
	1	Standby Person		LOTO	Shock[1], Arc Flash[2]
	2[4]	Safety Watch		YES	
	3[4]	Safety Watch		YES, EEWP	

[1] Determine PPE by performing a shock hazard analysis using methods covered in Section 7.1.
[2] Determine PPE by performing an arc flash hazard analysis using methods covered in Section 8.1.

e. [3] DO NOT move probes while energized.

f. [4] This mode of work should be avoided.

3.5 Hazard Class 3.x, Capacitors

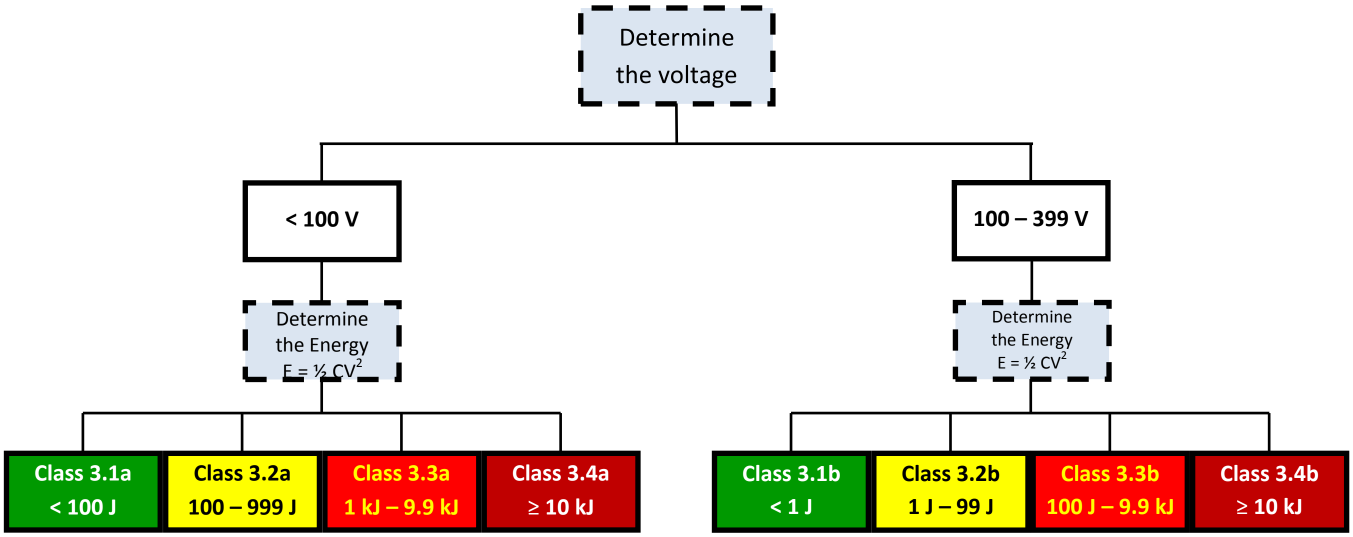


Fig. 3.5a – Hazard Classes 3.x, Capacitors, <400 V

Notes on use:

1. Voltage is peak of the AC, peak impulse or DC maximum charge voltage on the capacitor.
2. Energy is maximum energy stored in the capacitor as determined by $E = ½ CV^2$.
3. The hazards for less than 100 V, Classes 3.2a, 3.3a, 3.4a, are high current through a short circuit, such as tools and jewelry.
4. The hazards for 100 – 399 V, Classes 3.2b, 3.3b, 3.4b, are high current through a short circuit, and a shock hazard.
5. Class 3.4b has an added hazard of mechanical damage due to high currents and strong pulsed magnetic forces during a short circuit.

Table 3.5a. Control Table for Work in Hazard Classes 3.x, Capacitors (< 400 V)

Class	Mode	Two-Person	QEW Level	Work Control	PPE	Stored Energy Removal
3.1a < 100 V < 100 J	All	Alone	Non-QEW	None	None	
3.1b 100 – 399 V < 1 J	All	Alone	Non-QEW	None	None	
3.2a < 100 V 100 J – 999 J	0	Alone	QEW 1 + Capacitor Safety	LOTO	None	
	1	Alone		LOTO	Eye, No Jewelry	Soft Ground Hook
	2	Standby Person		YES	Eye, No Jewelry	
	3	Safety Watch		YES	Eye, No Jewelry	
3.2b 100 – 399 V 1 –99 J	0	Alone	QEW 1 + Capacitor Safety	LOTO	None	
	1	Alone		LOTO	Insulated tools, gloves	Soft Ground Hook > 5 J
	2	Standby Person		YES	Insulated tools, gloves	
	3	Standby Person		YES, EEWP	Insulated tools, gloves	
3.3a < 100 V 1 kJ –9.9 kJ	0	Alone	QEW 2 + Capacitor Safety	LOTO	None	
	1	Standby Person		LOTO	Eye, No Jewelry	Soft Ground Hook > 5 J
	2	Safety Watch		YES	Eye, No Jewelry	
	3	Safety Watch		YES, EEWP	Eye, No Jewelry	
3.3b 100 – 399 V 100 J –9.9 kJ	0	Alone	QEW 2 + Capacitor Safety	LOTO	None	
	1	Standby Person		LOTO	Eye, Insulated tools, gloves	Soft Ground Hook
	2	Safety Watch		YES	Eye, Insulated tools, gloves	
	3[4]	Safety Watch		YES, EEWP	Eye, Insulated tools, gloves	
3.4a <100 V ≥ 10 kJ	0	Alone	QEW 2 + Capacitor Safety	LOTO	None	
	1	Standby Person		LOTO	Eye, No Jewelry	Remote grounding
	2[3]	Safety Watch		YES	Eye, No Jewelry	Remote testing
	3[4]	Safety Watch		YES, EEWP	Eye, No Jewelry	
3.4b 100 – 399 V ≥ 10 kJ	0	Alone	QEW 2 + Capacitor Safety	LOTO	None	
	1	Standby Person		LOTO	Eye, Ear, shock[1], arc flash[2]	Remote grounding
	2[3]	Safety Watch		YES	Eye, Ear, shock[1], arc flash[2]	Remote testing
	3[4]	Safety Watch		YES, EEWP	Eye, Ear, shock[1], arc flash[2]	

[1] Determine PPE by performing a shock hazard analysis using methods covered in Section 7.1.
[2] Determine PPE by performing an arc flash hazard analysis using methods covered in Section 8.1.
[3] This mode of work should be avoided or done remotely.
[4] This mode of work should be avoided.

Notes on use:

1. PPE–eye is proper eye protection, either goggles or a face shield, for higher energies.
2. PPE–no jewelry for low voltage capacitors, means no jewelry on the hands (e.g., rings, watches) and no dangling jewelry or other objects (e.g., badge).
3. Column ‘Stored Energy Removal’ is the method used to discharge lower-energy capacitors, or apply a safety ground on higher-energy capacitors.
4. “Remote grounding” means using engineering methods to discharge and verify the capacitors without worker exposure (e.g., a capacitor remote “dump” or discharge system).
5. “Remote testing” means using sensors and instruments that are placed during a Mode 0 condition, then observed from a safe location during Mode 2 work.

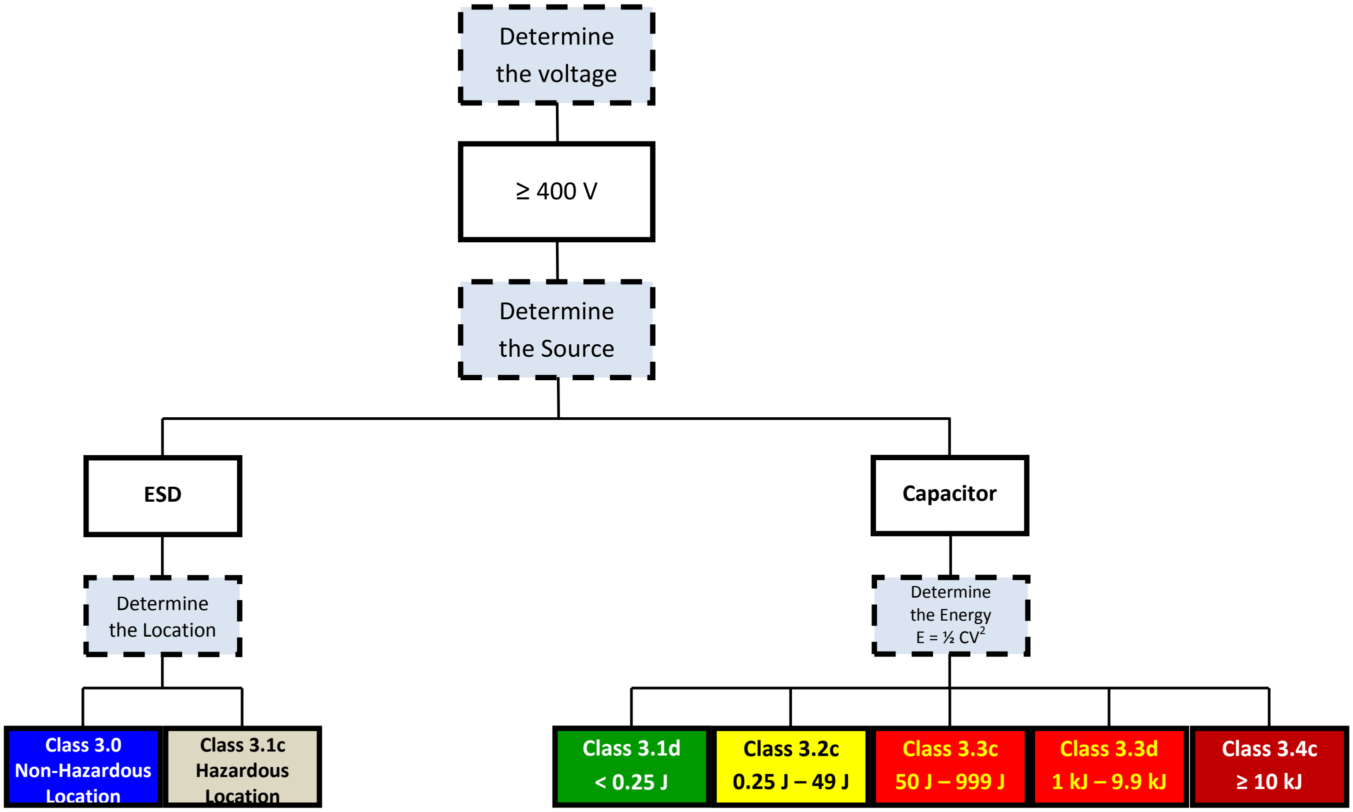


Fig. 3.5b. Hazard Classes 3.x, Capacitors, >400 V

Notes on use:

1. Voltage is peak of the AC, peak impulse or DC maximum charge voltage on the capacitor.
2. Energy is maximum energy stored in the capacitor as determined by $E = ½ CV^2$.
3. The hazards for greater than 400 V, Classes 3.2c, 3.3c, 3.3d, 3.4c are high current through a short circuit, and a shock hazard with a strong reflex action for Class 3.2c, and serious tissue injury and/or death for 3.3c and above.
4. Class 3.3d and 3.4c have the added hazards of mechanical damage due to high currents and strong pulse magnetic forces during a short circuit.
5. For Class 3.1c, the hazard is not electrical; refer to an explosive or hazardous location SME to manage the hazard.

Table 3.5b. Control Table for Work in Hazard Classes 3.x, Capacitors (≥ 400 V)

Class	Mode	Two-Person	QEW Level	Work Control	PPE	Stored Energy Removal
3.0–ESD	All	Alone	Non-QEW	None	None	
3.1d ≥ 400 V < 0.25 J	All	Alone	Non-QEW	None	None	
3.1c[1] – ESD Haz Loc	All	For Class 3.1c refer to explosive safety SME.				
3.2c ≥ 400 V 0.25 J – 49 J	0	Alone	QEW 1 + Capacitor Safety	LOTO	None	
	1	Alone		LOTO	Shock[1]	Soft Ground Hook > 5 J
	2[3]	Standby Person		YES	Shock[1]	
	3	Safety Watch		YES, EEWP	Shock[1]	
3.3c ≥ 400 V 50 J – 999 J	0	Alone	QEW 1 + Capacitor Safety	LOTO	None	
	1	Standby Person		LOTO	Eye, Ear, Shock[1]	Soft Ground Hook
	2[4]	Safety Watch		YES	Eye, Ear, Shock[1]	
	3	DO NOT do this mode of work.				
3.3d ≥ 400 V 1 kJ –9.9 kJ	0	Alone	QEW 2 + Capacitor Safety	LOTO	None	
	1	Standby Person		LOTO	Eye, Ear, Shock[1]	Soft Ground Hook > 5 J
	2[4]	Safety Watch		YES	Eye, Ear, Shock[1]	
	3	DO NOT do this mode of work.				
3.4c ≥ 400 V ≥ 10 kJ	0	Alone	QEW 2 + Capacitor Safety	LOTO	None	
	1	Standby Person		LOTO	Eye, Ear, Shock[1], Arc Flash[2]	Remote grounding
	2[6]	Safety Watch		YES	Eye, Ear, Shock[1], Arc Flash[2]	Remote testing
	3	DO NOT do this mode of work.				

[1] Determine PPE by performing a shock hazard analysis using methods covered in Section 7.1.
[2] Determine PPE by performing an arc flash hazard analysis using methods covered in Section 8.1.
[3] This mode of work should be done remotely.
[4] Do this mode of work remotely.

Notes on use:

1. PPE–eye is proper eye protection, either goggles or a face shield, for higher energies.
2. PPE–no jewelry for low voltage capacitors, means no jewelry on the hands (e.g., rings, watches) and no dangling jewelry or other objects (e.g., badge).
3. Column 'Energy Removal' is the method used to discharge lower-energy capacitors, or apply a safety ground on higher-energy capacitors. See definitions of hard and soft ground hooks.
4. "Remote grounding" means using engineering methods to discharge and verify the capacitors without worker exposure (e.g., a capacitor remote "dump" or discharge system).
5. "Remote testing" means using sensors and instruments that are placed during a Mode 0 condition, then observed from a safe location during Mode 2 work.

3.6 Hazard Class 4.x, Batteries <100 VDC

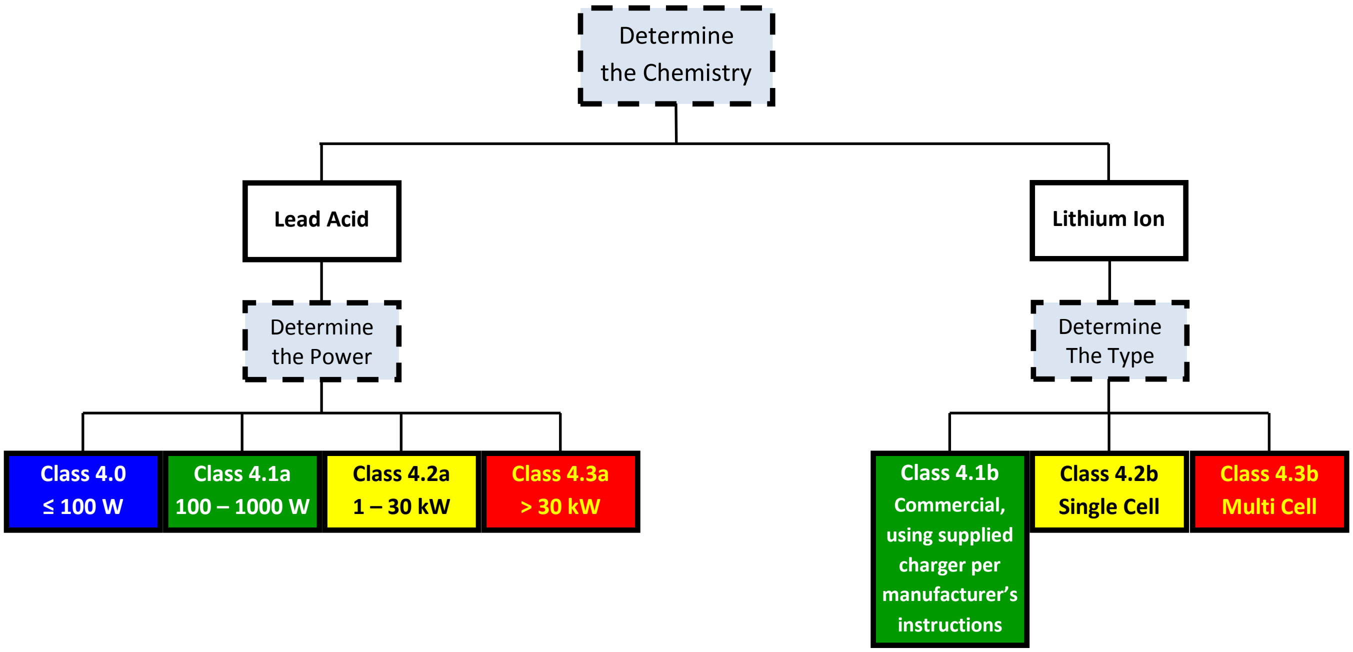


Fig. 3.6. Hazard Classes 4.x, Batteries and Battery Banks <100 VDC

Notes on use:

1. For battery systems ≥ 100 VDC, use hazard Classes 2.x to categorize the shock hazard.
2. Power is the short circuit available power from the battery.
3. There can be no Mode 0 or 1 for batteries, as they are always energized.
4. Additional PPE is necessary for vented lead-acid batteries, depending on the work activity (e.g., chemical PPE).
5. Although all work on Class 4.2 (e.g., automotive batteries) is Energized Work, some of this work (e.g. jump starting cars) is commonly done by the public. Caution should be used, however, and appropriate training and controls in place.
6. Some class 4.2 batteries (e.g., desktop UPS batteries) may have adequate engineering controls, such as recessed terminals, to reduce the need for administrative controls.
7. For batteries and battery systems other than Lead Acid and Lithium Ion, use hazard Classes 2.x to categorize the shock hazard.

Table 3.6a. Control Table for Work in Hazard Classes 4.xa, Batteries (Lead Acid) <100 VDC

Class	Mode	Two-Person	QEW Level	Work Control	PPE
4.0 <100 W	All	Alone	Non-QEW	None	None
4.1a 100–1000 W	All	Alone	Non-QEW	None	No Jewelry
4.2a 1–30 kW	2	Alone	Non-QEW	YES	Eye, No Jewelry
	3	Alone	Non-QEW	YES	Eye, No Jewelry
4.3a >30 kW	2	Alone	Non-QEW	YES	Eye, No Jewelry
	3	Alone	Non-QEW	YES	Eye, No Jewelry, Special Battery Tools

Notes on use:

1 For greater than 100 VDC, use hazard Classes 2.x to categorize the shock hazard.
2 For battery banks greater than 100 VDC, break up bank for energized work, when possible.

Table 3.6b. Control Table for Work in Hazard Classes 4.xb, Batteries (Lithium Ion) <100 VDC

Class	Mode	Two-Person	QEW Level	Work Control	Additional Controls
4.1b Commercial	While Charging	Alone	Non-QEW	Charge per manufacturer's instructions using the supplied charger.	None
4.2b[1] Single Cell	While Charging	Alone	Non-QEW	YES	None
4.3b[1] Multi Cell	While Charging	Alone	Non-QEW	YES	Containment, monitor temp using thermocouples

[1] Ensure, through AHJ equipment approval that the batteries and battery packs have integral protection and that the charging circuit is matched to the battery or battery pack.

Notes on use:

1. For greater than 100 VDC, use hazard Classes 2.x to categorize the shock hazard.
2. For battery banks greater than 100 VDC, break up bank for energized work, when possible.

3.7 Hazard Class 5.x, RF Circuits (5 kHz to 100 MHz)

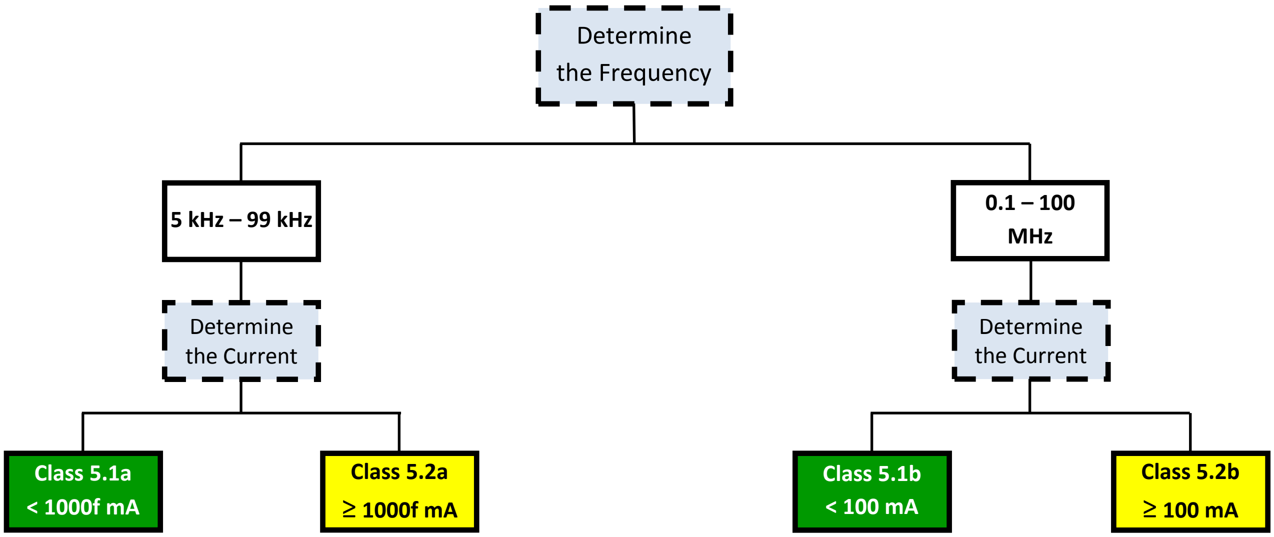


Fig. 3.7. Hazard Classes 5.x, RF Circuits 5 kHz to 100 MHz (f is in MHz)

1. "f" in the Chart is frequency in MHz. "1000f mA" means 1000 times the frequency in MHz. For example, if the frequency is 18 kHz, the shock current threshold is 0.018x1000 = 18 mA.

2. Classes 5.x only address the RF **shock** hazard. They do NOT address the exposure to electromagnetic fields. PUB-3000 Chapter 44, *Non-Ionizing Radiation* covers the exposure to electromagnetic fields.

3. The RF hazard classification chart in Fig. 3.7 determines if the RF source can put out sufficient current to be a shock/burn hazard. However, it does not take into account the body impedance, which is necessary to determine if the source can drive these currents into the body. The tools for body impedance modeling are too detailed to put into this document.

4. Types of waveforms and other factors that are not included in this table will need to be evaluated by competent persons for all hazards.

Table 3.7. Control Table for Work in Classes 5.x, RF Circuits (5 kHz to 100 MHz)

Class	Mode	Two-Person	QEW Level	Work Control	PPE
5.1a 0.003–0.1 MHz <1000f mA	All	Alone	Non-QEW	None	None
5.1b 0.1–100 MHz <100 mA	All	Alone	Non-QEW	None	None
5.2a 0.003–0.1 MHz ≥1000f mA	All	Alone	QEW 1	Must perform RF hazard analysis based on PUB-3000 Chapter 44, *Non-Ionizing Radiation*.	
5.2b 0.1–100 MHz ≥100 mA	All	Alone	QEW 1		

3.8 Hazard Class 6.x, Sub-RF Circuits (1 Hz to 5 kHz)

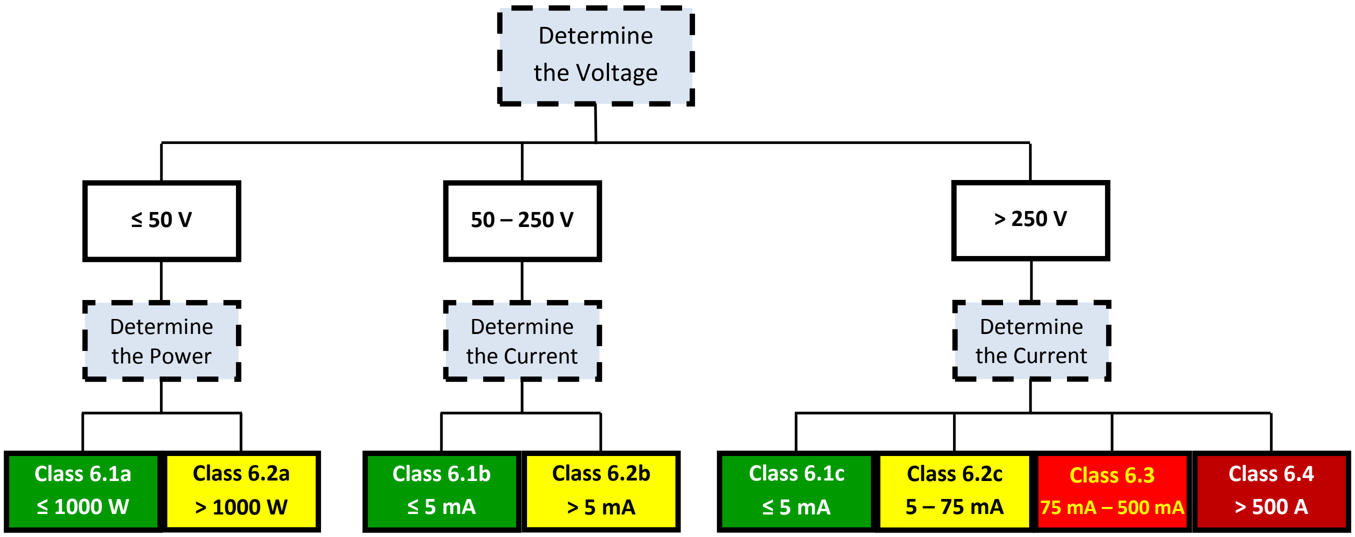


Fig. 3.8. Hazard Classes 6.x, Sub-RF Circuits (1 Hz to 5 kHz)

Notes on use:

1. This hazard class is not to be used for 50-60 Hz power, except for power limited 50-60 Hz circuits that cannot have currents over 5 mA.
2. Power is available short-circuit power.
3. Current is available short-circuit current.

Table 3.8. Control Table for Work in Classes 6.x, Sub-RF Circuits (1 Hz to 5 kHz)

Class	Mode	Two-Person	QEW Level	Work Control	PPE
6.1a,b,c ≤50 V, ≤1 kW or >50 V, ≤5 mA	All	Alone	Non-QEW	None	None
6.2a ≤50 V >1 kW	0	Alone	Non-QEW	LOTO	None
	1	Alone		LOTO	Shock[1]
	2	Standby Person		YES	Shock[1]
	3[4]	Safety Watch		YES, EEWP	Shock[1]
6.2b 50–250 V >5 mA	0	Alone	QEW 1	LOTO	None
	1	Alone		LOTO	Shock[1]
	2	Standby Person		YES	Shock[1]
	3[4]	Safety Watch		YES, EEWP	Shock[1]
6.2c >250 V 5–75 mA	0	Alone	QEW 1	LOTO	None
	1	Alone		LOTO	Shock[1]
	2	Standby Person		YES	Shock[1]
	3[4]	Safety Watch		YES, EEWP	Shock[1]
6.3 >250 V 75 mA–500 A	0	Alone	QEW 2	LOTO	None
	1	Standby Person		LOTO	Shock[1]
	2[3]	Safety Watch		YES	Shock[1]
	3[4]	Safety Watch		YES, EEWP	Shock[1]
6.4 >250 V >500 A	0	Alone	QEW 2	LOTO	None
	1	Standby Person		LOTO	Shock[1], Arc Flash[2]
	2[4]	Safety Watch		YES	Shock[1], Arc Flash[2]
	3[4]	Safety Watch		YES, EEWP	Shock[1], Arc Flash[2]

1 Perform a shock hazard analysis using methods covered in Section 7.1.
2 Perform an arc flash hazard analysis using methods covered in Section 8.1.
3 DO NOT move probes while energized.
4 This mode of work should be avoided.

PART II – ELECTRICAL SAFE WORK PRACTICES

4 Electrical Safety Principles & Controls

4.1 Principles of Electrical Safety

4.1.1 Electricity is different from other forms of hazardous energy, because it is both undetectable by human senses and potentially immediately fatal upon contact. Since we use electricity every day and everywhere in our lives, this requires a broad application of specialized equipment construction methods and safe work practices to prevent serious injuries or death.

4.1.2 All electrical equipment must be installed and used in accordance with manufacturer's instructions. Equipment shall be approved for use (accepted by the Electrical AHJ) and shall not be modified or used outside of its approval intent. See the Electrical Equipment Safety Program for more information.

4.1.3 Sufficient training is required to safely interact with electrical equipment. Operators must be trained to operate equipment within its design intent and to not defeat engineering controls.

4.1.4 Personnel who service, modify, repair or build electrical equipment must be able to recognize the hazards and establish controls to prevent injury. These personnel are called Qualified Electrical Workers (QEW's).

4.1.5 The most fundamental aspect of QEW training is the ability to Test Before Touch. Without an innate human sense to detect a hazardous condition, QEW's must understand how to properly use test equipment to prove an Electrically Safe Work Condition.

4.1.6 Live repair work is considered extremely hazardous and is generally prohibited. Exceptions can be made but require detailed justification and approval by senior management (EEWP – Section 6.6).

4.1.7 Whenever possible, all work performed on equipment will be performed deenergized. In order to prove and maintain deenergization, QEW's must follow a strict process to establish an Electrically Safe Work Condition. This process involves both Lockout/Tagout and Test Before Touch. Because this is so fundamental to safe electrical work, it is captured in the electrical safety medallion in Fig. 4.1.7.

Fig. 4.1.7 – Electrical Safety Medallion

4.1.8 Some forms of diagnostics require the equipment to be energized while circuit parts are exposed. Only QEW's with the proper PPE may perform diagnostics.

4.1.9 Some combinations of switching, testing and LOTO can involve significant procedural complexity. In these cases, written work plans are developed, reviewed and approved by knowledgeable parties in advance and executed with formal procedural compliance. Refer to 6.8 for how and when to build an Electrical Safe Work Procedure.

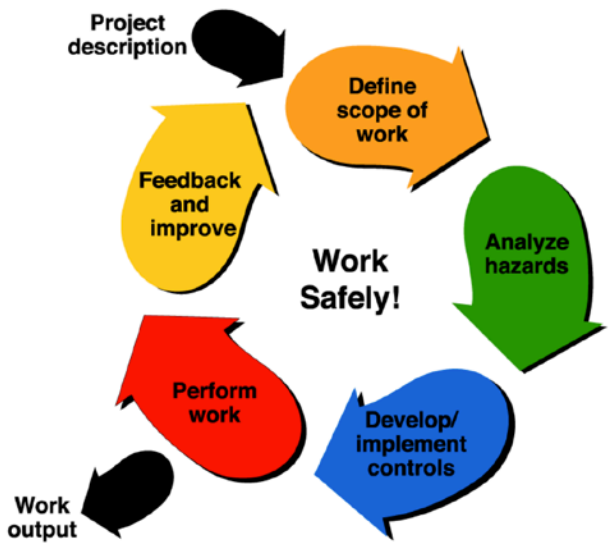
4.1.10 Proper body positioning must be an integral part of both everyday work habits and detailed work planning. This principle is embedded in the shock protection and arc flash protection boundaries, but must also be emphasized in everything from routine switching activities to setting up barriers and barricades.

4.2 Application of ISM to Electrical Safety

4.2.1 The Integrated Safety Management process applies in full to electrical work.

4.2.2 The general process for implementing ISM can be found in PUB-3140, *Integrated ES&H Management Plan*.

4.2.3 Every electrical job requires an appropriate level of electrical hazard analysis, work planning, authorization and direct field supervision that is commensurate with the risk level of the job.



4.2.4 ISM Steps for Electrical Work:

a. Step 1: Define the scope of work

b. Step 2: Analyze the hazards

c. Step 3: Develop/implement controls

d. Step 4: Perform work

e. Step 5: Feedback and improve

4.3 Planning Electrical Work

4.3.1 Every electrical job shall be planned in advance of performing the job briefing.

4.3.2 Planning can be formal or informal, depending on the level of risk and the determination of the risk assessment.

4.3.3 Planning is simply performing the first three steps in the ISM process loop in 4.2.4:

a. Define the scope of work

b. Analyze the Hazards

c. Develop/Implement controls

4.3.4 Certain higher risk jobs require the plan to be formally documented in an Electrical Safe Work Procedure (ESWP). See 6.8.

4.3.5 Electrical Hazard Analysis

a. If the energized electrical conductors or circuit parts operating above the shock hazard thresholds of 2.2.12 are not placed in an Electrically Safe Work Condition, other safety-related work practices, such as the ones described in Sections 6 through 10, shall be used to protect employees who might be exposed to the electrical hazards involved.

b. Such work practices shall protect each employee from arc flash and from contact with energized electrical conductors or circuit parts, operating above the shock hazard thresholds of 2.2.12, directly with any part of the body or indirectly through some other conductive object.

c. Work practices that are used shall be suitable for the conditions under which the work is to be performed and for the voltage level of the energized electrical conductors or circuit parts.

d. Appropriate safety-related work practices shall be determined before any person is exposed to the electrical hazards involved by using both shock hazard analysis and arc flash hazard analysis.
   - A shock hazard analysis shall be performed in accordance with 7.1.
   - An arc flash hazard analysis shall be performed in accordance with 8.1.

e. The electrical hazard analysis determines the type and rating of shock and arc flash PPE, as well as approach boundaries to be used.

4.3.6 Developing Controls

a. Depending on the results of the Electrical Hazard Analysis, controls must be selected to minimize both the risk to the persons performing the work and to persons who may be in the area. Controls are selected from Section 6. The following are examples of questions to consider when planning the work.

b. Determine who can perform the work.
   - Who will be the Person In Charge?
   - What level of QEW is required?
   - Is a Standby Person or Safety Watch required?

c. Determine what level of documentation or authorization is required.
   - Is a written ESWP required?
   - Is an EETP or EEWP required?
   - Is a complex LOTO procedure required?

d. Determine how to minimize exposure to the workers.
   - Can the arc flash energy be reduced?
   - Can parts of the system be locked out?
   - Can additional temporary barriers be placed over exposed parts or openings?

e. Determine how to control access to the work area.
   - Are barricades required?
   - Should attendants be stationed to control access?

f. Determine what other additional controls should apply.

4.4 Hierarchy of controls

4.4.1 To prevent and mitigate hazards, controls must be tailored to the work being performed, the risk of harm posed by the work, and the extent or degree of harm that could occur while performing the work. This tailoring of controls to hazards based upon risk is generally referred to as the "graded approach."

4.4.2 The preferred hierarchy of controls is:

a. **Elimination or substitution of the hazards**: in the design of equipment or apparatus, careful consideration should be made when applying hazardous electrical power to a device. For example, control and interlock circuitry could be designed to operate at 24 VDC instead of 120 VAC.

b. **Engineering controls**: in the design of equipment or apparatus, permanent guarding, enclosing, or insulation of hazardous voltage sources to prevent unnecessary exposure to the operator.

c. **Administrative controls**: implementation of an Electrically Safe Work Condition (Lockout/Tagout), restricted access to qualified electrical workers, and documented safe work plans are examples of administrative controls.

d. **Personal protective equipment**: working on energized equipment while protected with PPE is a last resort.

4.4.3 The tailoring process should include:

a. Identifying controls for specific hazards

b. Establishing boundaries for safe operation

c. Implementing and maintaining controls

4.5 Authorization

4.5.1 Authorization to perform electrical work is covered by the ES&H Manual *Safe Work Authorizations* program. All electrical work shall require line management authorization.

4.5.2 Specific authorization is to be provided by the supervisor after the employee has been approved as a Qualified Electrical Worker by the Electrical AHJ for Safe Work Practices, has satisfied the EHS course requirement and has received equipment-specific training. The supervisor must ensure that the employee is thoroughly familiar with the equipment (within the context of his or her job function) and with the energy-control procedures.

4.5.3 The authorizing person shall consider the following factors in authorizing electrical work:

a. Who is performing the work? Are they suitably qualified and experienced?

b. Who is supervising the work? Are they suitably qualified and experienced?

c. Is a written procedure necessary or advised (ESWP)?

d. Are any permits required and have they been approved?

e. What system operational conditions will (or should) be required? Are these accounted for in the plan?

f. What could go wrong and what should be done about it? Is the level of planning and supervision appropriate for the level of risk?

4.6 Executing the Plan

4.6.1 Every electrical job shall have a designated Person In Charge (PIC) (6.9).

4.6.2 The PIC shall perform a Job Briefing with all persons involved prior to executing the job (6.12).

4.6.3 Individual Qualified Electrical Workers should think through the set of self-control questions to ensure they are adequately prepared for the task (4.7).

4.6.4 The PIC should remain alert for changes in the scope of work that may naturally develop during the execution of the plan. Individual QEW's shall notify the PIC for any change in the scope of work. A change in scope shall trigger a review of the hazards and controls.

4.7 Self-Controls for the Qualified Electrical Worker

4.7.1 Electrical safety self-control is a process by which one performs his or her own safety analysis before beginning any task. This is the first step of a personal hazard/risk analysis. It can be accomplished by simply asking questions of oneself. If one can honestly answer "yes" to all of the following questions, he or she has done well at controlling his or her own safety. If one responds "no" to any of the questions, there is a safety concern that he or she should address before proceeding with the work.

4.7.2 This set of self-control questions makes the employee slow down and think about what he or she is going to do. Applying these controls can significantly reduce the probability of the employee being injured or killed while performing electrical work.

a. Do I fully understand the scope of the work?

b. Am I trained and qualified to perform this work safely?

c. Have I performed this type of task before; if not, have I discussed the details with my supervisor?

d. Have I thought about possible hazards associated with this work and taken steps to protect myself against them?

e. Have I determined whether or not I will be near exposed energized parts?

f. If I am going to be exposed to energized parts, can they be put into an Electrically Safe Work Condition? [If "No," skip to item i.]

g. Did I verify, using appropriate protective and test equipment, that the conductors or equipment are in a de-energized state?

h. Have I applied a lockout/tagout device?

i. If I will be exposed to energized parts, do I know what voltage levels are involved?

j. Do I know the safe approach distance to protect against the electrical shock hazard?

k. Do I know the safe approach distance to protect against the electrical arc/flash hazard?

l. If a permit for energized work is required, have I obtained one?

m. Do I have the proper electrical PPE for this type of energized electrical work?

n. Do I have the appropriate voltage-rated tools and test equipment, in the proper working order, to perform this work?

o. Have I considered and controlled the following factors in my work environment?
  - Close working quarters
  - High traffic areas
  - Intrusion/distraction by others
  - Flammable/explosive atmosphere
  - Wet location
  - Illumination in the area

p. Do I understand that doing the work safely is more important than the time pressure to complete the work?

q. Do I feel that all of my safety concerns about performing this work have been answered?

5 General Electrical Safety for All Persons

5.1 Scope

5.1.1 This section applies for all personnel at Berkeley Lab, both QEWs and non-QEWs.

5.1.2 This section deals primarily with workplace electrical safety. This includes working around or with electrical equipment, but does not include working on or inside electrical equipment.

5.2 General requirements

5.2.1 A fundamental principle of electrical safety is that only Qualified Electrical Workers (QEWs) may be authorized to perform electrical work. This includes both live and deenergized work, for build, service, maintenance, and repair of equipment. A more detailed description of electrical work and what non-QEWs may perform is in 6.3.

a. A QEW is one who has demonstrated skills and knowledge related to the construction and operation of electrical equipment and installations, has received safety training to identify and avoid the hazards involved, and who has been approved by the Electrical AHJ for Safe Work Practices.

b. Any person who is not a QEW is called a non-QEW.

5.2.2 Safe work practices for the non-QEW can generally be subdivided into the following categories:

a. Proper handling and use of cord- and plug- connected equipment.

b. Ensuring that electrical equipment is listed by an NRTL or inspected and found acceptable by the Electrical AHJ for non-NRTL equipment. The equipment must not be modified and must be used in accordance with its listing intent. See the *Electrical Equipment Safety Program*.

c. Reporting all instances of defective electrical equipment for repair by a Qualified Electrical Worker.

d. Proper safe work practices for switching electrical disconnects and circuit breakers.

5.3 Recognizing electrical hazards

5.3.1 Deenergizing electrical equipment

a. Power switches: The normal operator method for turning off electrical equipment typically does not remove all electric power from the equipment. Some electrical parts within equipment still remain live even after all visible or audible signs seem to show otherwise. Just because the external lights turn off, vibration sounds cease, and visible movement stops, do not assume that there is no shock hazard within electrical equipment. A shock hazard may still exist when enclosure panels or covers are removed.

Fig. 5.3.1.a – *This thermal evaporator was placed out of service because of a fluid leak. Although the power switch was turned off and the control panel showed no visible sign of electric power, the cord was still plugged in (behind the drawer cabinet to the left) and the 220V transformer in the bottom (next to the red wires) had exposed live parts. The cover panel, which was removed, did not have any shock hazard warning label. The evaporator is not listed by an NRTL and had not been inspected under the Electrical Equipment Safety Program. The evaporator should have been inspected, labeled, and unplugged prior to removing the panel.*

b. Emergency Stops (E-Stops) have various design parameters, but most are only designed to immediately stop moving parts when a person gets caught in the machinery. This does not remove electrical power from the system. A shock hazard may still exist when enclosure panels or covers are removed.

Fig. 5.3.1.b – An Emergency Stop (E-Stop) does not cut all electrical power to equipment.

5.3.2 Shock Hazard Labeling

a. Modern laboratory equipment that meets product safety codes and standards is required to be labeled with warning about electrical hazards. The international symbol for a shock hazard is found in Fig. 5.3.2.a.

Fig. 5.3.2.a – International Symbol for a Shock Hazard

b. However, with legacy laboratory equipment, or with new equipment that is not listed by an NRTL and that has not yet been inspected under PUB-3000 Chapter 14, *Electrical Equipment Safety Program*, sufficient labeling may or may not be in place. The user should use caution when opening equipment. When unsure, contact a QEW for assistance.

c. Actual shock hazard warnings may or may not be applied on all equipment enclosure panels. While Berkeley Lab electrical equipment inspectors apply additional shock hazard warning labels to equipment, many panels are not necessarily labeled with shock hazard warnings. Note that if a panel requires a TOOL or KEY to access, labeling is not required by product safety codes. Do not open panels with a tool or key unless you know there is no electrical hazard. Consult with a QEW for a proper determination. Typical labeling to watch for includes the samples in Fig. 5.3.2.c.

Fig. 5.3.2.c– Typical Hazard Warning Labels Found on Electrical Equipment

5.3.3 Sometimes it is necessary to open electrical equipment to perform non-electrical work that does not require a QEW. However, the electrical hazard must be locked out and verified safe prior to work. This is called "establishing an Electrically Safe Work Condition".

a. Hard-wired equipment will need to be locked out by a QEW in accordance with the Lockout/Tagout Program. Equipment that has been inspected under the EESP will be labeled according to Fig. 5.3.3.a.

Fig. 5.3.3.a – Example of label applied to hard-wired equipment, indicating requirement to lock out prior to servicing.

b. In general, cord-and-plug equipment can be placed in an Electrically Safe Work Condition by a non-QEW when there is no stored hazardous electrical energy. This is done simply by unplugging the equipment. Cord-and-plug equipment that has been inspected under the EESP will be labeled according to Fig. 5.3.3.b.

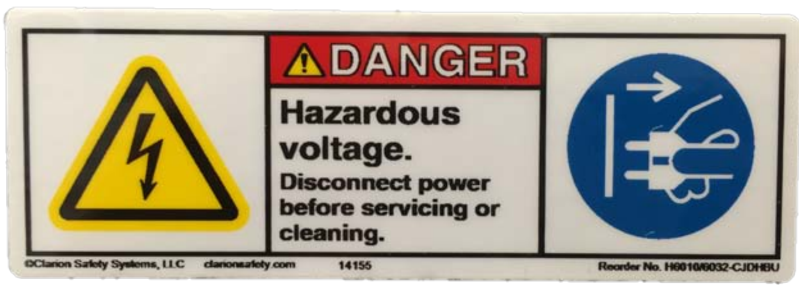


Fig. 5.3.3.b– Example of label applied to cord-and-plug equipment, indicating requirement to unplug prior to servicing.

c. Further, in accordance with the *Lockout/Tagout Program, Work Process C, Cord-and-Plug Equipment*, cord-and-plug equipment is exempt from LOTO controls when:
- There is a single energy source
- All hazardous energy is controlled by unplugging the equipment
- The plug remains under the continuous positive and exclusive control of the worker performing the work.

d. If there is stored electrical energy greater than the capacitor thresholds in Table 2.2.12, then the cord-and-plug exemption does not apply and there must be a Complex LOTO Procedure that includes safe discharge verification by a QEW.

- Note: For cord-and-plug 115 VAC chassis equipment, there is no stored energy hazard if the following conditions are met:
  - all voltage outputs are less than 100 VDC, and
  - there is no mechanical, video or radiation output

e. If there is more than one power source (multiple plugs), then the cord-and-plug exemption does not apply and there must be a Complex LOTO Procedure that accounts for all sources of hazardous energy. However a non-QEW may still establish the LOTO.

5.4 Portable electric equipment

5.4.1 This section applies to the use of cord- and plug-connected utilization equipment, including cord sets (extension cords).

5.4.2 Handling. Portable equipment shall be handled in a manner that will not cause damage.

a. Flexible electric cords connected to equipment shall not be used for raising or lowering the equipment.

b. Flexible cords shall not be fastened with staples or hung in such a fashion as could damage the outer jacket or insulation.

5.4.3 Grounding-Type Equipment.

a. A flexible cord used with grounding-type utilization equipment shall contain an equipment grounding conductor.

b. Attachment plugs and receptacles shall not be connected or altered in a manner that would interrupt continuity of the equipment grounding conductor. Additionally, these devices shall not be altered in order to allow use in a manner that was not intended by the manufacturer.

c. Adapters that interrupt the continuity of the equipment grounding conductor shall not be used.

5.4.4 Visual Inspection of Portable Cord- and Plug- Connected Equipment and Flexible Cord Sets.

a. Frequency of Inspection. Before each use, portable cord- and plug-connected equipment shall be visually inspected for external defects (such as loose parts or deformed and missing pins) and for evidence of possible internal damage (such as a pinched or crushed outer jacket).
   - Exception: Cord- and plug-connected equipment and flexible cord sets (extension cords) that remain connected once they are put in place and are not exposed to damage shall not be required to be visually inspected until they are relocated.

b. Defective Equipment. If there is a defect or evidence of damage that might expose an employee to injury, the defective or damaged item shall be removed from service and no employee shall use it until repairs and tests necessary to render the equipment safe have been made.

c. Proper Mating. When an attachment plug is to be connected to a receptacle (including on a cord set), the relationship of the plug and receptacle contacts shall first be checked to ensure that they are of mating configurations.

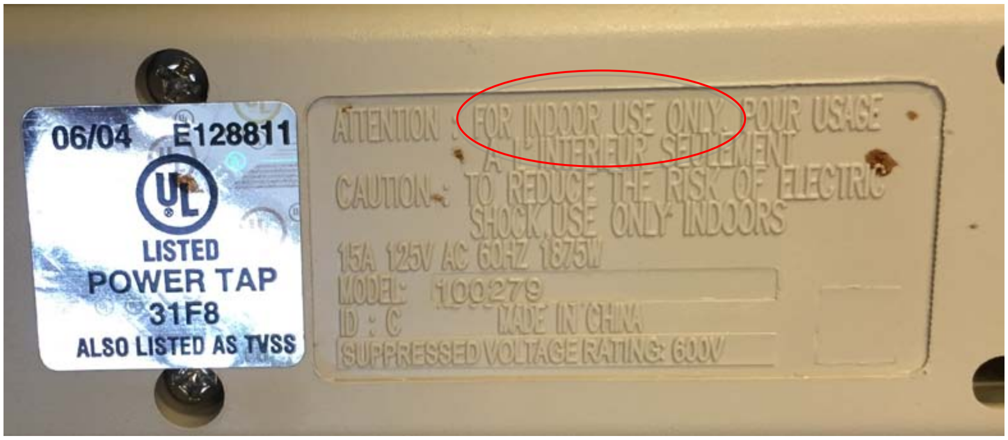
5.4.5 Conductive Work Locations (Damp or Wet)

a. Conductive work locations are typically classified as damp or wet. Equipment used in such locations must be rated accordingly. Most office and laboratory equipment is rated “For Indoor Use Only”, which precludes damp or wet locations unless additional measures are taken.

b. Wet locations include anywhere outdoors and anywhere within 3 feet of a liquid source where splashing is likely (such as emergency showers, eyewash stations, and some laboratory sinks with washdown hoses).

c. Damp locations include anywhere that is protected from direct exposure to the elements but not necessarily in an indoor environment with HVAC atmosphere controls. This can include garages, sheds, lean-tos and similar structures. Damp locations also include anywhere within 6 feet of a liquid source (such as emergency showers, eyewash stations, and sinks).

d. Portable electric equipment used in damp or wet locations, or in job locations where employees are likely to contact water or conductive liquids, shall be rated for damp or wet locations, or:
   - Equipment placed in damp locations that is not rated for the wet location must be protected with a GFCI.
   - Equipment placed in wet locations that is not rated for the wet location must be protected with a GFCI and a splash guard.



Pic 5.4.5.d – This listed equipment is rated for “FOR INDOOR USE ONLY”.

e. In job locations where employees are likely to contact or be drenched with water or conductive liquids, ground-fault circuit-interrupter (GFCI) protection for personnel shall also be used (see 5.8.3).

f. For temporary tasks, portable tools and equipment powered by sources other than 120 VAC, such as batteries, air, and hydraulics, should be used to minimize the potential for injury from electrical hazards for tasks performed in conductive or wet locations.

5.4.6 Connecting Attachment Plugs.

a. Employees’ hands shall not be wet when plugging and unplugging flexible cords and cord- and plug-connected equipment if energized equipment is involved.

b. Energized plug and receptacle connections shall be handled only with insulating protective equipment if the condition of the connection could provide a conductive path to the employee’s hand (for example, if a cord connector is wet from being immersed in water).

c. Locking-type connectors shall be secured after connection.

5.4.7 Overcurrent protection of circuits and conductors may not be modified, even on a temporary basis, beyond that allowed by beyond that permitted by applicable portions of electrical codes and standards dealing with overcurrent protection.

5.4.8 Rating of equipment.

a. Portable electric equipment and its accessories shall be rated for circuits and equipment to which they will be connected. Check the equipment nameplate for rating information. This will typically include voltage, amperes, and wattage.

b. Equipment marked “FOR INDOOR USE ONLY” is not suited for use outdoors, in construction, or in damp or wet environments.

5.5 Cord sets (extension cords)

5.5.1 Cord sets are for temporary use only and shall not take the place of permanent wiring. Unless part of a construction project, temporary is defined at Berkeley Lab as not exceeding one calendar month.

5.5.2 Do not use cord sets in place of permanent facility wiring. When equipment is no longer being used, the cord set should be unplugged and stored. Where equipment is intended to stay in a specific location, and a receptacle is not located close enough to plug in the equipment, submit a work order request to have a receptacle installed where needed.

5.5.3 Flexible cords and cables and extension cords shall not be run through holes in walls, structural ceilings, suspended ceilings, dropped ceilings, or floors, even if protected by piping, sleeving, grommets, or other means.

5.5.4 Flexible cords and cables and extension cords shall not be permanently attached to building surfaces, or concealed in walls, floors, or ceilings, or located above suspended or dropped ceilings.

5.5.5 Flexible cords and cables and extension cords shall not be installed in raceways (conduit). Short lengths of conduit may be used to protect flexible cord from damage. Flexible cords, cables and extension cords may not be used in cable tray.

5.5.6 Listing

a. Cord sets shall be listed by an NRTL, or

b. Where special circumstances require fabrication of a custom cord set, it shall be fabricated by a QEW Electrician and shall meet the requirements of wire gauge and length for the load as set in Table 5.5.15. Selection of materials shall be made in accordance with UL 817, *Standard for Safety, Cord Sets and Power Supply Cords*.

5.5.7 Only two extension cord sets may be daisy chained, unless they are equipped with locking connectors rated for the environment. When daisy chaining cords, the gauge of all cords shall be rated for the total length.

5.5.8 Protection from damage

a. Extension cords, flexible cords, and cable shall not be run through doorways, windows, or similar openings. If it is necessary to run cords or cables through these openings for short-term use for construction, demolition, remodeling, maintenance, or repair, ensure that the cord is suitably protected from pinching, cutting, or other damage.

b. An outdoor-use extension cord set is intended to be used in conjunction with portable electric equipment that is intended for use outdoors. The extension cord set is intended for use outdoors only while the portable equipment is in operation. It is intended to be stored indoors where it is not exposed to sunlight, weather, or both while not in use. It can also be used indoors.

5.5.9 Extension cord markings:

a. Cord markings determine the type and service duty of a cord.

b. All cord sets, whether for indoor or outdoor use, shall be of hard-service or junior hard-service only and shall have one of the following markings: SOW, SOOW, STW, STOW, STOOW, SEW, SEOW, SEOOW, SJOW, SJOOW, SJTW, SJTOW, SJTOOW, SJEW, SJEOW, or SJEOOW.

c. Cord sets for construction sites shall be of hard-service only and shall have one of the following markings: SOW, SOOW, STW, STOW, STOOW, SEW, SEOW, or SEOOW.

Marking	Meaning
S	Hard-service cord, rated for 600 V
SJ	Junior hard-service cord, rated for 300 V
E	Thermoplastic elastomer
T	Thermoplastic
O	Oil-resistant outer jacket
OO	Oil-resistant outer jacket and oil-resistant insulation
W	Weather and water resistant (suitable for outdoor use)

<table>
<tr><td rowspan="3">
</td><td>“(UL)” – this cord is NRTL-listed</td></tr>
<tr><td>“12/3” – 12 AWG, 3-conductor</td></tr>
<tr><td>“SJTW” – Junior hard service, Thermoplastic, Weather and water resistant. Suitable for outdoor use but not for construction sites.</td></tr>
</table>

5.5.10 Before Use

a. Inspect thoroughly before each use. Do not use if damaged. Use only properly maintained extension cords that have no exposed live parts, exposed ungrounded metal parts, damage, or splices.

b. A cord set not marked “FOR OUTDOOR USE” is to be used indoors only, and not on construction sites.

c. Look for the number of watts on appliances to be plugged into cord. See product or label markings for specific wattage. Do not plug more than the specified number of watts into this cord.

d. Do not run through doorways, holes in ceilings, walls or floors. Route the cord in a way that avoids tripping hazards.

e. Make sure appliance is off before connecting cord into outlet.

f. Fully insert plug into outlet. Do not use excessive force to make connections.

g. Do not connect a three-prong plug to a two-hole cord.

h. Do not remove, bend, or modify any metal prongs or pins of cord.

5.5.11 During Use

a. Keep away from water.

b. Do not use when wet.

c. Avoid overheating. Uncoil cord and do not cover it with any material.

d. Do not drive, drag or place objects over cord.

e. Do not walk on cord.

5.5.12 After use

a. Always unplug when no longer needed.

b. Grasp plug to remove from outlet. Do not pry the plug by sticking the fingers between the receptacle and plug face, as this could cause an electrical shock. Do not unplug by pulling on cord, as this could damage the plug.

c. Make sure the grounding prong is present in the plug. Make sure the plug and receptacle are not damaged.

d. Wipe the cord clean and examine for cuts, breaks, abrasions, and defects in the insulation.

e. Always store the cord indoors, even if the cord is marked for outdoor use. Coil or hang the cord for storage. Coiling or hanging is the best way to avoid tight kinks, cuts, and scrapes that can damage insulation or conductors.

5.5.13 Repairs

a. Only qualified electrical workers may make repairs of extension cords.

b. Never splice extension cords, even for a repair. If an extension cord is damaged, it may be made into two cords, provided the proper connectors are used in a proper manner.

c. Only qualified personnel may install cord caps for use with potentials greater than 50 V.

5.5.14 Grounding

a. Always use three-conductor (grounded) cord sets—even if the device has a two-conductor cord. Never use two-conductor extension cords at the Laboratory.

b. Do not cut off the ground pin of a cord set or compromise the ground protection in any way.

c. Do not use extension cords with a ground conductor that has less current-carrying capacity than the other conductors.

5.5.15 Amperage

a. Use of an undersized cord results in an overheated cord and insufficient voltage delivered to the device, thus causing device or cord failure and a fire hazard. An undersized cord also constitutes a serious shock hazard, as it may not allow the breaker feeding it to trip.

b. Make sure that the wire size is sufficient for the current and distance required. See Table 5.5.15 for recommended extension cord sizes for portable electric tools.
   - This table is copied from NFPA 70B-2013, Table 29.5.1. Size is based on current equivalent to 150 percent of full load of tool and a loss in voltage of not over 5 volts.
   - If voltage is already low at the source (outlet), voltage should be increased to standard, or a larger cord than listed should be used to minimize the total voltage drop.

Extension Cord Length (ft)	Nameplate Ampere Rating											
	0-2.0 Amps		2.1-3.4 Amps		3.5-5.0 Amps		5.1-7.0 Amps		7.1-12.0 Amps		12.1-16.0 Amps	
	115 V	230 V	115 V	230 V	115 V	230 V	115 V	230 V	115 V	230 V	115 V	230 V
25	18	18	18	18	18	18	18	18	16	18	14	16
50	18	18	18	18	18	18	16	18	14	16	12	14
75	18	18	18	18	16	18	14	16	12	14	10	12
100	18	18	16	18	14	16	12	14	10	12	8	10
200	16	18	14	16	12	14	10	12	8	10	6	8
300	14	16	12	14	10	14	8	12	6	10	4	6
400	12	16	10	14	8	12	6	10	4	8	4	6
500	12	14	10	12	8	12	6	10	4	6	2	4
600	10	14	8	12	6	10	4	8	2	6	2	4
800	10	12	8	10	6	8	4	6	2	4	1	2
1000	8	12	6	10	4	8	2	6	1	4	0	2

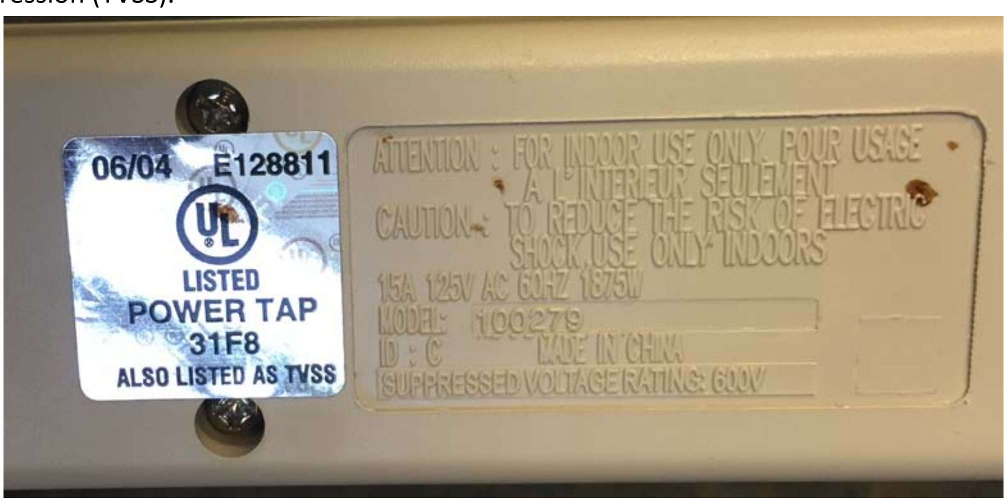
Table 5.5.15 – Recommended Wire Size (AWG) For Extension Cords

5.6 Relocatable Power Taps (Power Strips)

5.6.1 These requirements cover cord-connected, relocatable power taps rated 250 VAC or less and 20 A AC or less. A relocatable power tap (RPT, also referred to as a power strip or multiple outlet strip) is intended only for indoor use as an extension of a grounded alternating-current branch circuit for general use.

Pic - Example of Relocatable Power Tap

5.6.2 Only use NRTL-labeled relocatable power taps. Custom fabricated relocatable power taps shall not be permissible. Listed RPTs will typically have a UL sticker on the back such as the one in Fig., stating “Listed Power Tap”. RPTs that also have surge suppression are dual-listed for Transient Voltage Surge Suppression (TVSS).



5.6.3 Note that Power Distribution Units (PDU's) for Information Technology Equipment are for permanent installation and are listed to a different standard, UL 60950, *Standard for Safety, Information Technology Equipment – Safety – Part 1: General Requirements*. This section does not apply to PDU's.

5.6.4 Usage

a. Relocatable power taps are for indoor use only, and not approved for construction sites or for outdoor use. For other sites, use adapter sets rated for construction sites.

b. A cord-connected RPT is not intended to be connected to another cord-connected RPT. Do not daisy-chain relocatable power taps.

c. Relocatable power taps shall not be used at the end of extension cords.

5.6.5 Amperage

a. Exceeding the load rating of the device or outlet could introduce a fire hazard.

b. The total connected amperage load of the RPT shall not exceed its rating, regardless of whether all the equipment is used simultaneously or not (100% load factor).

c. Refer to limitations of use marked on the data plate of the device. Do not exceed the load rating of the device.

d. Plug high-current equipment (e.g., space heaters, hotplates, refrigerators, microwave ovens and coffee pots) directly into a wall receptacle whenever possible. Do not use RPT's for this purpose.

5.6.6 Mounting

a. Do not permanently mount relocatable power taps to any facility surface.

b. It is acceptable to hang them from screws or hooks if they are manufactured with slots or keyholes.

c. It is acceptable to attach them with Velcro or any means that will not require the use of a tool to remove.

d. It is not acceptable to use wire ties for mounting, as this is considered a permanent installation.

e. In equipment racks, the preferred method of supplying 120/208-V utility power to rack-mounted instruments is via a special relocatable power tap specifically designed to be rack-installed.

5.7 Adapter Cord Sets

5.7.1 An adapter cord set is intended for use at locations such as construction sites and is designed to convert one plug to 2 or 3 single-outlets of the same configuration as the plug or convert to another configuration.

Pic 5.7.1 – Examples of Adapter Cord Sets

5.7.2 Adapter cord sets are marked "Intended for use on construction sites and similar locations."

5.7.3 Care shall be taken to not overload either the branch circuit or any part of the assembled system of cord set(s) and adapter cord set(s).

5.7.4 When combining adapter cord sets and extension cord sets (which can also have multiple cord connectors at the load end), there shall be no more than 6 total available receptacles to which a tool or appliance can be plugged in. If the adapter cord set is placed at the load end of the extension cord set, the extension cord set shall be at least 12 AWG and no more than 100 feet long.

5.8 Ground Fault Circuit Interrupters

5.8.1 A Ground Fault Circuit Interrupter (GFCI) is a safety device designed to limit line-to-ground shock current to less than 5 mA. Listed devices are designed to trip between 4-6 mA in less than 20 msec.

5.8.2 Principle of Operation

a. GFCIs are devices that sense when current—even a small amount—passes to ground through any path other than the proper conductor. When this condition exists, the GFCI quickly opens the circuit, stopping all current flow to the circuit and to a person receiving the ground fault. Figure 5.8.2 shows a typical circuit arrangement of a GFCI designed to protect personnel. The incoming two-wire circuit is connected to a two-pole, shunt-trip overload circuit breaker.

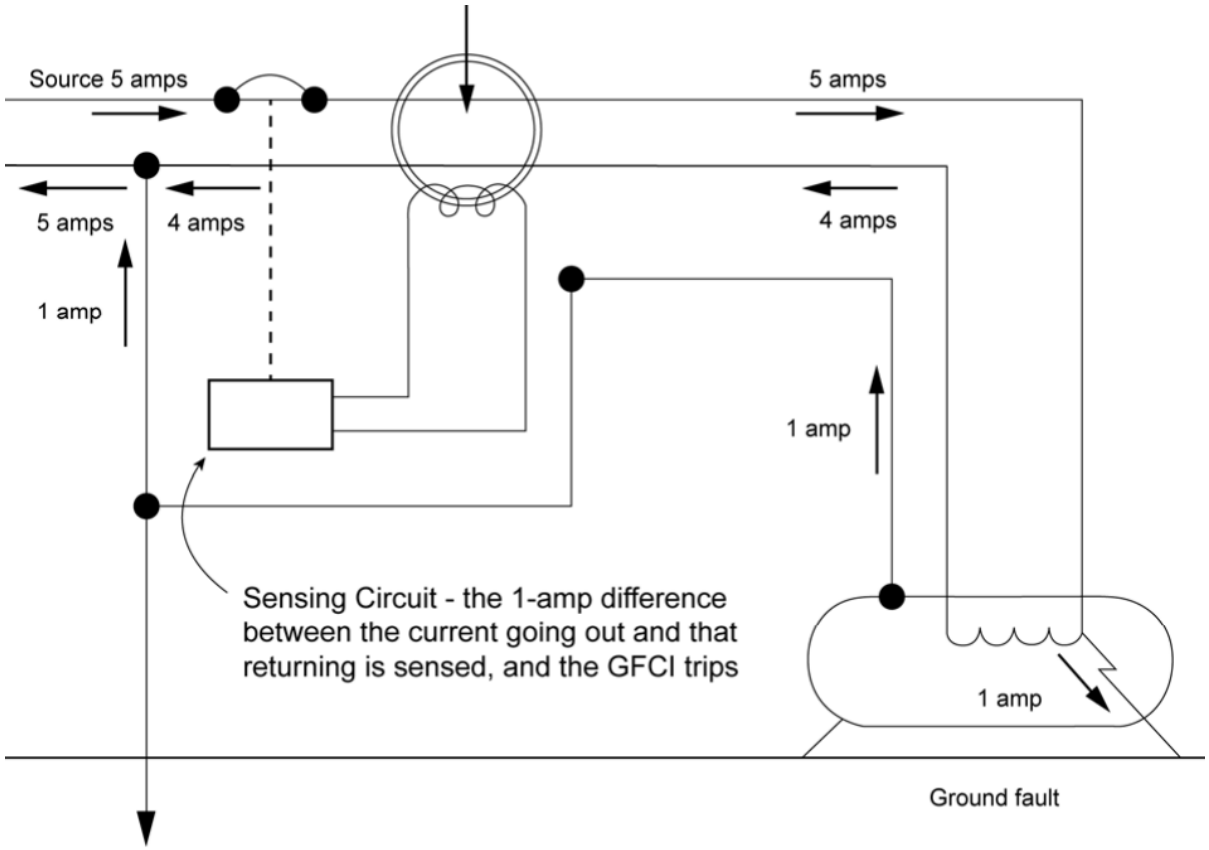


Fig. 5.8.2 – Principle of GFCI Operation

b. The load-side conductors pass through a differential coil onto the outgoing circuit. As long as the current in both load wires is within specified tolerances, the circuit functions normally. If one of the conductors comes in contact with a grounded condition or passes through a person's body to ground, an unbalanced current is established. In Fig. 5.8.2, 1 amp of ground fault current is flowing out of the circuit. The differential transformer picks up this unbalanced current, and a current is established through the sensing circuit to energize the shunt trip of the overload circuit breaker and quickly open the main circuit.

c. A fuse or circuit breaker cannot provide this kind of protection. The fuse or circuit breaker trips or opens the circuit only if a line-to-line or line-to-ground fault occurs that is greater than the circuit protection device rating.

d. Differential transformers continuously monitor circuits to ensure that all current that flows out to motor or appliances returns to the source via the circuit conductors. If any current leaks to a fault, the sensing circuit opens the circuit breaker and stops all current flow.

e. A GFCI does not protect the user from line-to-line or line-to-neutral contact hazards. For example, if an employee using a double-insulated drill with a metal chuck and drill bit protected by a GFCI device drills into an energized conductor and contacts the metal chuck or drill bit, the GFCI device does not trip (unless it is the circuit the GFCI device is connected to) as it does not detect a current imbalance.

5.8.3 Where required[5]:

a. Outdoors: Use a GFCI when working outdoors and operating or using cord- and plug-connected equipment supplied by 125-volt, 15-, 20-, or 30-ampere circuits. For other types of circuits, contact the EHS Electrical Safety Group for guidance.

b. Indoors: Use a GFCI around construction sites, in wet or damp areas, or in an area where a person may be in direct contact with a solidly grounded conductive object (e.g., working in a vacuum tank). Wet or damp areas include areas within 6 feet of a sink, shower, emergency eyewash station or other water source, but do not include fire sprinklers.

c. GFCI protection devices shall be tested in accordance with the manufacturer's instructions.

d. Where GFCI protection is not permanently installed, portable GFCI protection is acceptable.

e. Permanently installed GFCIs take the form of GFCI receptacles or GFCI circuit breakers. Standard receptacles that are protected by an upstream GFCI must be marked "GFCI PROTECTED OUTLET".

[5] The National Electric Code requires installation of permanent GFCI protection in certain areas. The list of areas where permanent GFCIs are required grows every code cycle but is not retroactive to old installations. However, NFPA 70E requires the use of GFCI protection in conductive work locations (5.4.5) and in all locations currently required by the latest edition of the NEC. This means that portable GFCI protection must be used wherever an older NEC code of record did not require permanent GFCI installation.

f. Portable GFCIs consist of either plug-mounted GFCI devices or portable inline GFCI devices. When using a portable inline GFCI, it shall be placed between the receptacle and the cord.

g. It is best practice to always use GFCI protection with portable electric hand tools even when not required. GFCI protection is permitted to be used in any location, circuit, or occupancy to provide additional protection from line-to-ground shock hazards.

5.8.4 Auto-reset feature:

a. There are two types of portable GFCI's. Some have an automatic reset and some do not.

b. For temporary use with extension cords and power tools, use a portable GFCI without an auto-reset feature. This requires the user to test the device by resetting it every time the device is plugged in.

c. For permanent use where a GFCI receptacle or breaker is not installed, consider using a portable GFCI with an auto-reset feature. This is especially critical for loads that should restart automatically after a short power outage, like refrigerators.

5.8.5 Tripped GFCI

a. When a GFCI has tripped, it is usually an indication that there is a problem with a short to ground. Examine the equipment to see if there are any wet areas that may be causing the trip. It is okay to reset the GFCI. If it trips again, call a QEW to investigate.

b. If you suspect that the equipment design is causing current leakage, contact the Electrical Safety Group and schedule an inspection of the equipment.

c. Do no continue to reset the GFCI if it trips repeatedly. Stop work and call a QEW to investigate.

d. Do not bypass a GFCI or look for a non-GFCI protected outlet if a GFCI trips repeatedly. The tripping is a sign of a potentially fatal shock hazard and should be evaluated carefully. Stop work and call a QEW to investigate.

5.8.6 Testing a GFCI

a. The actual test of a GFCI is very simple and can be done safely by anyone. Apply a load to the GFCI, press the TEST button, and verify the load trips off. Press the RESET button and verify the load comes back on.

b. In general, GFCIs are required to be tested "in accordance with manufacturer's instructions". Today's manufacturers require monthly testing. While monthly testing may not be practicable due to the sheer number of devices and the repeated power disruption to the loads, users should know that the typical failure rate for GFCIs is fairly high, somewhere between 10-25% over just a few years use.

c. Best practice:
   - Portable inline GFCIs: test every time it is used. Portable GFCIs without an auto-reset feature require resetting anyways when initially plugging in. Test the GFCI once more after the initial reset.
   - Receptacle GFCIs: if you have not used this receptacle before, test the GFCI before plugging in a device. However, be aware that some GFCIs provide downstream protection for other receptacles. Testing will interrupt the power to all downstream devices.
   - Plug-mounted GFCI's: test every time it is used. If used frequently, test monthly.

d. If a GFCI fails the test, either through obvious mechanical jamming of the buttons or failure to interrupt the load, call a QEW Electrician for a repair.

5.9 Heating Tapes and Cords

5.9.1 Many experiments at Berkeley Lab use heating tapes or cords, including many high-vacuum apparatuses. The heating tapes or cords pose an electrical shock hazard if not used properly. This section also applies to heating pads, wraps, or similar components intended to be applied directly to a laboratory apparatus.

5.9.2 General Electrical Safety Requirements for Use of Heating Tape

a. Whenever possible, use heating tapes that bear a listing mark by UL or another NRTL.

b. Use three-wire (grounded) heating tape and cord systems whenever practical. Two-wire heat tapes and cords, while allowed for use at LBNL, are inherently less safe than three-wire systems.

c. Inspect heating tapes and cords before use and discard any that display signs of excessive wear, fraying, or overheating. Do not repair damaged items.

d. Properly ground all conductive equipment surfaces before heating tapes are powered.

e. Equipment undergoing heating with a variable AC transformer controlled heat tape must be monitored on a regular basis to prevent overheating of either the chamber or the heating device.

f. Heating tapes and cords with an AC plug that can be split into two pieces must have the plug replaced or glued together.

g. Read all the manufacturer's instructions before using any heating device.

h. Do not plug heating tape directly into a receptacle. There must be some type of controller such as a variac or a heat controller system.

i. Use heat tapes only on surfaces for which they are designed. Glas-Col® heating cords are an example of a cord that may not be used at LBNL for any purpose but heating glassware and nonmetallic apparatuses.

j. If you are unsure whether or not your heating tape or cord is approved for use at LBNL, refer to PUB-3000 Chapter 14, *Electrical Equipment Safety Program* or contact the EHS Electrical Safety Group.

5.9.3 Heating Tape Power Source Requirements

a. A ground fault current interrupter (GFCI) protected power source must be used. Portable GFCI adaptors are acceptable.

b. A maximum of 1920 W (16 A) of heating capacity may be placed on a 20-amp circuit breaker.

c. A maximum of 1440 W (12 A) heating capacity may be placed on any individual power cord or receptacle

d. Do not use relocatable power taps (power strips) for heating tape.

5.10 Portable Heating Devices

5.10.1 Use of portable electric heating devices is covered by PUB-3000, Chapter 12, *Fire Prevention and Protection*, Work Process J, *Portable Heating Devices*. It includes include portable electric space heaters, coffee pots, and hot plates.

5.11 Holiday Lights

5.11.1 Holiday lights are permitted for temporary installation up to 90 days in office areas. They are not permitted in laboratory areas or technical spaces.

5.11.2 Always use GFCI protection on holiday lights.

5.11.3 Do not staple holiday lights.

5.11.4 Holiday lights are designed to be daisy-chained. Observe the maximum total load restrictions when daisy-chaining holiday lights.

5.12 Working Space Around Electrical Equipment

5.12.1 Clear Spaces. Working space required by this section shall not be used for storage.

5.12.2 Working space around electrical enclosures or equipment shall be adequate for conducting all anticipated maintenance and operations safely, including sufficient space to ensure safety of personnel working during emergency conditions and workers rescuing injured personnel.

5.12.3 Spacing shall provide the dimensional clearance (addressed in the following subsections) for personnel access to equipment likely to require examination, adjustment, servicing, or maintenance while energized. Such equipment includes panelboards, switches, circuit breakers, switchgear, controllers, and controls on heating and air conditioning equipment.

5.12.4 These working clearances are not required if the equipment is not likely to require examination, adjustment, servicing, or maintenance while energized. However, sufficient access and working space is still required.

5.12.5 Dead-Front Assemblies

a. Working space shall not be required in the back or sides of assemblies, such as dead-front switchboards, switchgear, or motor control centers, where all connections and all renewable or adjustable parts, such as fuses or switches, are accessible from locations other than the back or sides.

b. Where rear access is required to work on nonelectrical parts on the back of enclosed equipment, a minimum working space of 30 in horizontally shall be provided.

5.12.6 Working spaces may overlap.

5.12.7 Height of Working Space

a. The working space shall be clear and extend from the grade, floor, or platform to a height of 6½ ft or the height of the equipment, whichever is greater.

b. Within the height requirements of this section, other equipment that is associated with the electrical installation and is located above or below the electrical equipment shall be permitted to extend not more than 6 in beyond the front of the electrical equipment.

5.12.8 Width of Working Space

a. A minimum working space 30 inches wide shall be provided in front of electrical equipment rated at 600 V or less and is likely to require servicing while energized. This provides room to avoid body contact with grounded parts while working with energized components of the equipment.

b. The width of the working space may be centered in front of the equipment or can be offset. The depth of the working space shall be clear to the floor.

c. For equipment rated above 600 V, the width of the working space shall be 36 inches.

d. In all cases, there shall be clearance in the work area to allow at least a 90-degree opening of equipment doors or hinged panels on the service equipment.

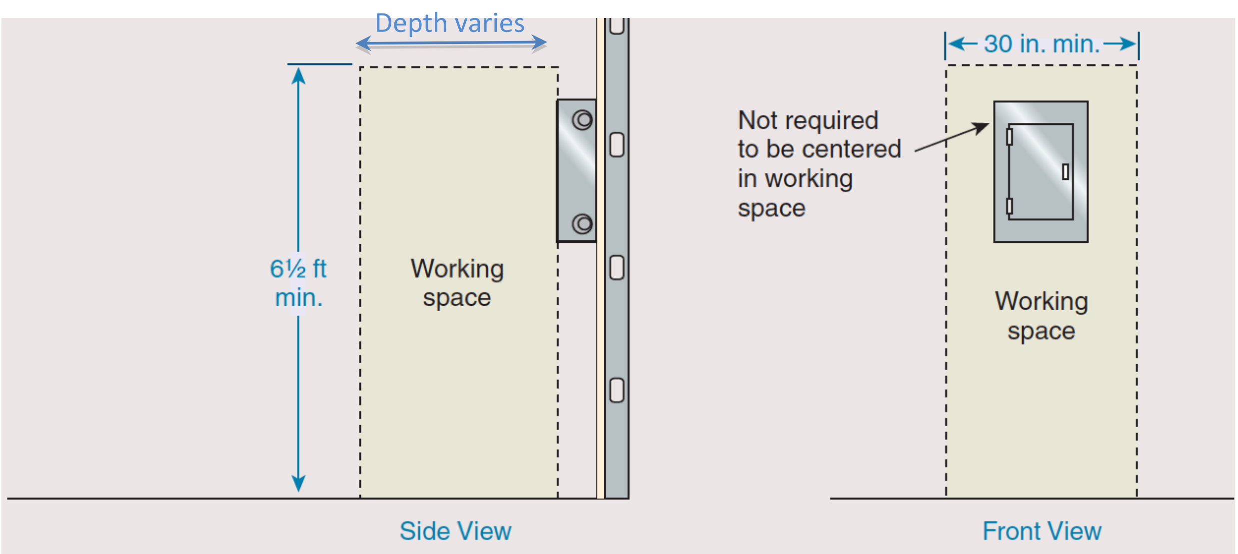


Fig. 5.12.7 – Working space in front of a panelboard <600 V. Depth varies depending on Voltage and Condition.

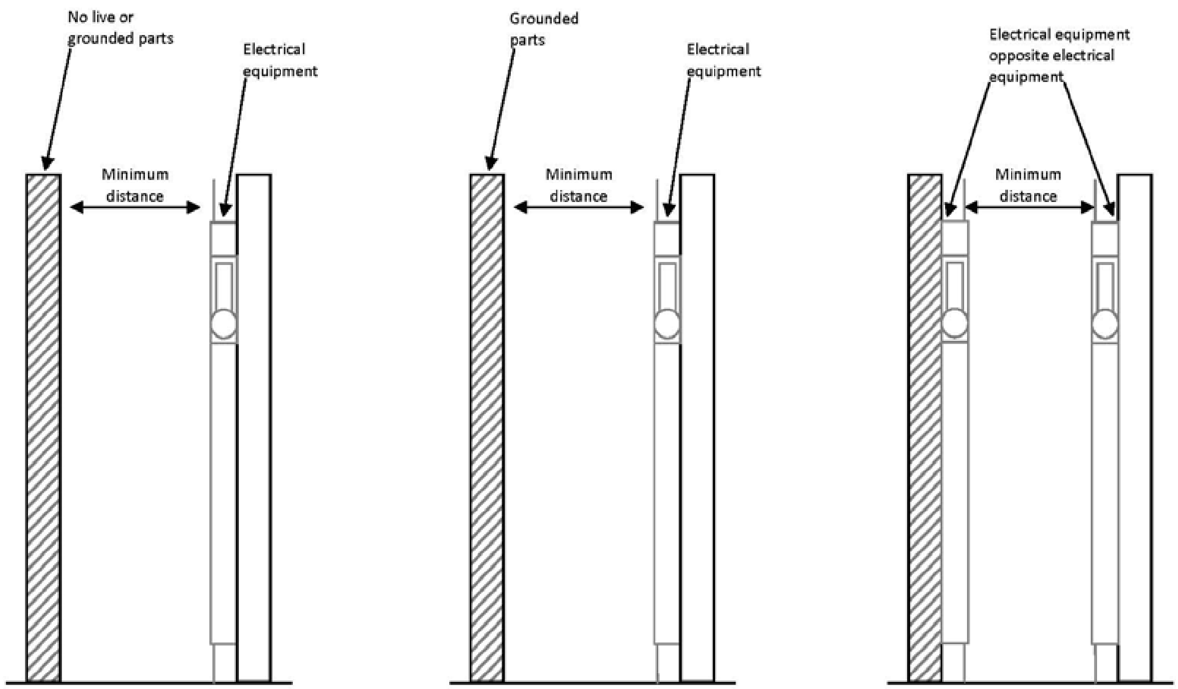
5.12.9 Depth of Working Space

a. The depth of the working space varies depending upon existing conditions (Table 5.12.9, Fig. 5.12.9).

b. Condition 1: Exposed live parts on one side of the working space and no live or grounded parts on the other side of the working space, or exposed live parts on both sides of the working space that are effectively guarded by insulating materials.

c. Condition 2: Exposed live parts on one side of the working space and grounded parts on the other side of the working space. Concrete, brick, or tile walls shall be considered as grounded.

d. Condition 3: Exposed live parts on both sides of the working space.



Condition 1 Condition 2 Condition 3

Fig 5.12.9 – Illustration of Conditions for Working Clearance

Minimum Depth of Working Clearance in Front of Panel Face			
Volts to Ground	**Condition 1**	**Condition 2**	**Condition 3**
0-150 V	3 ft	3 ft	3 ft
151-600 V	3 ft	3.5 ft	4 ft
601-2500 V	3 ft	4 ft	5 ft
2501-9000 V	4 ft	5 ft	6 ft
9001-25000 V	5 ft	6 ft	9 ft

Table 5.12.9 – Minimum clearances in front of electrical equipment

5.13 Switching

5.13.1 This section concerns the switching of electrical disconnects and circuit breakers for normal operation of electrical equipment.

5.13.2 All non-QEWs who perform switching on premises wiring panelboards or any circuit breaker or fused disconnect rated at 15 Amps or greater must take the class EHS0536 – *Electrical Switching Safety for non-QEWs*.

5.13.3 Switching is the manual operation (opening or closing) of any electrical isolation on energized equipment. Manual operation includes the operation of through-the-door breaker handles or other dead-front switching.

5.13.4 Non-QEWs are permitted to perform switching where there is no shock or arc flash hazard. To help non-QEWs in determining when switching is allowed, the following rules are established. These rules are more restrictive than the rules established in Sections 7 or 8, which are applied by QEWs.

a. For more information on determining a shock hazard or an arc flash hazard, see Sections 7 or 8 respectively and contact a QEW for assistance.

5.13.5 Determination of a shock hazard for switching

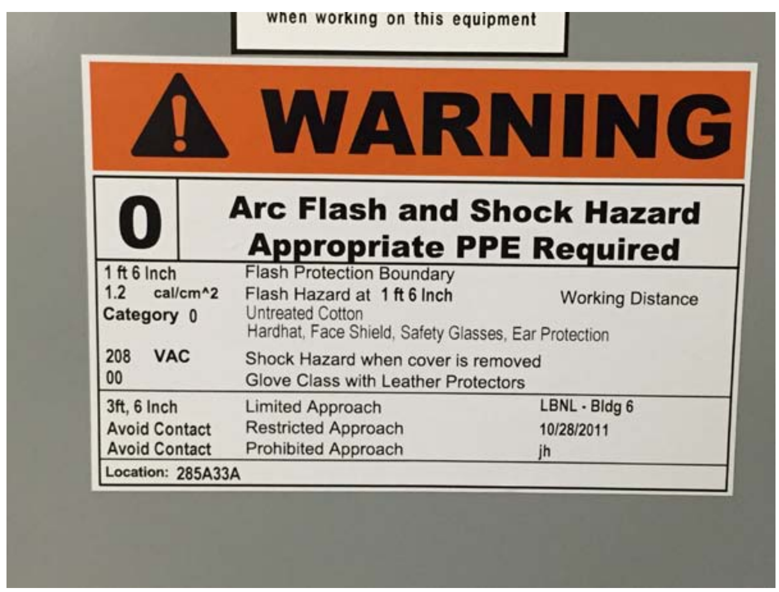
a. Check the condition of the panel enclosure. Switching is allowed where the panel is fully enclosed and in good repair. There can be no visible exposed live parts. Covers must be latched tight and all fasteners must be in place.

b. Finger safe rating is not sufficient for switching of disconnects inside enclosures by non-QEWs.

5.13.6 Determination of an arc flash hazard for switching

a. An arc flash hazard is a dangerous condition associated with the possible release of energy caused by an electric arc, resulting in second-degree burns to the skin or ignition of clothing. An arc flash hazard may exist when performing normal switching of electrical equipment.

b. Where a panel is labeled with an arc flash label, check the incident energy at the working distance. Switching is allowed where the incident energy is 4 cal/cm^2 or less.



c. Where the panel is not labeled with an arc flash label, check the panel voltage and main circuit breaker or fuse amp ratings. Switching is allowed where:
   - Voltage 120 VAC or less – all cases
   - Voltage less than 250 VAC and main protective device less than 250 A
   - Voltage less than 750 VAC and main protective device less than 60 A

d. In all other cases, a Qualified Electrical Worker is required to perform the switching.

Pic – In this case, the panel is not labeled with arc flash energy. However, it is a 120/208 VAC panel and the main breaker is rated for only 100 A, so non-QEWs are allowed to perform switching in this panel.

5.13.7 Minimum PPE: the minimum PPE for electrical switching is a leather glove on the switching hand and safety glasses.

5.13.8 Switching method: when performing switching, the worker will take the following standard precautions:

a. Stand to the side. Where possible, do not reach across the panel to the switch handle, instead stand on the same side of the panel as the switch handle.

b. Place hand on the switch handle but do not operate the switch.

c. Face away from the switch, close the eyes, take a deep breath and hold it.

d. Forcefully throw the switch in a complete full motion.

e. Verify system response.

5.13.9 Tripped circuit breakers. The following applies to molded case circuit breakers commonly operated by non-QEWs.

a. Circuit breakers are designed to trip for two types of overcurrent condition: overload and short-circuit.

b. In an overload condition, the thermal element will open the breaker after a certain time depending on the amount of overload. This can take anywhere from an hour (135% overload) to a couple of minutes (200% overload). This action protects the wiring insulation from overheating and causing a fire. This can happen when multiple high current loads are run at the same time on the same circuit. For example, running a space heater, a coffee maker, and a microwave at the same time.

c. In a short-circuit condition, the breaker is subjected to a high current surge (>2000 Amps) and uses the resulting magnetic impulse to trip the breaker instantaneously. This can happen either by a ground fault (for grounded equipment) or a phase to neutral short. It is important to note that while breakers are rated to interrupt a short circuit once without failing, it is possible (even likely) that they will fail catastrophically should they be reclosed on short circuit. This can result in injury to the hands and face.

d. If it is readily apparent that the circuit breaker tripped on an overload condition, correct the condition by removing the excess load. After removing the excess load, reset and close the breaker. If the circuit breaker trips again, leave it alone and call a Qualified Electrical Worker for assistance.

e. If there is no apparent cause of overload, do not assume that the breaker can be reclosed, even once. Leave the breaker alone and call a Qualified Electrical Worker for assistance.

f. See 10.4.13 for more information on reclosing circuits after protective device operation.

5.13.10 Switching of Fluorescent Lighting

a. For routine switching of fluorescent lighting, do not use circuit breakers in panel boards unless these are specifically rated for switching duty.

b. A switching duty (SWD) circuit breaker is listed under UL 489 specifically for switching fluorescent lighting loads on a regular basis.

c. SWD circuits breakers can be identified by a "SWD" marking on the front or side of the breaker. However, panel board trim pieces may need to be temporarily removed by a QEW for visual confirmation.

d. Note that there are no 480 VAC, 3-phase SWD breakers. SWD circuit breakers are limited to 15 or 20 Amps and less than 347 Volts.

6 Electrical Safe Work Controls

6.1 Scope

6.1.1 This section establishes the necessary work planning and control requirements for Qualified Electrical Workers (QEWs) performing electrical work.

6.2 Qualified Electrical Workers (QEWs)

6.2.1 A Qualified Electrical Worker (QEW) is one who has demonstrated skills and knowledge related to the construction and operation of electrical equipment and installations, has received safety training to identify and avoid the hazards involved, and who has been approved by the Electrical AHJ for Safe Work Practices.

6.2.2 Any person who is not a QEW is called a non-QEW.

6.2.3 By definition (6.3.1), only QEWs may be authorized to perform electrical work. This includes both live and deenergized work, for build, service, maintenance, and repair of equipment designed to operate above the following shock hazard thresholds:

Source	Includes	Thresholds
AC	50-60 Hz nominal	≥ 50 V and ≥ 5 mA
DC	All	≥ 100 V and ≥ 40 mA
Capacitors	All	≥ 100 V and ≥ 1 J, or ≥ 400 V and ≥ 0.25 J
Batteries	Lead-Acid and Lithium Ion	≥ 100 V
Sub-RF	1 Hz to 3 kHz (excluding 50-60 Hz nominal)	≥ 50 V and ≥ 5 mA
RF	3 kHz to 100 MHz	A function of frequency

Table 6.2.3 – Shock Hazard Thresholds

6.2.4 QEWs shall be classified in accordance with Table 6.2.4, depending primarily on the type of utility power feeding the equipment they perform electrical work upon.

QEW Level	Utility Source Type (Volts Phase to Phase)
QEW 1 (Researchers, Fire Alarm Technicians and Engineers)	50 – 300 VAC, 50-60 Hz power, provided there is no arc flash hazard
QEW 2 (Lighting Electricians, HVAC, Electricians, Electronics Technicians and Electrical Engineers)	50 – 750 VAC, 50-60 Hz power, with or without arc flash hazard
QEW 3 (High Voltage Electricians and High Voltage Electrical Engineers)	>750 VAC Utility 60 Hz

Table 6.2.4 – QEW Levels

a. A QEW 2 can be authorized to perform work on QEW 1 level equipment. A QEW 3 can be authorized to perform work on QEW 2 and QEW 1 level equipment.

b. Determination of an arc flash hazard for the purposes of QEW 1 level determination shall be done in accordance with Section 8.

6.2.5 AHJ approval of QEW's

a. AHJ approval of QEWs shall be in accordance with PUB-3000, Chapter 8, *Electrical Safety Program*, Work Process E, *AHJ Approval of Berkeley Lab QEWs*. Some exceptions apply when non-QEWs perform work under the supervision of a QEW.

b. Construction subcontractors tasked with performing electrical work under the cJHA process are also required to be accepted as QEWs, and fall under PUB-3000, Chapter 8, *Electrical Safety Program*, Work Process F, *AHJ Acceptance of Construction Subcontractor QEWs*.

c. Vendors tasked with performing electrical work under the sJHA process are also required to be accepted as QEWs, and fall under PUB-3000, Chapter 8, *Electrical Safety Program*, Work Process G, *AHJ Acceptance of Non-Construction Subcontractor QEWs*. Some exceptions apply when non-QEWs perform work on their own equipment and under the supervision of a QEW.

d. The EHS Electrical Safety Group will issue a QEW badge to approved QEWs. The badge is to be carried with the employee's LBNL Badge. In addition to name, photo, and employee ID number, the QEW Badge will indicate QEW level and any restrictions on the approval.

6.2.6 Training requirements for QEWs shall be in accordance with PUB-3000, Chapter 8, *Electrical Safety Program*, Work Process I, *Electrical Safety Training for Berkeley Lab QEWs*.

6.3 Electrical Work and Requirement for a QEW

6.3.1 Electrical work is defined as any task requiring a Qualified Electrical Worker. It includes any work that involves a shock or arc flash hazard or could create potential shock or arc flash hazards for future users.

6.3.2 Qualified Electrical Workers shall be required for the following tasks, which are classified as electrical work:

a. Any modification, repair, build or assembly of electrical circuit parts or wiring designed to operate above the shock thresholds of Table 6.2.3, even after being placed in an Electrically Safe Work Condition. Examples include:
   - Making or tightening electrical terminal connections with tools, as poor or improper connection can create serious hazards.
   - Any work on the grounding and bonding system
   - Any work on the power entry module or field wiring terminals
   - Replacing critical components with new components of different ratings. Critical components include electrical components or assemblies used in a power or safety circuit whose proper operation is essential to the safe performance of the system or circuit (e.g. fuses, circuit breakers, power wiring, transformers, heaters, motors, overloads, interlocks, emergency stops, etc.).

b. Any operation of equipment that does not meet the requirements for normal operation of 6.3.5.

c. Hazardous switching, where there is a shock or arc flash hazard in accordance with 6.3.6.

d. Any task within the Restricted Approach Boundary of exposed live parts that have not been placed in an Electrically Safe Work Condition, including placing equipment in an Electrically Safe Work Condition.

6.3.3 Non-QEWs may perform the following types of tasks:

a. Normal operation of approved electrical equipment in accordance with 6.3.5.

b. Non-hazardous switching, where there is no shock or arc flash hazard in accordance with 6.3.6.

c. Access within the Limited Approach Boundary of exposed live parts that have not been placed in an Electrically Safe Work Condition, if escorted by a QEW as required in 7.3.2.c.

d. Any task that does not involve the modification, repair, build or assembly of electrical circuit parts or wiring designed to operate above the shock thresholds of Table 6.2.3, within the Limited Approach Boundary of exposed live parts that have been placed in an Electrically Safe Work Condition. Zero Voltage Verification (ZVV) must be performed by a QEW and the non-QEW must apply a personal LOTO lock in accordance with PUB-3000, Chapter 18, *Lockout/Tagout Program*.

6.3.4 Some tasks may or may not require a QEW, where the presence of a shock or arc flash hazard is dependent on the configuration of the equipment.

a. Non-QEWs shall seek the help of a QEW or other knowledgeable individual (like an Electrical Safety Advocate or supervisor) in determining whether such a task requires a QEW. The Electrical AHJ for Safe Work Practices shall have final authority over such determinations.

b. Typical R&D equipment may or may not have sufficient engineered safeguards to mitigate shock or arc flash hazards when performing common tasks such as adjusting system parameters in digital controllers with cabinet doors open while the system is energized. Where a shock or arc flash hazard is present, a QEW is required. Alternatively, a QEW may place temporary safeguards over exposed live parts to eliminate the shock or arc flash hazard. This would allow the non-QEW to perform non-electrical work.

c. Examples of tasks that may or may not require a QEW include:
   - Work in proximity to energized components that are protected by finger safe designs (see 7.2.3). A QEW is required to determine whether parts are in fact finger safe for the scope of work being proposed.
   - Like-for-like replacement of electrical components designed to be user-serviceable by the manufacturer. This can include replacement of bulbs, fuses, circuit boards, relays or other plug-and-play devices. Some devices are designed to eliminate the hazard and require no special tools or methods, and therefore could be performed by a non-QEW.
   - Adjusting variable speed drive control parameters in a cabinet with live exposed 208 VAC. A QEW can apply temporary barriers over exposed parts, allowing a non-QEW to safely perform the work.

6.3.5 Normal operation

a. Under normal operation of approved electrical equipment, the user/operator is protected by engineering controls, including insulation, enclosures, barriers, grounds and other methods to prevent injury. Approved means that it has been accepted either by the Electrical AHJ for Safe Installations in accordance with ___ or by the Electrical AHJ for Safe Equipment in accordance with PUB-3000, Chapter 14, *Electrical Equipment Safety Program*.

b. Where all of the following conditions are satisfied, normal operation of electric equipment is not considered electrical work and shall be permitted by non-QEWs:
   - The equipment is properly installed, in accordance with applicable industry codes and standards and the manufacturer's recommendations.
   - The equipment is properly maintained by qualified persons.
   - The equipment doors are closed and secured.
   - All equipment covers are in place and secured.

- There is no evidence of impending failure (10.4.10 and 10.4.11).

c. Where the conditions for normal operation are not satisfied, it is assumed that a shock or arc flash hazard may exist when operating the equipment.

6.3.6 Switching

a. Switching is the manual operation (opening or closing) of any electrical isolation. This includes the operation of through-the-door breaker handles or other dead-front switching.

b. Energized switching is classified as either hazardous or non-hazardous, depending on whether a shock or arc flash hazard is present.

c. Non-hazardous switching is any switching where there is no shock or arc flash hazard. In all cases the conditions for normal operation of must be satisfied for non-hazardous switching. Non-QEWs may only be authorized to perform non-hazardous switching. The restrictions in 5.13 are designed for a non-QEW to be able to identify when safe switching can be performed. As an alternative, a QEW may perform a shock and arc flash hazard analysis in accordance with 7.1 and 8.1 to determine if a non-QEW can perform safe switching in a specific instance.

d. Hazardous switching, where a shock or arc flash hazard is present, is classified as electrical work. Only QEWs may be authorized to perform hazardous switching, wearing the appropriate level of PPE in accordance with the shock and arc flash hazard analyses.

e. Where a QEW performs non-hazardous switching, only the minimum PPE of 5.13 shall be required.

f. In all cases, only load-rated switches, circuit breakers, or disconnects shall be used for the opening, reversing, or closing of circuits under load conditions.

6.3.7 Types of Electrical Work. When engineering controls are not yet in place, not approved, or removed for diagnostics, maintenance, or repair, work on electrical equipment is classified as electrical work and falls into one of the following modes. These modes are primarily used as short hand terminology for indexing types of electrical work:

a. Mode 0 – Electrically Safe Work Condition

b. Mode 1 – Establishing an Electrically Safe Work Condition (LOTO)

c. Mode 2 – Energized Diagnostics (Testing & Troubleshooting)

d. Mode 3 – Energized Repair/Installation (EEWP)

6.4 Mode 0 – Electrically Safe Work Condition

6.4.1 An Electrically Safe Work Condition is a state in which an electrical conductor or circuit part has been disconnected from energized parts, locked/tagged in accordance with the Berkeley Lab Lockout/Tagout Program, tested by a QEW to ensure the absence of voltage (Zero Voltage Verification – ZVV), and grounded if determined necessary.

6.4.2 Work performed in an Electrically Safe Work Condition may or may not be classified as electrical work, in accordance with 6.3.

6.4.3 Energized electrical conductors and circuit parts shall be put into an Electrically Safe Work Condition by following the process in 6.5 before an employee performs work if any of the following conditions exist:

a. There is a shock hazard, as determined by a shock hazard analysis in Section 7.1.

b. There is an arc flash hazard, as determined by an arc flash hazard analysis in Section 8.1.

6.4.4 Exceptions:

a. Normal operation as described in 6.3.5.

b. Switching: Where a disconnecting means or isolating element that has been properly installed and maintained is operated, opened, closed, removed, or inserted to achieve an Electrically Safe Work Condition for connected equipment or to return connected equipment to service that has been placed in an Electrically Safe Work Condition, the equipment supplying the disconnecting means or isolating element shall not be required to be placed in an Electrically Safe Work Condition provided a risk assessment is performed and does not identify unacceptable risks for the task.
   - Note: if the arc flash incident energy is greater than 40 cal/cm^2, the risk is considered unacceptable unless an engineered remote switching device can be used (see 8.11).

c. Additional Hazards or Increased Risk: Energized work shall be permitted where line management can demonstrate that de-energizing introduces additional hazards or increased risk. Examples of additional hazards or increased risk include, but are not limited to, interruption of life-support equipment, deactivation of emergency alarm systems, and shutdown of hazardous location ventilation equipment.

d. Infeasibility: Energized work shall be permitted where the line management can demonstrate that the task to be performed is infeasible in a de-energized state due to equipment design or operational limitations. Examples of work that might be performed within the limited approach boundary of exposed energized electrical conductors or circuit parts because of infeasibility due to equipment design or operational limitations include performing diagnostics and testing (for example, start-up or troubleshooting) of electric circuits that can only be performed with the circuit energized and work on circuits that form an integral part of a continuous process that would otherwise need to be completely shut down in order to permit work on one circuit or piece of equipment.

e. Non-hazardous voltage: Energized electrical conductors and circuit parts that operate at less than the shock thresholds of 6.2.3 shall not be required to be deenergized where the capacity of the source and any overcurrent protection between the energy source and the worker are considered and it is determined that there will be no increased exposure to electrical burns or to explosion due to electric arcs.

6.5 Mode 1 – Process for Establishing an Electrically Safe Work Condition (LOTO)

6.5.1 An Electrically Safe Work Condition shall be achieved where required by 6.4 by executing the following process:

a. Determine all possible sources of electrical supply to the specific equipment. Check applicable up-to-date drawings, diagrams, and identification tags.

b. After properly interrupting the load current, open the disconnecting device(s) for each source.

c. Wherever possible, visually verify that all contact points of the disconnecting devices are fully open or that drawout-type circuit breakers are withdrawn to the fully disconnected position.

d. Perform Zero Voltage Verification (ZVV) to verify that the circuit parts are deenergized. Follow the requirements in Section 9.

e. Where the possibility of stored electrical energy exists, dissipate the stored energy by grounding the phase conductors or circuit parts with an approved rated tool designed for the purpose. For high voltage circuits apply temporary personal protective grounds rated for the available fault duty.

f. Apply lockout/tagout devices in accordance with PUB-3000, Chapter 18, *Lockout/Tagout Program*. Depending on the configuration of the circuit it may be necessary to perform this step prior to steps d or e.

6.5.2 Mode 1 work is considered energized electrical work but exempt from the requirements for an EEWP. If the Mode 1 process exposes the worker to any hazard, the activity should be covered by work control procedures, and a hazard analysis should be performed.

6.5.3 When Mode 1 work is performed in the context of a Complex LOTO Procedure that involves more than just electrical hazards, care shall be taken to appoint a designated Person In Charge for the electrical portion of the work. The electrical PIC will conduct the electrical portion of the LOTO Briefing, which will count as the Job Briefing.

6.5.4 Placing cord and plug equipment into an Electrically Safe Work Condition is not electrical work and does not require a QEW, provided that it meets the requirements of LOTO Exemption in PUB-3000, Chapter 18, *Lockout/Tagout Program*, Work Process C, *Cord-and-Plug Equipment*.

6.5.5 Electrical requirements for proper lockout points

a. Where fuses are used, the simple removal of the fuse is an acceptable means of isolation for lockout. To prevent the fuse from being replaced by others, lock out access to the fuse holder. Locking away the fuses themselves without preventing insertion of different fuses is not a sufficient method of control.

b. Fuseholders with exposed energized terminals shall temporarily be placed in an Electrically Safe Work Condition while removing or replacing the fuses.

c. Fuseholders with guarded terminals, but where removal of the fuse exposes energized terminals that can be touched, shall temporarily be placed in an Electrically Safe Work Condition while removing or replacing the fuses.

d. Where the lockout point requires the disconnection of wires, the requirements of 10.4.15 shall be followed.

6.5.6 The process for clearing a LOTO and restoring equipment to normal operation is considered Mode 1 work until all grounding devices have been removed the equipment has been verified safe. After that, restoration falls under normal operation. When performing Temporary Partial Restoration for testing and the equipment is not placed in a fully safe normal operating condition, electrical work shall be performed in Mode 2.

6.6 Mode 2 – Energized Diagnostics (Testing & Troubleshooting)

6.6.1 Energized diagnostics are permitted without an Energized Electrical Work Permit (EEWP) and include testing, troubleshooting, voltage measuring and visual inspections. While energized diagnostics do not require an EEWP, they still require full application of electrical safe work controls. This includes proper planning, qualifications, job briefing, PPE, temporary barriers, barricades, and other suitable controls as necessary.

6.6.2 In Mode 2, measurements, diagnostics, testing, and visual inspection of equipment functions are conducted with the equipment energized and with some, or all, of the normal protective barriers removed and interlocks bypassed. Zero Voltage Verification (ZVV) Verification is covered by the Mode 1 process and is not considered Mode 2.

6.6.3 Mode 2 work is considered energized electrical work but exempt from the requirements for an EEWP. If the Mode 2 process exposes the worker to any hazard, the activity should be covered by work control procedures, and a hazard analysis should be performed.

6.6.4 If any portion of the worker's body passes the Restricted Approach Boundary, appropriate shock PPE should be worn. If any portion of the worker's body passes the Arc Flash Boundary, the appropriate arc flash PPE should be worn.

6.6.5 Limited diagnostics are permitted under the QEW skill of the craft subject to the limitations in 6.10. Complex diagnostics may require additional planning, an Electrical Safe Work Procedure (6.8), direct field supervision (6.11), or a combination of controls as necessary for the complexity of the diagnostics and the degree of hazard involved.

6.6.6 All diagnostic work requires a designated Person In Charge and a Job Briefing.

6.6.7 Visual inspection of normally-enclosed, exposed energized facilities distribution equipment greater than 750 VAC (Class 1.4) is prohibited. Other energized electrical equipment may be visually inspected without placing it in an Electrically Safe Work Condition under the following conditions:

a. Cover panels are hinged or can be removed without risking breaking the plane of the opening.

b. The equipment is not deranged per Section 10.4.11.

c. Only Qualified Electrical Workers, and persons escorted by a Qualified Electrical Worker, are authorized to perform the visual inspection.

d. The worker must wear the appropriate minimum PPE per Section 10.1.

e. No part of any tool or body may enter the Restricted Approach Boundary.

f. The worker must position his/her body in such a way as to preclude inadvertent movement that would break the Restricted Approach Boundary.

6.6.8 Infrared Inspections

a. Infrared scans are performed with equipment and/or systems in an energized state due to load current requirements.

b. During an infrared scan no person will break the Restricted Approach Boundary of the electrical equipment that has the doors open or covers removed.

c. Infrared inspections on energized low-voltage equipment shall follow the requirements of Visual Inspection in 6.6.5.

d. Infrared inspections on energized high-voltage equipment shall require using permanently installed infrared inspection ports.

e. Although performing infrared inspections does not in itself create an arc flash hazard (8.2.4.f), opening or closing enclosures for the purpose of performing the infrared inspection can create an arc flash hazard (8.2.5.d).

6.6.9 Subcontractor Energized Electrical Testing Permit (EETP)

a. Where Required: When subcontractor QEWs perform testing or troubleshooting on exposed energized electrical conductors or circuit parts that are not placed in an Electrically Safe Work Condition work.

b. Exceptions:
   - Where the equipment is labeled with the arc flash and shock hazards, and the testing or troubleshooting is performed within the skill of the craft of the Subcontractor QEW, an EETP shall not be required.
   - Where a Subcontractor LOTO Permit already specifies all the relevant hazards and controls, an additional EETP shall not be required.

c. Elements of the EETP: The energized electrical testing permit shall include, but not be limited to, the following items:
   - An Electrical Safe Work Procedure (see section 6.8) approved by the EHS Electrical Safety Group
   - Verification that the Subcontractors are current in their QEW certification.

d. Approval: The EHS Electrical Safety Group is the final approver for the EETP.

e. Documented Job Briefing:
   - All persons participating in the EETP job briefing shall sign in to the EETP.
   - The completed EETP, Electrical Safe Work Procedure, and job briefing sign-in sheet shall be returned to the Electrical AHJ for Safe Work Practices for record keeping.

f. Application for an EETP: Contact the Electrical Safety Group to apply for an EETP.

6.7 Mode 3 – Energized Repair Work (EEWP)

6.7.1 Energized electrical work that does not meet the requirements for Normal Operation, Switching, Placing the equipment in an Electrically Safe Work Condition, or Energized Diagnostics shall be classified as Electrical Repair Work and shall be performed in an Electrically Safe Work Condition unless it meets one of the exemptions in 6.4.4.

6.7.2 When performing Electrical Repair Work on energized electrical conductors or circuit parts that are not placed in an Electrically Safe Work Condition (i.e., for the reasons of increased or additional hazards or infeasibility per 6.4.4), work to be performed shall be considered Energized Electrical Repair Work and shall require an approved Energized Electrical Work Permit (EEWP).

6.7.3 Elements of the EEWP. The energized electrical work permit shall include, but not be limited to, the following items:

a. An Electrical Safe Work Procedure (see section 6.8) approved by the EHS Electrical AHJ for Safe Work Practices

b. Justification for why the work must be performed in an energized condition

c. Energized work approval by a senior line manager designated by the EHS Electrical AHJ for Safe Work Practices.

6.7.4 Justification:

a. The justification for the EEWP is one of the critical elements of an EEWP. The EEWP requester must provide sufficient information to substantiate the request. Energized repair, modification or installation is a high-risk activity that is most often avoided with proper planning and coordination.

b. Justification shall be based on the increased or additional hazards clause of 6.4.4.c or the infeasibility clause of 6.4.4.d, or both.

c. Additionally, justification for the following shall also be provided in the EEWP application:
   - Reason why the work must be performed and no alternatives have been found adequate, including not doing the work at all.
   - Reason why the work cannot be delayed until the next scheduled or unscheduled outage.

6.7.5 Approval:

a. The EHS Electrical AHJ for Safe Work Practices is not the final approver for the EEWP. Only a senior line manager who has the authority to require an outage instead of energized work is authorized to approve an EEWP.

b. After consideration of the scope of work and the justification statement, the EHS Electrical AHJ for Safe Work Practices will select the appropriate senior line managers for approval of the EEWP. In most cases this will be a division director (or their deputy) for the division most impacted by the outage. In some cases the EHS Electrical AHJ for Safe Work Practices will refer the EEWP to the Chief Operating Officer (COO) for final approval.

6.7.6 Documented Job Briefing:

a. The job briefing for the EEWP shall be documented. All persons participating in the EEWP job briefing shall sign in to the EEWP.

b. The completed EEWP, Electrical Safe Work Procedure, and job briefing sign-in sheet shall be returned to the Electrical AHJ for Safe Work Practices for record keeping.

6.7.7 Application for an EEWP: Contact the Electrical AHJ for Safe Work Practices to apply for an EEWP. Note that as a matter of policy, the AHJ will normally reject all applications for an EEWP unless the justification is fully substantiated.

6.8 Electrical Safe Work Procedure (ESWP)

6.8.1 An Electrical Safe Work Procedure is a documented, step-by-step procedure for executing a specific task or set of tasks on electrical equipment. It is required for all jobs where the complexity of the task exceeds the normal skill of the craft for the Qualified Electrical Worker, or where a significant level of coordination is required between multiple individuals.

6.8.2 An Electrical Safe Work Procedure is the interface between the "planning" and the "doing." It is designed to provide an awareness of both electrical hazards and discipline for all personnel who are required to work in an energized electrical environment. A procedure on safe practices on or near electrical conductors allows for an instant audit of what is required to perform work on or near energized electrical conductors and circuit parts.

6.8.3 Procedural compliance.

a. Procedures shall be executed as written and approved. No shortcuts or spur-of-the-moment activity shall be permitted.

b. Work on or near energized conductors and circuit parts that develops, and which has not been previously identified by a procedure, should be reviewed, and a special procedure should be written prior to the performance of the work.

c. When a procedure cannot be safely followed, because the qualified electrical worker feels there is information missing, an incorrect step, this will be a stop work condition. Work will not proceed until guidance has been received and the problem resolved to each person's satisfaction.

d. Field changes to the Electrical Safe Work Procedure are permissible after review by an Electrical Safety Officer.

6.8.4 An Electrical Safe Work Procedure may be required for any mode of electrical work.

6.8.5 An Electrical Safe Work Procedure shall be required for the following types of activities:

a. Energized Electrical Work Permit (EEWP)

b. Switching of high voltage distribution equipment (Switching Tags are a form of ESWP)

c. All activities performed on equipment where arc flash incident energy at the typical working distance is calculated at >40 cal/cm^2, before other controls are applied

d. Activities performed less than once per year, unless performed under direct field supervision (6.11)

e. Any activity as deemed necessary by the work lead or an Electrical Safety Officer

6.8.6 The Electrical Safe Work Procedure shall be prepared by one or more QEWs who are familiar with a given facility or plant.

6.8.7 The Electrical Safe Work Procedure shall be reviewed and approved by an Electrical Safety Officer.

6.8.8 Elements of the Electrical Safe Work Procedure:

a. Title. The title identifies the specific equipment where the procedure applies.

b. Purpose. The purpose is to identify the job to be performed.

c. Qualification. The training and knowledge that qualified personal shall possess in order to perform particular tasks are identified.

d. Supervision. The level of direct field supervision, and the training and knowledge that supervisor shall possess in order to supervise the execution of the ESWP.

e. Emergency response plan. Identification of how and where to call for help, emergency egress, emergency lighting, AED, insulated rescue hook, location of nearest electrical disconnect, etc.

f. Hazard identification. The hazards that were identified during development of the procedure are highlighted. These are the hazards that may not appear obvious to personnel performing work on or near the energized equipment.

g. Hazard classification. Results of the shock hazard analysis and arc flash hazard analysis. The degree of risk, as defined by the hazard analysis, is identified for the particular job to be performed.

h. Limits of approach. The approach distances and restrictions are identified for personnel access around energized electrical equipment. Specify requirement for attendants and/or barricades.

i. Safe work practices. The controls that shall be in place prior to, and during the performance of, work on or near energized equipment are emphasized.

j. Personnel protective clothing and equipment. The minimum types and amounts of protective clothing and equipment that are required by personnel to perform the tasks described in the procedures are listed. Personnel performing the work shall wear the protective clothing at all times while performing the tasks identified in the procedure.

k. Test equipment and tools. All the test equipment and tools that are required to perform the work described in this procedure are listed. The test equipment and tools shall be maintained and operated in accordance with the manufacturer's instructions.

l. Reference data. The reference material used in the development of the procedure is listed. It includes the appropriate electrical single-line diagrams, equipment rating (voltage level), and manufacturer's operating instructions.

m. Procedure steps. The steps required by qualified personnel wearing personal protective clothing and using the approved test equipment to perform specific tasks in a specified manner are identified.

n. Sketches/drawings. Sketches or drawings are used, where necessary, to properly illustrate and elaborate specific tasks.

6.8.9 Documented Job Briefing:

a. All persons participating in the Electrical Safe Work Procedure shall sign in to the job briefing.

b. The completed Electrical Safe Work Procedure and job briefing sign-in sheet shall be retained by the work supervisor for record keeping.

6.9 Person in Charge (PIC)

6.9.1 Every electrical job shall be assigned a Person In Charge (PIC). The PIC shall be a Qualified Electrical Worker with suitable competence and experience in the set of tasks to be performed.

6.9.2 The PIC is responsible for the safe execution of the work.

6.9.3 The PIC shall ensure that:

a. For skill of the craft level tasks, that all persons assigned are suitably competent, experienced and trained prior to starting work.

b. For specific tasks beyond skill of the craft, that there is an approved Electrical Safe Work Procedure, or appropriate direct field supervision, or both.

c. When a question arises that cannot be resolved in the field with the personnel present, the PIC shall place the equipment in a safe state, pause the work (hold point) and seek additional assistance. The PIC shall not resume work until the questions have been satisfactorily resolved.

6.10 QEW Skill of the Craft

6.10.1 Skill of the craft is defined as the set of tasks for which a Qualified Electrical Worker is fully competent and can perform without additional planning support or supervision. These vary depending on the individual's experience, position description and routine daily work assignments.

6.10.2 When performing skill of the craft level work, all Qualified Electrical Workers shall be able to determine the degree and extent of the hazard, and the PPE and job planning necessary to perform the task safely.

6.10.3 Where two or more QEWs are performing work under skill of the craft, one shall be designated as Person in Charge. When working alone, the QEW shall be the Person In Charge of his or her own work.

6.10.4 Tasks beyond the normal skill of the craft shall require support in the form of additional planning and/or direct field supervision. A risk assessment should determine the appropriate level of control. A written work plan may be a substitute for direct field supervision. Conversely, direct field supervision may be a substitute for a written work plan. For higher risk jobs, both a written work plan and direct field supervision may be required.

6.10.5 Specific training is required for new equipment or when the QEW is not familiar or experienced with the construction and operation of specific electrical equipment or installation methods. Line management is responsible for ensuring that training or extra instruction is made available prior to performing work. QEWs are responsible for identifying when they do not have the required knowledge or skill related to specific equipment, and for seeking out training or extra instruction prior to performing work.

6.11 Direct Field Supervision

6.11.1 Direct field supervision means that a designated competent QEW is present on site and is providing oversight, guidance and instruction on a specific task or set of tasks to another person.

6.11.2 Depending on the level of risk, direct field supervision can be performed by a designated QEW, a QEW Work Lead, a QEW Supervisor, an Electrical Engineer or an Electrical Safety Officer. In all cases, the designated QEW providing direct field supervision shall be suitably competent for the set of tasks.

6.11.3 Where an ESWP is required, the level of direct field supervision shall be specified in the ESWP.

6.12 Job Briefing

6.12.1 A job briefing is a verbal communication of the job plan to employees involved with the job. A job briefing is required for EVERY JOB.

6.12.2 The job briefing is conducted by the designated Person in Charge (PIC) of the work. The PIC shall conduct the job briefing with the involved employees before the start of each job.

6.12.3 The job briefing shall be documented with a sign-in sheet for all work requiring an Electrical Safe Work Procedure. The completed sign-in sheet shall be saved for record keeping.

6.12.4 The job briefing shall at a minimum, cover the following subjects:

a. hazards associated with the job,

b. work procedures involved,

c. special precautions,

d. energy source controls,

e. two-person rule, and

f. PPE requirements.

6.12.5 If the work or operations to be performed during the workday are repetitive and similar, at least one job briefing shall be conducted before the start of the first job of each day or shift. Additional job briefings shall be held if significant changes, which might affect the safety of the employees, occur during the course of the work.

6.12.6 A brief discussion is satisfactory if the work involved is routine, and if the employee, by virtue of training and experience, can reasonably be expected to recognize and avoid the hazards involved in the job. A more extensive discussion shall be conducted if the work is complicated or extremely hazardous, or if the employee cannot be expected to recognize and avoid the hazards involved in the job.

6.13 Working Alone or Accompanied

6.13.1 In accordance with the Berkeley Lab *Working Alone Policy*, workers at Berkeley Lab are not allowed to work alone when the mitigated hazards associated with their work could incapacitate them such that that they could not "self-rescue" or activate emergency services. This includes when an individual may receive severe electrical shock or arc flash injury.

a. Working alone is defined as when a worker performs electrical work out of sight and earshot of anyone who can help in the event of an emergency.

b. Working accompanied is defined as when a worker performs work with a Standby Person or a Safety Watch. If either the Standby Person or the Safety Watch has to leave the area, the activity is considered to be Working Alone, and must terminate if prohibited in the work authorization.

6.13.2 Working Alone. Typically, the following types of work are allowed to be performed alone, as the risk of shock or arc flash is considered to be negligible:

a. Normal operation

b. Switching, unless Facilities Distribution High Voltage (>750 VAC) Switching (Class 1.4)

c. Work performed in an Electrically Safe Work Condition (Mode 0)

d. Placing electrical equipment in an Electrically Safe Work Condition (Mode 1) when the hazard classification is Yellow (Class X.2) or lower

6.13.3 Standby Person

a. A Standby Person is a second person designated to fulfill the requirements of working accompanied when a QEW is performing certain types of high hazard electrical work. While the primary purpose of the second person is to initiate the emergency response system, a Standby Person is also expected to know how to deenergize electrical equipment and to safely release a QEW from contact with energized parts. This triggers additional controls and training.

b. Both the Standby Person and the QEW performing work for which a Standby Person is required may perform separate jobs or tasks so long as safety is not compromised.

c. For Facilities High Voltage Distribution (>750 VAC) work, the Standby Person must also be a QEW 3. For other work, a Standby Person may be a non-QEW provided that the emergency disconnect can be operated as non-hazardous switching. A non-QEW performing the role of a Standby Person shall complete and remain current in the training requirements for Standby Persons set in Chapter 8, *Electrical Safety Program*, Work Process J, *Electrical Safety Training for Non-QEWs*.

d. A Standby Person is required when work is considered high hazard electrical work, as established by the conditions (hazard class and mode of work) in Tables 3.3 - 3.8, by the Electrical Safe Work Procedure or by the work supervisor:
   - Normal operation: not required
   - Switching: requires a Standby Person for Facilities Distribution High Voltage (>750 VAC) Switching (Hazard Class 1.4).
   - Mode 0: not required
   - Mode 1: requires a Standby Person when the hazard classification is Red (Hazard Class X.3) or higher.
   - Mode 2: requires a Standby Person when the hazard classification is Yellow (Hazard Class X.2) or higher. *Exception - Mode 2 in Hazard Class 1.2 may be performed alone, if proper voltage rated gloves and leather protectors are worn.*
   - Mode 3: must always be a Safety Watch (6.13.4).

e. Briefing. The standby person must be briefed in emergency procedures and the electrical work being performed. During the briefing process, the QEW will assess the qualifications of the standby person to determine that the work may proceed safely.

f. The Standby Person must:
   - If a non-QEW, remain outside of the limited approach boundary or the flash protection boundary except to initiate a rescue attempt
   - Be aware of the QEW's tasks. Remain in visual and audible contact with the QEWs performing the work.
   - Be able to deenergize equipment. The electrical disconnecting means must be located outside of the limited approach boundary and the flash protection boundary. If it would take more than 1 minute to reach the designated electrical disconnect, then an acceptable means (such as an insulated rescue hook) shall be selected and prepared to rescue the QEW without first disconnecting power.
   - Know the location of nearest telephones, and how to alert emergency rescue personnel
   - Know the location of the nearest AED
   - Know how to free an injured worker from the hazard
   - Be trained and current in first aid
   - Be trained and current in cardiopulmonary resuscitation (CPR), including Automatic External Defibrillator (AED) operation

g. When two or more QEWs are working together, a separate Standby Person is not required. All QEWs shall be prepared to fulfill the duties of Standby Person for each other.

h. In the event of an electrical incident, the Standby Person shall initiate Chapter 8, *Electrical Safety Program*, Work Process K, *Electrical Shock Emergency Response*.

6.13.4 Electrical Safety Watch

a. A Safety Watch is a *more stringent* hazard control measure than the Standby Person and must be implemented when there are grave consequences from a failure to follow safe work procedures.

b. A Safety Watch is required when work is considered very high hazard electrical work, as established by the conditions (hazard class and mode of work) in Tables 3.3 - 3.8, by the Electrical Safe Work Procedure or by the work supervisor.
   - Normal operation: not required
   - Switching: not required
   - Mode 0: not required
   - Mode 1: not required
   - Mode 2: requires a Safety Watch when the hazard classification is Red (Hazard Class X.3) or higher.
   - Mode 3: requires a Safety Watch when the hazard classification is Yellow (Hazard Class X.2) or higher.

c. The Safety Watch must be a Qualified Electrical Worker of the same level as that required for the QEWs performing the work, and shall be responsible for monitoring the Qualified Electrical Worker(s) doing the work. Qualifications of the Safety Watch include:
   - Be a Qualified Electrical Worker of the same level as what is required for the work
   - Know how to free an injured worker from the hazard
   - Be trained and current in first aid
   - Be trained and current in cardiopulmonary resuscitation (CPR), including Automatic External Defibrillator (AED) operation

d. Duties of the Safety Watch include:
   - Remain outside of the limited approach boundary or the flash protection boundary except to initiate a rescue attempt
   - Have a thorough knowledge of the specific working procedures to be followed and the work to be done.
   - Know the location of nearest telephones, and how to alert emergency rescue personnel
   - Have an AED at the job location but outside of the limited approach boundary or arc flash boundary, whichever is greater.
   - Be able to deenergize equipment. The electrical disconnecting means must be located outside of the limited approach boundary and the flash protection boundary. If it would take more than 1 minute to reach the designated electrical disconnect, then an acceptable means (such as an insulated rescue hook) shall be selected and prepared to rescue the QEW without first disconnecting power.
   - At all times, remain in visual and audible contact with the QEWs performing the work. For critical tasks, remain close enough to the work in progress to safely monitor the progress and methods of the QEWs doing the work.
   - Closely monitor the progress of the work. Have a copy of the written work control documents (such as EEWP, ESWP, LOTO Permit, Switching Tag, etc.) and check or initial tasks or steps as necessary. The Safety Watch may call out specific steps and instructions to the QEWs performing the work, record test measurements on the procedures.
   - Use clothing and PPE appropriate to the hazard and the distance from the work in progress
   - In no case be more than 50 feet from the qualified person (s) performing the work
   - Ensure only qualified persons are allowed to enter the limited approach boundary
   - Ensure that the limited approach boundaries are properly barricaded and controlled
   - Have no other duties that preclude continually observing, coaching, and monitoring for potential hazards and mistakes

e. If signs and barricades do not provide sufficient warning and protection for the limited approach boundary, one or more attendants shall also be stationed as necessary to warn and prevent non-QEWs from entering (see 10.3).

7 Shock Protection

7.1 Performing a Shock Hazard Analysis

7.1.1 The purpose of a shock hazard analysis is to determine shock hazards and appropriate safety controls to prevent a shock.

7.1.2 A shock hazard analysis shall determine whether parts are exposed, the voltage to which personnel will be exposed, the shock protection boundary requirements, and the personal protective equipment necessary in order to minimize the possibility of electric shock to personnel.

7.1.3 Where special body positioning techniques are required to prevent shock in the completion of tasks, these shall be listed. However, consideration shall first be given to improve barriers, barricades and other precautionary techniques instead of relying solely on body positioning.

7.1.4 A shock hazard analysis shall be completed prior to performing any work within the Limited Approach Boundary of exposed electrical conductors or circuit parts that are or might become energized.

7.1.5 Results of the shock hazard analysis shall be integrated with the arc flash hazard analysis results as appropriate, and documented into the Electrical Safe Work Procedure as required.

7.1.6 Steps in performing a shock hazard analysis:

a. Determine the scope of work.

b. Determine the shock hazard by identifying the voltage of energized conductors or circuit parts that will be exposed during the work.

c. Determine the shock protection boundaries associated with the shock hazards.

d. Accounting for body position during the various phases of the work, determine an appropriate combination of rubber insulating gloves, rubber insulating blankets, and barriers for all work within the Restricted Approach Boundary.

7.2 Determination of a Shock Hazard

7.2.1 A shock hazard exists when an energized electrical conductor or circuit part is exposed.

7.2.2 Energized electrical conductors and circuit parts are considered exposed if capable of being inadvertently touched or approached nearer than a safe distance by a person, by not being enclosed, guarded or insulated.

a. A part is considered suitably enclosed when it is surrounded by a case, housing, fence, or wall(s) that prevents persons from accidentally contacting the part.

b. A part is considered suitably guarded when it is covered, shielded, fenced, enclosed, or otherwise protected by means of suitable covers, casings, barriers, rails, screens, mats, or platforms to remove the likelihood of approach or contact by persons or objects to a point of danger.

c. A part is considered suitably insulated when it is separated from other conducting surfaces by a dielectric (including air space) offering a high resistance to the passage of current.

7.2.3 Finger-safe designs.

a. Finger safe designs eliminate the likelihood of inadvertent or accidental contact with bare hands and fingers by Qualified Electrical Workers.

b. Finger safe design requirements are set by IEC 60529, *Degrees of Protection Provided By Enclosures (IP Code)*. Equipment is normally not labelled for finger safe design. A field evaluation of finger safe design compliance can be made by a QEW using an Articulated Test Finger (Fig. 7.2.3). Either the UL or the IEC test fingers may be used and can be borrowed from the Electrical Safety Group. The panel must first be placed in an Electrically Safe Work Condition.

c. The two designations for finger safe ratings are IP2*X* and IP*X*B, where *X* is a placeholder for another rating, such as water resistance or dust resistance. Both are equivalent as far as the fingers are concerned.

d. When performing a shock hazard analysis, finger safe parts are not considered exposed even when energized, so long as the QEW is only interacting with the hands and/or insulated tools.

e. Finger safe parts shall be considered exposed in any of the following conditions:
   - The QEW is handling conductive tools or parts, such as loose wires, bolts, or non-insulated tools.
   - Any non-QEW is escorted within the Limited Approach Boundary.

f. Non-QEWs are not trained to recognize hazardous conditions in electrical panels, and are not expected to be able to determine whether parts are finger safe or not. Non-QEWs may be authorized to work inside finger safe live panels provided they receive a job briefing from a QEW detailing the shock hazard posed by the live components.

7.2.4 Temporary barriers.

a. Temporary barriers may be placed over exposed parts. When these are in place, the exposure is eliminated.

b. When placing barriers for non-QEWs and QEWs alike, the barriers shall be sufficient to:
   - Insulate against the voltage hazard
   - Remain securely in place for the duration of work

- Prevent inadvertent contact by bare hands and fingers, when using insulated tools
- Prevent inadvertent contact by conductive tools and parts if necessary

Fig. 7.2.3 – Articulated Test Fingers. IEC at the top, UL at the bottom.

7.3 Shock Protection Boundaries

7.3.1 Shock protection boundaries are defined based on equipment voltage alone and are illustrated in Figure 7.3 and listed in Tables 7.3.AC and 7.3.DC. Shock protection boundaries are not defined unless an energized conductor is exposed (7.2). There are three shock protection boundaries:

a. Limited Approach Boundary

b. Restricted Approach Boundary

c. Prohibited Approach Boundary

7.3.2 Limited Approach Boundary

a. The Limited Approach Boundary is the closest distance that a non-QEW can approach exposed energized conductors without escort.

b. For AC equipment <750 VAC, the Limited Approach Boundary of 42 inches is based on the depth of the required working space in Condition 2 (5.12.9). This in turn is based on the standard human arm length of 3 feet, plus 6 inches of lean. The idea is that non-QEWs looking over the shoulder of a QEW are very likely to want to point at the equipment and may inadvertently make contact with exposed parts.

c. A non-QEW may be escorted within the Limited Approach Boundary by a Qualified Electrical Worker, but may never enter the Restricted Approach Boundary. Where there is a need for a non-QEW to cross the limited approach boundary, a QEW shall advise him or her of the possible hazards and continuously escort the non-QEW while inside the limited approach boundary. Under no circumstance shall the escorted non-QEW be permitted to cross the restricted approach boundary.

d. Where one or more non-QEWs are working at or close to (but outside of) the limited approach boundary, the designated person in charge (PIC) of the work space where the electrical hazard exists shall advise the non-QEW of the electrical hazard and warn him or her to stay outside of the limited approach boundary.

e. The Limited Approach Boundary is also the trigger distance for implementing an Electrically Safe Work Condition (see 6.4). Note that this applies even though shock protection boundaries are defined when the equipment is not in an Electrically Safe Work Condition. Following the LOTO Program requirements, each individual must apply their personal LOTO lock(s) prior to working within the Limited Approach Boundary.

f. All tools that enter the Limited Approach Boundary shall be insulated for the equipment voltage.

7.3.3 Restricted Approach Boundary

a. The Restricted Approach Boundary is based on adding 12 inches of inadvertent movement to the minimum air flashover distance for the voltage.

b. Access to the Restricted Approach Boundary shall be restricted to Qualified Electrical Workers only.

c. All parts of the Qualified Electrical Worker's body that enter the Restricted Approach Boundary shall be insulated or guarded from the energized electrical conductors or circuit parts as follows:
   - The Qualified Electrical Worker shall wear rubber insulating gloves (or rubber insulating gloves and sleeves) to protect the hands (or hands and arms) from shock. These are

considered insulation only with regard to the energized parts upon which work is being performed.

- If there is a need for other parts of the Qualified Electrical Worker's body to cross the Restricted Approach Boundary to other energized electrical conductors or circuit parts, those energized electrical conductors or circuit parts shall be insulated from the Qualified Electrical Worker and from any other conductive object at a different potential, using a combination of insulating blankets, insulating sheeting or barriers as determined by analysis.

7.3.4 Prohibited Approach Boundary

a. Coming closer than the Prohibited Approach Boundary is considered the same as making contact with energized parts.

b. There are no additional requirements at Berkeley Lab for entering the Prohibited Approach Boundary[6].

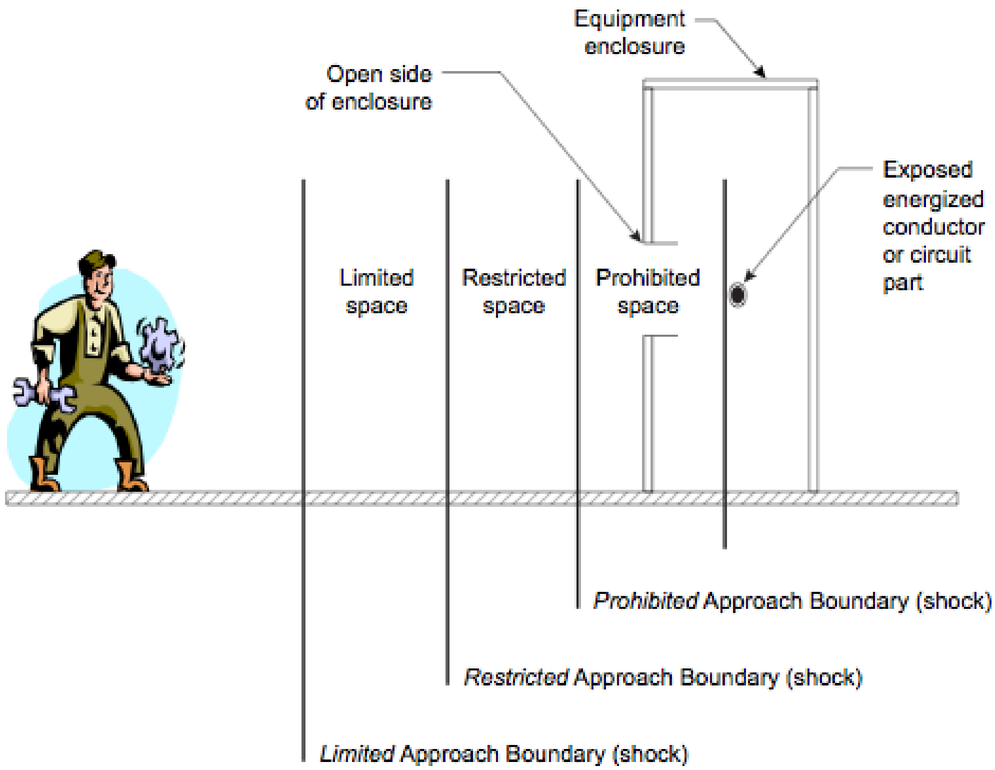


Fig. 7.3 – Shock Protection Boundaries for an exposed, energized conductor.

[6] *Note: In this Electrical Safety Manual, all NFPA 70E requirements for entering the Prohibited Approach Boundary are rolled up into the Limited and Restricted Approach Boundaries.*

Nominal System AC Voltage Range, Phase to Phase [a]	Limited Approach Boundary		Restricted Approach Boundary
	Exposed Movable Conductor [b]	**Exposed Fixed Circuit Part**	
<50 V	Not specified	Not specified	Not specified
50 V–300 V [c]	10 ft	3 ft 6 in	Avoid contact
301 V–750 V [d]	10 ft	3 ft 6 in	12 in
751 V–15 kV	10 ft	5 ft	2 ft 2 in
15.1 kV–36 kV	10 ft	6 ft	2 ft 7 in
36.1 kV–46 kV	10 ft	8 ft	2 ft 9 in
46.1 kV–72.5 kV	10 ft	8 ft	3 ft 3 in
72.6 kV–121 kV	10 ft 8 in	8 ft	3 ft 4 in
>121 kV	Contact the Electrical Safety Group for direction		

Note: All dimensions are distance from exposed energized electrical conductors or circuit parts to worker.
a. For single-phase systems, select the range that is equal to the system's maximum phase-to-ground voltage multiplied by 1.732.
b. *Exposed movable conductor* describes a condition in which the distance between the conductor and a person is not under the control of the person. The term is normally applied to overhead line conductors supported by poles.
c. Does not include 277 V single phase, as this is not the phase to phase voltage.
d. Includes 277 V single phase, as the phase to phase voltage is 480 V.

Table 7.3.AC – Shock Protection Boundaries for AC Systems

Nominal DC Potential Difference	Limited Approach Boundary		Restricted Approach Boundary
	Exposed Movable Conductor [a]	**Exposed Fixed Circuit Part**	
<100 V	Not specified	Not specified	Not specified
100 V–300 V	10 ft	3 ft 6 in	Avoid contact
301 V–1 kV	10 ft	3 ft 6 in	12 in
1.1 kV–5 kV	10 ft	5 ft	1 ft 5 in
5 kV–15 kV	10 ft	5 ft	2 ft 2 in
15.1 kV–45 kV	10 ft	8 ft	2 ft 9 in
45.1 kV– 75 kV	10 ft	8 ft	3 ft 2 in
75.1 kV–150 kV	10 ft 8 in	10 ft	4 ft 0 in
150.1 kV–250 kV	11 ft 8 in	11 ft 8 in	5 ft 3 in
250.1 kV–500 kV	20 ft 0 in	20 ft 0 in	11 ft 6 in
500.1 kV–800 kV	26 ft 0 in	26 ft 0 in	16 ft 5 in

Note: All dimensions are distance from exposed energized electrical conductors or circuit parts to worker.
a. *Exposed movable conductor* describes a condition in which the distance between the conductor and a person is not under the control of the person. The term is normally applied to overhead line conductors supported by poles.

Table 7.3.DC – Shock Protection Boundaries for DC Voltage Systems

7.4 When Voltage Rated Gloves Are Required

7.4.1 Qualified Electrical Workers shall wear rubber insulating gloves with leather protectors where there is a shock hazard to the hands due to contact with energized electrical conductors or circuit parts.

7.4.2 This includes:

a. For exposures at 50-300V, where the Restricted Approach Boundary is "Avoid Contact":
   - Any time QEW is required to reach over, across, or near exposed live parts, unless all exposures are finger safe per 7.2.3.
   - When performing a voltage test with a contact voltmeter, unless the terminals are finger safe per 7.2.3 or using probes with finger guards.

b. For exposures 301-750V:
   - When temporarily defeating or bypassing an electrical safety interlock per 10.4.14.
   - Any time the hands enter the Restricted Approach Boundary (12 inches from the exposure).
   - When manipulating insulated wires <750 V that are not jacketed for physical protection. For example, separating THHN wires in an MCC to perform a load check with a clamp-on ammeter.
   - When removing bolted covers (not hinged).

c. When manipulating high voltage insulated wires >750 V.

7.5 When Leather Protector Gloves Are Required

7.5.1 Leather protector gloves may be omitted under limited use conditions, where small equipment and parts manipulation require unusually good finger dexterity, provided the following conditions of ASTM F 496, *Standard Specification for In-Service Care of Insulating Gloves and Sleeves*, section 8.7.4 are met:

a. For Class 00 gloves, the rating shall be halved to 250 VAC/375 VDC.

b. For Class 0 gloves, without other restriction.

c. For gloves of Class 1-4, only where the possibility of physical damage to gloves is unlikely and provided the voltage class of the glove used is one class above the voltage exposure.

7.5.2 Rubber insulating gloves that have been used without protectors shall not be used with protectors until given an inspection and electrical retest. It is recommended to exchange the gloves for a new set of tested gloves immediately after use without leather protectors.

7.5.3 Note that "small equipment and parts manipulation" does not include testing with a meter and usually implies work in Mode 3, which requires an Energized Electrical Work Permit (EEWP).

7.6 When Voltage Rated Blankets or Sheeting Are Required

7.6.1 QEWs shall apply insulated blankets or insulated sheeting over exposed parts that could come in contact with the arms or other parts of the body that are not adequately protected by the use of rubber insulating gloves.

7.6.2 Alternatively, QEWs may also wear rubber insulating sleeves where there is a danger of arm injury from electric shock due to contact with energized electrical conductors or circuit parts. Note that blind reaching is prohibited per 10.4.2.

7.7 When Insulated Sticks (Hot Sticks) Are Required

7.7.1 Insulated sticks shall be used for high voltage exposures (> 750 VAC or > 1000 VDC), where the Restricted Approach Boundary exceeds 1 foot.

7.7.2 Insulated sticks shall be used for all tasks within the Restricted Approach Boundary.

7.8 Selection of Shock Protection PPE

7.8.1 Shock protection PPE shall be based primarily on the voltage of the highest exposure. Rubber insulating gloves, sleeves, and blankets shall be rated according to the following table:

Class	Class Color	Max Use Voltage AC/DC
00	Beige	**500 VAC** / 750 VDC
0	Red	**1,000 VAC** / 1,500 VDC
1	White	**7,500 VAC** / 11,250 VDC
2	Yellow	**17,000 VAC** / 25,500 VDC
3	Green	**26,500 VAC** / 39,750 VDC
4	Orange	**36,000 VAC** / 54,000 VDC

Table 7.8.1 – ASTM Classification of Voltage Glove and Blanket Ratings

7.8.2 More information about Shock PPE standards, care, inspection and use can be found in Section 16.

7.9 Primary vs. Secondary Shock Protection

7.9.1 Primary shock protection is defined as a protective device (rubber insulating glove, sleeve, blanket, barrier or insulating stick) that, used alone, is fully sufficient in preventing a shock to personnel that might be exposed.

7.9.2 Secondary shock protection is defined as a supplementary measure, used in conjunction with a primary shock protection method, to further reduce the risk of a shock. Some of the PPE available for secondary protection was used for bare-hand work. Bare-hand work is not authorized.

7.9.3 Secondary shock protection methods include:

a. EH (Electrical Hazard) shoes meeting ASTM F2413 can provide a secondary source of electric shock protection under dry conditions. EH rated shoes are regular work shoes with an insulated barrier built into the sole.

Fig. 7.9.3 – Example of Electrical Hazard (EH) Rated Work Shoes

b. Dielectric floor mats

c. Rubber insulating gloves (above 34 kVAC/54 kVDC)

7.9.4 When working on high voltage systems (>750 VAC), the primary shock protection device is the insulating stick (hot stick). Rubber insulating gloves and sleeves may be substituted as primary shock protection up to 34 kVAC/54 kVDC (Class 4 maximum use voltages) as long as no other part of the body enters the restricted approach boundary. Above this level there are no rubber insulating gloves and the insulating stick becomes the sole primary shock protection device.

7.9.5 Primary shock protection devices shall be tested before issue and periodically in accordance with the requirements in 16. Tests for devices used as secondary protection is recommended but not required.

8 Arc Flash Protection

8.1 Arc Flash Hazard Analysis

8.1.1 The purpose of an arc flash hazard analysis is to determine whether an arc flash hazard exists and what appropriate safety controls are necessary to prevent a second-degree burn.

8.1.2 An arc flash hazard analysis shall be required for all AC systems above the thresholds of 2.3.3 when planning work under either of the following conditions:

a. Work within the limited approach boundary of exposed energized electrical conductors or circuit parts.

b. Work involves interaction with equipment where conductors or circuit parts are not exposed but an increased likelihood of injury from an exposure to an arc flash hazard exists.

8.1.3 An arc flash hazard analysis shall not be required for DC systems[7].

8.1.4 An arc flash hazard analysis shall determine whether an arc flash hazard exists, and if so, the arc flash boundary, the incident energy at the working distance, and the personal protective equipment that people within the arc flash boundary shall use.

8.1.5 At Berkeley Lab, calculation of the incident energy for AC systems shall be performed using the incident energy analysis method. The "table method" of NFPA 70E-2012 Article 130.7(C)(15) shall not be used.

8.1.6 Where special body positioning techniques are recommended to stay out of the line of fire during the performance of tasks, these shall be listed. However, consideration shall first be given to improve barriers, barricades and other precautionary techniques instead of relying solely on body positioning.

8.1.7 Results of the arc flash hazard analysis shall be integrated with the results of the shock hazard analysis as appropriate, and documented into the Electrical Safe Work Procedure as required.

8.1.8 Steps in performing a arc flash hazard analysis:

a. Determine the scope of work.

b. Determine whether an arc flash hazard exists.

c. Perform an incident energy analysis to determine the incident energy at the working distance and the arc flash boundary.

[7] NFPA 70E-2012 has introduced methods to perform an arc flash hazard analysis for DC systems. These have not been adopted by Berkeley Lab.

d. Accounting for body position during the various phases of the work, determine an appropriate combination of arc flash PPE, arc flash blankets, and barriers for all work within the Arc Flash Boundary.

8.2 Arc Flash Hazard

8.2.1 An arc flash hazard is a dangerous condition associated with the possible release of energy caused by an electric arc, resulting in second-degree burns to the skin or ignition of clothing.

8.2.2 An arc flash hazard may exist when a person is interacting with the equipment in such a manner that could cause an electric arc, regardless of whether energized electrical conductors or circuit parts are exposed. However, under normal operating conditions, enclosed energized equipment that has been properly installed and maintained is not likely to pose an arc flash hazard.

8.2.3 The following equipment, when rated at 50-250 VAC, 50-60 Hz power, does not pose an arc flash hazard, regardless of the activity:

a. Any equipment for which the calculated incident energy at the working distance is 1.2 cal/cm^2 or less.

b. Any equipment that is plug and cord and less than 100 A rated input.

c. Any equipment rated at 120 VAC.

d. Any equipment rated at 208-240 VAC when at least two overcurrent protective devices (circuit breakers or fuses) are installed between the equipment and the closest upstream transformer.

e. Any equipment rated at 208-240 VAC when the closest upstream transformer is rated at less than 125 kVA.

8.2.4 The following activities do not create an arc flash hazard:

a. Reading a panel meter while operating a meter switch

b. Work on control circuits with exposed energized electrical conductors and circuit parts, 120 VAC or below without any other exposed energized equipment over 120 VAC. Includes opening of covers to gain access

c. Insulated cable examination with no manipulation of cable

d. For DC systems, insertion or removal of individual cells or multi-cell units of a battery system in an open rack

e. Removal or installation of covers for equipment such as wireways, junction boxes, and cable trays that does not expose bare energized electrical conductors and circuit parts

f. Infrared thermography and other visual inspections outside the restricted approach boundary. This activity does not include opening of doors or covers.

g. Application of temporary protective grounding equipment after ZVV

8.2.5 The following activities create an arc flash hazard when the available incident energy at the working distance is 1.2 cal/cm^2 or greater:

a. Work within the Restricted Approach Boundary of energized electrical conductors and circuit parts greater than 120 VAC, including voltage testing

b. Operation of a circuit breaker, switch, contactor, or starter
   - Exception: when conditions for normal operation are satisfied (6.3.5), the threshold for an arc flash hazard is 4 cal/cm^2 or greater.

c. Removal of bolted covers to expose bare energized electrical conductors and circuit parts

d. Opening hinged door(s) or cover(s) to expose bare energized electrical conductors and circuit parts

e. Insertion or removal of individual starter buckets from motor control center (MCC). See requirements of 8.12.

f. Insertion or removal (racking) of circuit breakers or starters from cubicles, doors open or closed

g. Insertion or removal of plug-in devices into or from busways

h. Insulated cable examination with manipulation of cable

i. Insertion and removal of revenue meters (kW-hour, at primary voltage and current)

j. Application of temporary voltage and current monitoring sensors or clips inside panelboards or switchboards

k. Opening voltage transformer or control power transformer compartments

l. Outdoor disconnect switch operation (hookstick operated) at 1 kV through 15 kV

m. Outdoor disconnect switch operation (gang-operated, from grade) at 1 kV through 15 kV

n. Application of temporary protective grounding equipment without ZVV

8.2.6 All other activities will be evaluated on a case-by-case basis.

8.3 Incident Energy Analysis

8.3.1 The incident energy analysis is the calculation of arc flash incident energy by competent engineering persons for a circuit, panel, or system. It is typically performed by an electrical engineer in conjunction with the short circuit and protection study.

8.3.2 The incident energy analysis shall be updated when a major modification or renovation takes place. It shall be reviewed periodically, not to exceed 5 years, to account for changes in the electrical distribution system that could affect the results of the arc flash hazard analysis.

8.3.3 The incident energy analysis shall take into consideration the design of the overcurrent protective device and its opening time, including its condition of maintenance. Improper or inadequate maintenance can result in increased opening time of the overcurrent protective device, thus increasing the incident energy.

8.3.4 The incident energy analysis method shall be used to calculate:

a. The arc flash boundary, and

b. The incident energy at the specified work distance

8.3.5 The incident energy analysis shall be documented and kept on file.

8.4 Arc Flash Boundary

8.4.1 The arc flash boundary is the distance from an exposed, energized conductor at which the arc flash incident energy is 1.2 cal/cm^2. This is the threshold at which an arc flash could result in a second-degree burn to the worker, should an arc occur at that conductor. In general, the arc flash boundary is determined by the available fault current and the time to clear the fault, which determines the energy deposited into the arc.

8.4.2 The arc flash boundary may be inside or outside the approach boundaries. Figure 8.4.2a shows an arc flash boundary that is outside of the Limited Approach Boundary, as is typical with many facility circuits, and Fig. 8.4.2b shows an arc flash boundary that is inside the Prohibited Approach Boundary, as is common with many high-voltage, low-energy circuits.

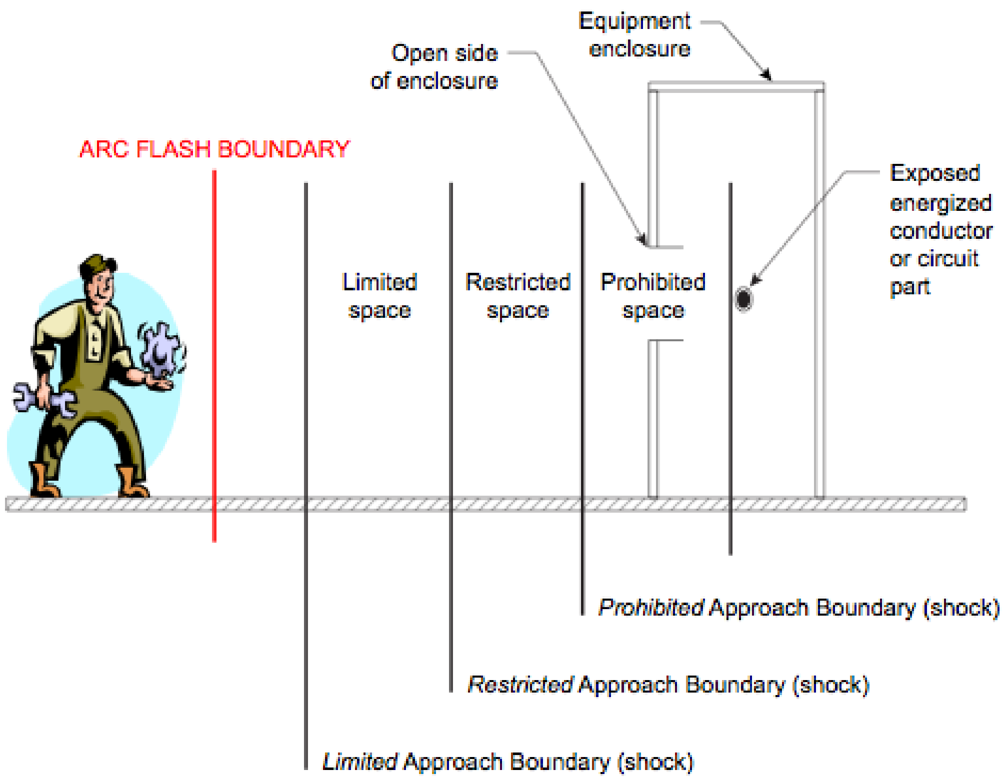


Fig. 8.4.2a Arc flash boundary outside of the limited approach boundary.

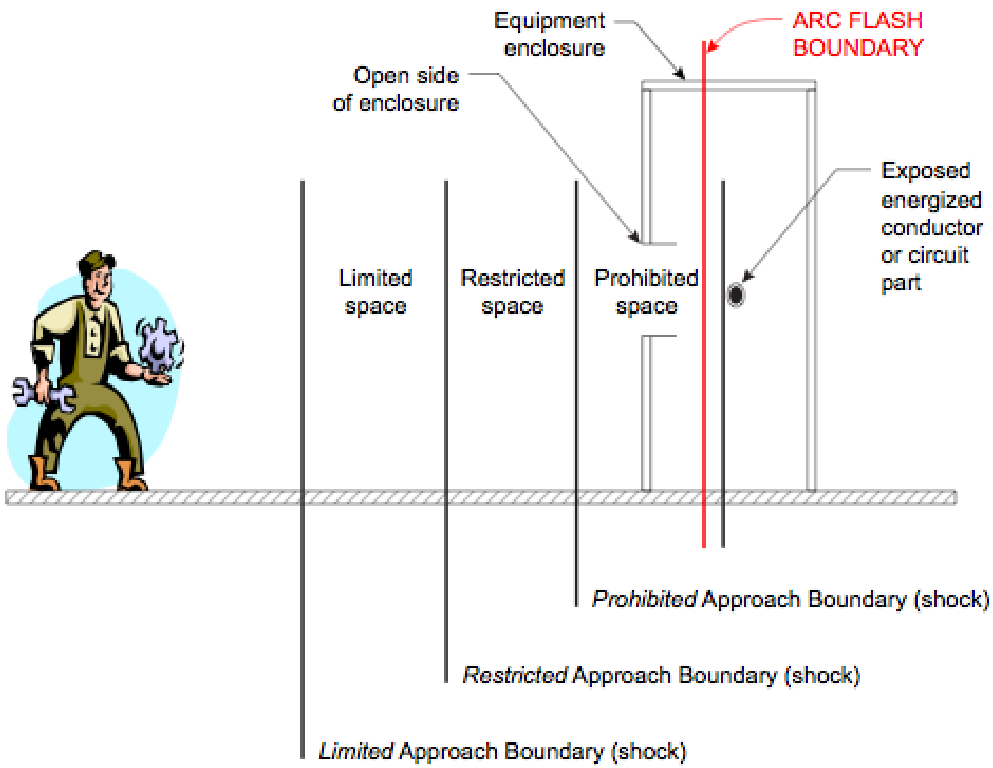


Fig. 8.4.2b Arc flash boundary inside of the prohibited approach boundary.

8.5 Working Distance

8.5.1 Arc-flash protection is always based on the incident energy level on the person's head and torso at the working distance, not the incident energy on the hands or arms. The degree of injury in a burn depends on the percentage of a person's skin that is burned. The head and torso make up a large percentage of total skin surface area and injury to these areas is much more life threatening than burns on the extremities.

8.5.2 Care must be taken to note the working distance that is associated with the calculated incident energy. Where the task requires a working distance that is closer than the working distance, the incident energy must be recalculated under engineering supervision. Conversely, tasks that are performed farther than the indicated working distance may allow a relaxation in the specified PPE and controls provided that the incident energy is recalculated under engineering supervision. In either case, the arc flash hazard analysis and controls shall be documented.

8.6 Incident Energy Analysis for Facility Power Systems

8.6.1 For facility power systems (i.e., Hazard Classes 1.2, 1.3, and 1.4) that are from 200 VAC to 15 kVAC, the incident energy analysis shall be performed under engineering supervision in accordance with IEEE Std 1584, *Guide for Performing Arc Flash Hazard Calculations*, including 1584a – *Amendment 1* and 1584b – *Amendment 2: Changes to Clause 4*. Equipment >15 kVAC will be accounted for using ArcPRO.

8.6.2 Typical working distances are shown in Table 8.6.2. These are incorporated in the incident energy analysis.

Classes of Equipment	Typical Working Distance (in)
15 kV switchgear	36
5 kV switchgear	36
Low-voltage switchgear	24
Low-voltage MCC's and panelboards	18
Cable	18
Other	To be determined in the field

Table 8.6.2 – Typical working distances for arc flash incident energy calculation

8.6.3 2-second rule:

a. A maximum time exposure cap of 2 seconds is normally applied in the calculation of incident energy, where the overcurrent protective device does not trip at the calculated arcing current. This practice is based on an assumption that the worker will likely remove himself or herself from the arc flash if physically possible, within a maximum time of 2 seconds. See NFPA 70E Annex D.6 or IEEE 1584b-2011 4.6, Step 5 for more information.

b. The 2-second rule shall not be applied for any work within electrical manholes, in vaults, on elevated platforms, or in any other situation where the worker is unlikely to be physically capable of exiting the arc flash boundary on their own.

c. Workers who are working in spaces where they are unlikely to be physically capable of exiting the arc flash boundary on their own shall seek EHS support in performing the arc flash hazard analysis.

8.7 Incident Energy Analysis for R&D Systems

8.7.1 Specialized system knowledge and methods may be necessary to calculate the incident energy and arc flash boundaries for some non-typical electrical equipment found in DOE workplaces, such as DC or capacitor systems, as methods are not available in existing codes and standards. Engineering supervision should be used to determine whether an arc flash hazard exists.

8.8 Arc Reduction Maintenance Switches (ARMS)

8.8.1 An arc-reducing maintenance switch (ARMS) allows a worker to set a circuit breaker trip unit to operate faster while the worker is working within an arc flash boundary, and then to set the circuit breaker back to a normal setting after the potentially hazardous work is complete.

8.8.2 ARMS is usually available on newer installation Low Voltage Power Circuit Breakers (LVPCB) inside low voltage switchgear. ARMS functions by temporarily lowering the instantaneous electronic trip setpoint to its lowest current setting. In doing so, the setting disables the normal selective coordination with other overcurrent protective devices in the system. Should a fault happen in the system downstream of the breaker, there is a risk of wider power outage because the breaker in ARMS is likely to trip before other devices located downstream.

8.8.3 Control. When placing the ARMS into maintenance mode, the switch should be controlled by placing an administrative lock on the switch cover.

8.8.4 Restoration. After completion of the work that required placing the ARMS in maintenance mode, the ARMS shall be restored to normal. Failure to restore the switch to normal could lead to unnecessary power outages due to lack of proper selective coordination.

8.9 Arc Flash Labeling

8.9.1 Electrical equipment such as switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers that are likely to require examination, adjustment, servicing, or maintenance while energized, shall be field marked with a label containing all the following information:

a. A warning about the potential for an arc flash, with the word “WARNING” on an orange colored background

b. Nominal system voltage

c. Available incident energy and the corresponding working distance

d. Arc flash boundary

e. Date of the arc flash hazard analysis

8.9.2 Labeling shall conform to the requirements of ANSI Z535.

8.9.3 Labels applied prior to September 30, 2011, are acceptable if they contain the available incident energy or required level of PPE.

8.9.4 The labeled incident energy shall be that of the highest source, faulting under the most conservative system lineup, and shall not rely on a protective device contained within the enclosure.

8.9.5 Where work is planned to take account of a lower incident energy, based on a less conservative system lineup or the use of an Energy Reduction Maintenance Switch, the arc flash hazard analysis shall be documented in an Electrical Safe Work Procedure. LOTO controls shall be used to implement the alternate system lineup. It is acceptable to post alternate arc flash labels where such controls are likely to be frequently used, and thereby the Electrical Safe Work Procedure is not required.

8.9.6 Where the incident energy exceeds 40 cal/cm^2 at the standard working distance of 8.6.2, additional requirements for arc flash labeling are listed in 8.11.4.

8.10 Arc Flash PPE Selection

8.10.1 After determining the incident energy exposure at the working distance, the worker shall select the appropriate site-specific level of arc flash PPE from Table 8.10.1.

8.10.2 More information about arc flash PPE standards, care, inspection and use can be found in 0.

Arc Flash PPE Level	Incident Energy Range	Arc-Rated Gear	Other PPE
1	>1.2 cal/cm^2 to 4.0 cal/cm^2	Rating: minimum of 4 ATPV • Arc-rated long-sleeve shirt and pants (or arc-rated coveralls) • Arc-rated faceshield	• Hard hat • Safety glasses • Hearing protection • Leather work shoes • Heavy-duty leather gloves
2	>4.0 cal/cm^2 to 8.0 cal/cm^2	Rating: minimum of 8 ATPV • Arc-rated long-sleeve shirt and pants (or arc-rated coveralls) • Arc-rated faceshield • Arc-rated balaclava	• Hard hat • Safety glasses • Hearing protection • Heavy-duty leather work boots • Heavy-duty leather gloves
2+	>8 cal/cm^2 to 12 cal/cm^2	Rating: minimum of 12 ATPV • Arc-rated long-sleeve shirt and pants (or arc-rated coveralls) • Arc-rated faceshield • Arc-rated balaclava	• Hard hat • Safety glasses • Hearing protection • Heavy-duty leather work boots • Arc-rated gloves, or rubber insulating gloves with leather protectors
3	>12 cal/cm^2 to 25 cal/cm^2	Rating: minimum of 25 ATPV • Arc-rated flash suit (pants and jacket) • Arc-rated flash suit hood	• Hard hat • Safety glasses • Hearing protection • Heavy-duty leather work boots • Arc-rated gloves, or rubber insulating gloves with leather protectors
4	>25 cal/cm^2 to 40 cal/cm^2	Rating: minimum of 40 ATPV • Arc-rated flash suit (pants and jacket) • Arc-rated flash suit hood	• Hard hat • Safety glasses • Hearing protection • Heavy-duty leather work boots • Arc-rated gloves, or rubber insulating gloves with leather protectors

Table 8.10.1 – LBNL Site-Specific Arc Flash PPE Levels

8.11 Arc flash incident energy >40 cal/cm^2

8.11.1 Where the incident energy exceeds 40 cal/cm^2, there is an increased risk that the blast effects will exceed the capacity of the arc flash PPE. Arc-rated gear protects primarily against the thermal effects of an arc flash, not the blast effects.

8.11.2 Where the incident energy exceeds 40 cal/cm^2 at the standard working distance of 8.6.2, additional controls shall be implemented to reduce the exposure. These include but are not limited to:

a. Placement of the ARMS switch in maintenance mode to reduce the incident energy at the working distance.

b. Use of an alternate system lineup to eliminate high energy contributors to the system. For example, lock out an emergency generator.

c. Using engineered remote switching devices to extend the working distance. If possible, extend the distance outside of the calculated arc flash boundary. Otherwise, request engineering assistance to recalculate the distance at which the arc flash energy is reduced to 40 cal/cm^2, or calculate the incident energy at another feasible working distance.

d. Unless specific controls are labeled on the equipment, these alternative measures shall be documented in an approved Electrical Safe Work Procedure.

8.11.3 Where none of the methods identified in 8.11.2 are achievable, consult with the Electrical AHJ for Safe Work Practices.

8.11.4 Arc flash labeling for conditions where the incident energy exceeds 40 cal/cm^2 at the standard working distance shall conform to 8.9 but shall additionally be modified as follows:

a. The label shall state DANGER instead of WARNING, on a background colored red instead of orange.

b. The label shall also include the working distance at which the incident energy equals 40 cal/cm^2.

c. The label shall include the following statement: “The available arc flash incident energy in this panel is considered to be extremely dangerous. Consult with the Electrical Safety Group to develop the necessary safe work procedure prior to performing any work on this panel, including switching and LOTO.”

8.12 Removal and Insertion of MCC Buckets

8.12.1 Energized removal and insertion of MCC buckets presents a high probability of an arc flash when compared to other activities, especially on older equipment or equipment that has not been well maintained. Because there is no remote racking option available, the QEW is in very close proximity to the source of energy and often has to exert physical effort in the task.

8.12.2 Where the incident energy available in the MCC is calculated at greater than 12 cal/cm^2, energized removal and insertion of MCC buckets shall only be performed under an approved EEWP.

8.13 Daily Arc-Rated Work Wear for Electrical Work

8.13.1 The purpose of the daily arc-rated work wear requirement is to protect electrical workers from injuries sustained when the equipment is thought to be in an Electrically Safe Work Condition (Mode 0). Many injuries occur after LOTO or Test Before Touch have been incorrectly performed. The daily arc-rated work wear will not fully protect the worker, but can significantly reduce the likelihood of a life-altering burn injury.

8.13.2 Daily arc-rated work wear shall be required for all craft QEWs levels 2-3 and their immediate supervisors, if the supervisors are also QEWs.

8.13.3 Daily arc-rated work wear by QEW classification:

a. QEW 1: No requirement

b. QEW 2: Minimum of arc-rated pants and long-sleeve shirt (or equivalent combination), rated at least 4 cal/cm^2, with non-melting undergarments.

c. QEW 3: Minimum of arc-rated pants and long-sleeve shirt (or equivalent combination), rated at least 4 cal/cm^2, with non-melting undergarments. Note that arc-rated undergarments are recommended for high voltage work because of the possibility of a tracking arc under the arc-rated PPE.

8.14 Body Positioning for Arc Flash

8.14.1 Arc flash calculations are roughly based on spherical expansion, with the incident energy decreasing proportionally to the square of distance. This is especially accurate for an arc in open air.

8.14.2 For arc in a box, the calculation is modified twice. First, to account for the gain of reflecting all the energy in one direction. Second, to give different exponent factors (other than square) to account for the varying focusing effect of different switchgear. For example, larger switchgear tends to approximate a planar source, while a MCC bucket tend to approximate a point source.

8.14.3 However, arc flash calculations do not yet account for convective plasma flow patterns commonly observed in real world arc flash events. Convective flow can lead to very high concentration of the available energy that exceeds the calculated incident energy at the working distance and can possibly exceed the arc rating of the PPE ensemble. Proper body positioning can help the worker avoid standing with part of the body in the line of fire (2.3.3.b and 10.2.7).

8.14.4 Proper switching technique in 10.2.7 incorporates proper body positioning for arc flash.

8.14.5 For other cases, see 10.2.8.

9 Zero Voltage Verification (ZVV)

9.1 Purpose

9.1.1 Zero Voltage Verification (ZVV) is the practice of testing for the absence of hazardous voltage on circuits that have been or are being placed in an Electrically Safe Work Condition.

9.1.2 ZVV is challenging because the worker is required to prove a negative. Special testing techniques and protocols are therefore required to ensure a valid test.

9.1.3 ZVV is intended to identify any remaining shock hazard present under the following conditions:

a. Selection of wrong isolation point: In the case where Circuit A is to be isolated, and the device for Circuit B is inadvertently selected as the isolation point.

b. Mechanical or electrical failure of isolation device: The isolation device may fail internally. One or all of the phases may still be closed even though the device shows all external indications of being open.

c. Circuit backfeed or alternate power source: Another source of energy may still be energizing the circuit. This could be an Uninterruptable Power Supply (UPS), a temporary generator, incorrect wiring, or other source of energy.

d. Residual charge: A circuit may retain a built-up capacitive charge, or may be powered from a DC supply.

e. Adjacent energized components: Nearby energized components will present an electrical hazard if they are not identified and controls put in place.

9.1.4 ZVV is considered Mode 1 energized electrical work and requires a QEW. All circuit parts shall be considered energized until the equipment has been placed in an Electrically Safe Work Condition per 6.5. As such, the QEW is required to wear all PPE as if the test were a live diagnostics test (Mode 2). However, the two-person rule is relaxed in Mode 1 compared to Mode 2.

9.2 Live-Dead-Live Test Method

9.2.1 All voltage detectors shall be checked before and after each use. This is known as the Live-Dead-Live test. The Live-Dead-Live test shall consist of measuring or detecting voltage on a known energized circuit. The known energized circuit can be:

a. A utility outlet

b. The line side of the isolation

c. A battery (resistive-type detectors only)

d. A proofing unit specifically designed for this application

9.2.2 While not always feasible, it is highly preferable that the known live source be as close as possible a match in voltage and waveform as the circuit to be proven dead. The ideal test is to use the source immediately upstream of the isolation point as the known live source.

9.3 Steps to perform ZVV

9.3.1 Test voltage on a known live source to verify meter function.

9.3.2 The following steps should be performed in order, where possible:

a. Verify absence of voltage difference, neutral-to-ground (for single phase circuits). Verifies no floating neutral or shared neutral with current.

b. Verify absence of voltage difference, phase-to-ground on each phase. Keeps meter referenced to ground for most of the test and keeps exposure lower (ie. 277 V vs. 480 V).

c. Verify absence of voltage difference, phase-to-neutral (if available). Provides a backup test to phase-to-ground.

d. Verify absence of voltage difference, phase-to-phase on each phase (if available). May be the only valid test on ungrounded systems.

9.3.3 Test voltage on a known live source to verify meter function.

9.4 Location of Test Points for ZVV

9.4.1 Test for Lockout:

a. Use the Live-Dead-Live method to test each lockout isolation disconnect for absence of voltage as close as possible to the disconnect to verify that the isolation is effective.

b. For this to be a valid proof, there can be no other component between the disconnect and the test location that might be temporarily opening the circuit. This includes fuses, contactors, thermal overloads and other disconnects.

c. Testing for absence of voltage is not valid when there is no voltage on the line side of the intended lockout point. Two options are available:
   - Shift the lockout point for the duration of the lockout. The lockout should be placed at the location upstream where there is still power on the line side.

- For low voltage isolations only, shift the lockout point temporarily and perform a continuity test through the intended isolation disconnect. Do not perform the continuity test without locking out power to the line side of the intended isolation. Continuity testing is not allowed for high voltage isolations.

9.4.2 Test Before Touch:

a. Use the Live-Dead-Live method to test the equipment to be worked upon for absence of voltage immediately after opening the electrical enclosure. This is to verify that the proper isolation was selected and that there are no other sources of voltage remaining in the enclosure.

b. Test every conductor to be touched. Testing must be done at each location where conductors are going to be touched.

9.4.3 Job Continuity:

a. When circuit conditions change or when the job location has been left unattended, perform Test Before Touch again before resuming work.

b. Should any circumstance arise which leads the worker to suspect a part may have remained or become energized, the worker shall stop work and perform full ZVV, wearing all required PPE.

9.5 Types of Voltage Detectors

9.5.1 All voltage detectors used for ZVV shall be approved by an ESO. A list of voltage detectors pre-approved for ZVV is included in Appendix E. For other types, contact your ESO or the Electrical Safety Group.

9.5.2 Requirements for voltage detectors used for ZVV are:

a. Meet the requirements for Voltage Testers in 18.1.2.

b. Be of the two-pole contact type, except as allowed by Section 11.

c. Be digital high-impedance, except as allowed by 9.5.6.

d. Voltmeters with a resistance- or continuity-measuring feature shall have a safety circuit built into the meter.

9.5.3 Permanently installed meters shall not be relied upon for ZVV, as a live dead live test may not be performed.

9.5.4 Proximity testers (non-contact voltage testers) shall not be used alone for ZVV for <750 VAC.

a. Proximity testers, also known as capacitive type detectors, are only designed to detect AC voltage (50-60 Hz) above a certain threshold, sometimes as high as 90 VAC.

b. As single pole devices, they do not have a clear reference to ground or to another phase. While they are excellent tools for confirming presence of nominal operating voltage, they are not always adequate for proving absence of voltage.

c. However, where there is a possibility that the contact probes do not make certain contact with the conductor, as when testing though small ports or before removing electrical insulating tape, a proximity detector shall be used in addition to the contact voltmeter.

d. Proximity testers shall additionally be used as a pre-check prior to breaking into insulation, like taped up motor connections, Molex connectors or wire nuts, or before cutting an insulated wire, where a contact tester cannot get good access to test. As soon as there is good access, a follow up test is to be done with a contact tester.

9.5.5 Test probes must be selected to match the physical requirements of the test point. Some test points are shielded, and the test leads must be narrow enough to fit through access ports and long enough to reach the conductors.

9.5.6 High-Impedance vs. Low-Impedance Testing

a. Certain configurations of electrical/electronic equipment may induce voltages on disconnected circuits. These are usually non-standard voltages different from the nominal system voltage. Causes can include shared neutrals, floating neutrals, residual capacitive charges from electronic circuits and coupling of power waveforms across circuits.

b. Use of manufacturer-designed low-impedance adapters (such as the Fluke SV225 Stray Voltage Eliminator) should be considered when there is the possibility of small induced voltages to detect when those voltages would be hazardous.

10 General Electrical Safe Work Practices

10.1 Minimum PPE for Electrical Work

10.1.1 The purpose of the minimum PPE requirement is to protect QEWs from injuries sustained when the equipment is thought to be in an Electrically Safe Work Condition (Mode 0). Many injuries occur after LOTO or Test Before Touch have been incorrectly performed. The minimum PPE will not fully protect the worker, but can significantly reduce the likelihood of a life-altering injury.

10.1.2 The minimum PPE requirement applies at all times when performing electrical work, even when it has been placed in an Electrically Safe Work Condition.

10.1.3 At a minimum, all QEWs performing electrical work shall wear:

a. Safety glasses, and

b. Non-melting clothing to include long pants and long sleeves, and

c. Non-melting safety footwear that fully covers the feet.

10.1.4 Note that some QEWs that work with arc flash hazards (QEW 2 and QEW 3) have daily arc-rated wear as described in 8.13 instead of non-melting clothing.

10.2 Body Positioning

10.2.1 Body positioning is a fundamental concept in safe electrical work practices. Nearly all of the required and recommended electrical safe work practices are directly related to body positioning. The QEW should learn to visualize their physical interaction with the equipment in advance in order fully integrate these requirements into a cohesive set of safe electrical work habits.

10.2.2 Note that the shock approach boundaries are also related to body positioning. See 7.3.2.b and 7.3.3.a. Barriers and PPE are used to complement body positioning techniques where these may not be sufficient to prevent electrical shock.

10.2.3 Proper body positioning for shock protection is primarily related to inadvertent movement and should incorporate an understanding of the following elements:

a. Balance

b. Safe approach vector

10.2.4 Balance is necessary to prevent falling forward into energized components. Proper body positioning includes a stable stance, on a level standing surface. The worker shall consider how to position his or her body to minimize the chance of incidental contact with exposed energized conductors. The worker shall always position his or her body in such a way as to reduce the likelihood of slipping, tripping or falling into energized equipment. Examples include:

a. The worker should avoid bending over at the waist to perform electrical work, as this could lead to falling into energized gear.

b. Where there is a risk that doors, hinged panels, and the like could swing into an employee and cause the employee to contact exposed energized electrical conductors or circuit parts, they shall be secured to prevent swinging.

c. When accessing a cabinet above the worker's eye level, the worker shall use an approved non-conductive step-stool or step-ladder to provide adequate access. Non-approved items such as toolboxes, buckets, or miscellaneous parts are not allowed for access to electrical equipment.

d. When working in an area with pedestrian traffic, the QEW should establish alerting techniques (signs, barricades and/or attendants per 10.3) at a sufficient distance to prevent anyone from bumping into the QEW while work is being performed.

10.2.5 Safe approach vector incorporates balance while purposefully moving towards energized gear.

a. The worker shall consider how best to approach exposed live components.

b. Walking directly towards exposed live gear is not recommended, as a slip, trip or fall would cause the worker to fall directly towards the exposed gear. Instead, workers should approach with an indirect route.

c. Kneeling down or bending directly in front of exposed live gear is also not recommended. Instead, the worker should get down on the knees at some distance away from the cabinet, then approach the cabinet to perform the work from a kneeling or sitting position.

10.2.6 Older techniques for shock protection derived from bare hand methods. While bare hand work is no longer authorized, the techniques are still good practice, especially when performing visual inspection of energized panels:

d. Placing left hand in the pocket to avoid a shock pathway through the heart

e. Standing on rubber insulating mats as secondary protection

10.2.7 Proper body positioning for arc flash protection is primarily related to the concept of Line of Fire.

a. This is the understanding that certain hazards have directionality when things go wrong. Some arc flash hazards are very directional (see 2.3.3.b and 8.14).

b. For this reason, when operating a load-rated switch, circuit breaker, or other device specifically designed as a means for a disconnect, the worker should position his or her body to the side of the circuit breaker to minimize the exposure to the body should an arc blast occur during the operation.

10.2.8 Steps for proper body positioning for arc flash:

a. Determine the busbar configuration where the arc flash is likely to occur.
   - Vertical
   - Horizontal

b. Determine the source side of the busbar (top, bottom, left, right). The convective flow will be directed along the busbar away from the source.

c. Determine if the panel configuration will redirect the ejected plasma.

d. Determine the line of fire based on b and c.

e. Determine body positioning such that the worker is not in the line of fire. If the work must be performed in the line of fire, consider:
   - Upgrading the arc flash PPE ensemble to a higher level
   - Using arc-rated blankets or other suitable barriers

f. Ensure that when turning away, the arc rated flash suit hood is not pulled up around the shoulders to expose the skin.

10.2.9 Proper body positioning for switching is primarily a protection for arc blast:

a. Stand to the side. Where possible, do not reach across the panel to the switch handle, instead stand on the same side of the panel as the switch handle.

b. Place hand on the switch handle but do not operate the switch.

c. Face away from the switch, close the eyes, take a deep breath and hold it.

d. Forcefully throw the switch in a complete full motion.

e. Verify system response.

10.3 Alerting Techniques

10.3.1 Signs

a. Safety signs, safety symbols, or accident prevention tags shall be used where necessary to warn employees about electrical hazards, which may endanger them.

b. The person in charge of the work shall be responsible to place these signs and tags where appropriate and ensure they meet regulatory requirements.

c. Appropriate signs shall be placed at suitable intervals to specify the nature of the hazard and the expectations for personnel in the area. The sign will list the type of work being performed, the name of the Person In Charge, the contact phone number for the Person In Charge, and instructions such as "KEEP OUT", or "CONTACT PIC AND APPLY LOTO PRIOR TO ENTRY".

d. Such signs and tags shall meet the requirements of ANSI Z535, *Series of Standards for Safety Signs and Tags*.

10.3.2 Barricades

a. Barricades shall be used in conjunction with safety signs where it is necessary to prevent or limit employee access to work areas exposing employees to exposed non-insulated energized conductors or circuit parts.

b. Conductive barricades shall not be used where it might cause an electrical hazard. The person in charge of the work shall be responsible to evaluate the need for barricades on a case-by-case basis.

c. Barricades shall be installed no closer than the limited approach boundary or the arc flash boundary, whichever is greater. While the barricade is being installed, the restricted approach boundary distance shall be maintained, or the energized conductors or circuit parts shall be placed in an Electrically Safe Work Condition.

d. Caution tape shall be selected when barricading an area that has been placed in an Electrically Safe Work Condition (Mode 0). Danger tape shall be used when barricading an area that contains energized exposed parts, whether for Establishing an Electrically Safe Work Condition (Mode 1), Diagnostics (Mode 2) or Repair Work (Mode 3).

10.3.3 Attendants

a. An Attendant is a person who is helping to warn other personnel about electrical hazards, which may endanger them. An Attendant may be a QEW or a non-QEW. An Attendant may also be assigned duties as a Standby Person or a Safety Watch (6.13).

b. An Attendant is required when normal alerting techniques such as safety signs, barricades are not sufficient to prevent or limit access to exposed energized conductors or circuit parts (10.3.3).

c. The person in charge of the work shall be responsible to evaluate the need for attendants on a case-by-case basis.

d. The Attendant shall:
   - Remain in the area as long as there is a potential for employees to be exposed to the electrical hazards
   - Be stationed outside the barricade
   - Provide manual signaling and alerting to keep non-QEWs outside a work area where the non-QEW might be exposed to electrical hazards.

10.3.4 Look-Alike Equipment

a. Where work performed on equipment that is de-energized and placed in an Electrically Safe Work Condition exists in a work area with other energized equipment that is similar in size, shape, and construction, one (or more) of the altering methods in 10.3.1, 10.3.2, or 10.3.3 shall be employed to prevent the employee from entering look-alike equipment.

b. The person in charge of the work shall be responsible to evaluate the need for attendants on a case-by-case basis.

10.4 Other Precautions for Personnel Activities

10.4.1 Alertness

a. When Hazardous. Electrical Workers shall remain alert at all times when they are working within the limited approach boundary of energized electrical conductors or circuit parts operating at 50 volts or more and in work situations where electrical hazards might exist.

b. When Impaired. Electrical Workers shall not be permitted to work within the limited approach boundary of energized electrical conductors or circuit parts operating at 50 volts or more, or where other electrical hazards exist, while their alertness is recognizably impaired due to illness, fatigue, or other reasons.

c. Changes in Scope. Electrical Workers shall remain alert for changes in the job or task that may lead the person outside of the Electrically Safe Work Condition or expose the person to additional hazards that were not part of the original plan. Also see 4.6.4 and 6.12.5.

10.4.2 Blind Reaching. Electrical Workers shall never reach blindly into areas that might contain exposed energized electrical conductors or circuit parts where an electrical hazard exists.

10.4.3 Illumination

a. General. QEWs shall not enter spaces containing electrical hazards unless illumination is provided that enables the employees to perform the work safely.

b. Obstructed View of Work Area. Where lack of illumination or an obstruction precludes observation of the work to be performed, QEWs shall not perform any task within the Limited Approach Boundary.

10.4.4 Conductive Articles Being Worn:

a. Conductive articles of jewelry and clothing (such as watchbands, bracelets, rings, key chains, necklaces, metalized aprons, cloth with conductive thread, metal headgear, or metal frame glasses) shall not be worn where they present an electrical contact hazard with exposed energized electrical conductors or circuit parts.

b. In all cases conductive articles of jewelry and clothing shall be removed from the worker's body prior to entering the Restricted Approach Boundary.

10.4.5 Conductive Materials, Tools, and Equipment Being Handled

a. General. Conductive materials, tools, and equipment that are in contact with any part of an employee's body shall be handled in a manner that prevents accidental contact with energized electrical conductors or circuit parts. Such materials and equipment shall include, but are not limited to, long conductive objects, such as ducts, pipes and tubes, conductive hose and rope, metal-lined rules and scales, steel tapes, pulling lines, metal scaffold parts, structural members, bull floats, and chains.

b. Approach to Energized Electrical Conductors and Circuit Parts. Means shall be employed to ensure that conductive materials approach exposed energized electrical conductors or circuit parts no closer than that permitted by 6.4. When long conductive objects are handled in the vicinity of exposed energized conductors or circuit parts, each end of the object should be under the control of different persons. For example, a length of metal pipe should be handled by assigning one person to each end of the pipe.

10.4.6 Confined or Enclosed Work Spaces. When an employee works in a confined or enclosed space (such as a manhole or vault) that contains exposed energized electrical conductors or circuit parts operating at 50 volts or more, or where an electrical hazard exists, the employer shall provide, and the employee shall use, protective shields, protective barriers, or insulating materials as necessary to avoid inadvertent contact with these parts and the effects of the electrical hazards.

10.4.7 Foreign Body Exclusion. Care should be taken to prevent objects from falling into electrical panels or equipment.

10.4.8 Housekeeping

a. Cleaning inside electrical cabinets shall not be performed unless the cabinet has been placed in an Electrically Safe Work Condition.

b. Personnel performing cleaning around the exterior of cabinets that have not been placed in an Electrically Safe Work Condition shall be mindful to prevent foreign debris, sprays and dusts from entering the cabinet.

c. Combustible materials shall not be stored around electrical equipment or in electrical rooms. Paperwork related to the electrical equipment may be left in electrical rooms when stored in closed metal cabinets.

d. A clear working space shall be maintained in the front of electrical enclosures in accordance with 5.11.

10.4.9 Occasional Use of Flammable Materials

a. Where flammable materials are present only occasionally in Unclassified Locations, electric equipment capable of igniting them shall not be permitted to be used, unless measures are taken to prevent hazardous conditions from developing.

b. Such materials shall include, but are not limited to, flammable gases, vapors, or liquids; combustible dust; and ignitable fibers or flyings.

c. This does not apply to equipment used in Classified Locations per the NEC, where fire or explosion hazards may exist more than occasionally due to flammable gases, flammable liquid–produced vapors, combustible liquid–produced vapors, combustible dusts, or ignitible fibers/flyings.

10.4.10 Anticipating Failure

a. When there is evidence that electric equipment could fail and injure employees, the electric equipment shall be de-energized, unless line management can demonstrate that de-energizing introduces additional hazards or increased risk or is infeasible because of equipment design or operational limitation.

b. Evidence that electric equipment could fail includes:
   - Loose or bound equipment parts
   - Overheating
   - Deterioration
   - Any indication of severe electrical failure per 10.4.11.a

c. Contact an Electrical Safety Officer immediately for guidance. For additional guidance on this justification, see 6.4.4.c and 6.4.4.d. Keeping the equipment running may require an EEWP.

d. Until the equipment is de-energized or repaired, employees shall be protected from hazards associated with the impending failure of the equipment by suitable barricades and other alerting techniques necessary for safety of the employees.

10.4.11 Deranged Equipment

a. Whenever electrical equipment has been subjected to a severe electrical failure, it is considered deranged equipment until its electrical integrity can be verified by testing and inspection. The normal means of deenergization may not be sufficient. Indications of severe electrical failure include but are not limited to:
    - Smoke, charring or fire
    - Arcing, arc flash or arc blast
    - Severe physical damage or deformation
    - Report of sparking
    - Report of electric shock

b. Determining if equipment is deranged is a judgment call. Employees should err on the side of caution. Deranged equipment must be treated with more caution than equipment in normal operating condition. Normal lockout and deenergization procedures may not be sufficient to provide adequate safety.

c. Prior to beginning work on deranged equipment, a shock and arc flash hazard analysis must be conducted with an Electrical Safety Officer.

d. Depending on the results of the hazard analysis, initial zero voltage verification (ZVV) may need to be performed on the cabinet external casing and other normally grounded metal surfaces. Voltage gloves are required for these tests.

10.4.12 Routine Opening and Closing of Circuits

a. Load-rated switches, circuit breakers, or other devices specifically designed as disconnecting means shall be used for the opening, reversing, or closing of circuits under load conditions.

b. Cable connectors not of the load-break type, fuses, terminal lugs, and cable splice connections shall not be permitted to be used for such purposes, except in an emergency.

10.4.13 Reclosing Circuits After Protective Device Operation

a. After a circuit is de-energized by the automatic operation of a circuit protective device (such as a circuit breaker trip or blown fuse), the circuit shall not be manually reenergized until it has been determined that the equipment and circuit can be safely energized.

b. The repetitive manual reclosing of circuit breakers or reenergizing circuits through replaced fuses is prohibited.

c. When it is determined that the automatic operation of a device was caused by an overload rather than a fault condition, examination of the circuit or connected equipment shall not be required before the circuit is reenergized.

10.4.14 Safety Interlocks

a. Only qualified persons following the requirements for working inside the restricted approach boundary as covered by 7.3.3.c shall be permitted to defeat or bypass an electrical safety interlock over which the person has sole control, and then only temporarily while the qualified person is working on the equipment.

b. The safety interlock system shall be returned to its operable condition when the work is completed.

10.4.15 Disconnection/reconnection of wires

a. Wires shall not be disconnected or reconnected without first being in an Electrically Safe Work Condition.

b. Disconnected wires shall not be reenergized.

c. Pending permanent removal, permanently disconnected wires shall be disconnected at the power supply end and tagged out at the power supply end in accordance with the Lockout/Tagout Program.

d. Temporarily disconnected wires may be disconnected at the load end only, provided that their power supply remains locked out for the duration. If the power supply isolation for the wires needs to be closed to power up other loads, then the wires need to be disconnected at both ends, and locked out at the power supply end in accordance with the Lockout/Tagout Program
    - Note: After safing off the wire line-side ends, tape a solid object to the wires and affix a cord cap box and LOTO lock. This avoids the use of a Tagout-Only situation.

e. The phase wires shall be disconnected first, followed by the neutral wire, followed by the earth wire.

f. All disconnected wire ends shall be electrically insulated, using electrician's tape, wire nuts, or another suitable insulator.

g. Any wires that are discovered bare shall be treated as energized. A qualified electrical worker shall be called to investigate and make the condition safe.

10.4.16 Electrical Single Line Drawings

a. Electrical single line drawings shall be made available for QEWs in the field, either through physical copies or electronic access.

b. All Facilities Distribution High Voltage Switch Stations shall have a single line drawing of the relevant circuits posted in the switch station. The drawings shall be laminated and posted on the wall or be stored in a designated and labelled metal cabinet.

c. All electrical single lines shall be kept current.

10.4.17 Light Fixtures

a. Light fixtures that are designed to allow bulb replacement while preventing incidental contact with exposed energized circuit parts are not required to be placed in an Electrically Safe Work Condition to replace the light bulbs.

b. Replacement of the ballasts or of the light fixture itself shall require that the fixture be placed in an Electrically Safe Work Condition. Energized replacement of these items is prohibited and is not justified under an Energized Electrical Work Permit.

10.4.18 Cabinet Enclosures

a. All electrical cabinet covers shall be closed and fully bolted or latched when not opened for inspection or work.

b. When temporary cables are required to be placed through a cover opening, which prevent closing and latching the cover, the cabinet shall be treated as if it were opened. All electrical approach boundaries and PPE requirements shall be in effect.

11 High Voltage Facilities Distribution Systems (>750 VAC)

11.1 Scope

11.1.1 This section applies to Berkeley Lab owned or operated facilities distribution installations where nominal system voltage exceeds 750 VAC. This also includes programmatic equipment >750 VAC directly connected to facilities distribution equipment. It does not cover open-air switchyards or substations, but is limited to the operation and maintenance of metal clad or metal enclosed medium voltage switchgear and transformers, and associated equipment.

11.1.2 High Voltage DC installations or equipment are not within the scope of this section (see section 12).

11.2 Qualification requirements

11.2.1 All persons performing work on high voltage facilities distribution systems shall be qualified to level QEW 3. This includes persons performing the role of Electrical Safety Watch.

11.3 Restricted Access to High Voltage Enclosures

11.3.1 In all electrical work, test before touch is a fundamental principle. However, if a QEW 1 or QEW 2 were to unknowingly test a high voltage circuit with a tester that is not properly rated, serious injury or death would ensue. Therefore, it is imperative that high voltage circuits are kept marked and nominally out of reach from casual access.

11.3.2 All high voltage electrical enclosures shall be marked with a high voltage warning label that includes the highest nominal operating voltage in the enclosure.

11.3.3 All high voltage electrical enclosures with hinged doors or panels shall be kept locked closed with a HV Admin Lock controlled by the Electrical Utilities Coordinator. Trapped key interlock systems satisfy and exceed this requirement.

11.3.4 All non-load-rated high voltage disconnect switches shall be kept locked with a HV Admin Lock in their normal operating position (closed or open) to prevent operation under load. Trapped key interlock systems satisfy and exceed this requirement.

11.3.5 High voltage components shall not be located in low voltage enclosures that typically require access by others who are not QEW Level 3. Where this is unavoidable, the enclosure shall be considered a high voltage enclosure, subject to the restrictions in this section.

11.4 Switching

11.4.1 All high voltage switching activities shall be performed under an approved Switching Tag, which is a form of an Electrical Safe Work Procedure. The Switching Tag shall be prepared, reviewed and approved by separate persons qualified as QEW3.

11.4.2 All high voltage work shall be supervised by a QEW 3 designated as Person In Charge.

11.4.3 The Electrical Utilities Coordinator shall maintain a High Voltage Distribution Status Board, consisting of a single-line diagram of the high voltage distribution system operated by the Lab, and displaying all connections to the utility. The status board may be physical or electronic. The status board shall be kept updated with temporary markings indicating any switches out of their normal operating position, and the location of all temporary wiring, temporary grounds and temporary generators connected to the system.

11.4.4 High voltage vacuum circuit breakers shall be fully racked out to the disconnect position for LOTO. The LOTO lock shall physically prevent racking in the breaker. If the breaker is to be removed for testing, then the racking mechanism shall be locked out to prevent racking in another breaker. If necessary, lockout the shutter assembly or the door to the breaker enclosure to prevent access to the line side connections of the breaker.

11.4.5 Where possible, high voltage circuit breakers of the drawout type shall be racked in and out with remote racking mechanisms that allow the High Voltage Operator to stay outside of the switch room. Remote racking mechanisms shall be approved by the Electrical Utilities Coordinator, with torque interlocks to prevent jamming. Where remote operation is not possible, a QEW 3 electrical safety watch is required according to 6.13.4.

11.4.6 Where possible, high voltage circuit breakers shall be opened and closed remotely, with remote operating devices that allow the High Voltage Operator to stay outside of the switch room. Where remote operation is not possible, a QEW 3 electrical safety watch is required according to 6.13.4.

11.5 Zero Voltage Verification

11.5.1 Zero Voltage Verification (ZVV) of high voltage circuits shall conform to Section 9, as amended in this section.

11.5.2 The preferred method for ZVV is to use a proximity type detector on a hot stick, followed by application of temporary personal protective grounds with a hot stick, both wearing full PPE for shock and arc flash protection. This requires grounding points that are very accessible, usually using a combination of ball studs and matching clamps.

11.5.3 Because this configuration is often not available, the next best method for ZVV is to use a proximity type detector on a hot stick, followed by a contact type detector on a hot stick, both wearing full PPE for shock and arc flash protection. Then if grounds are ***immediately*** installed after checking with proximity and contact tester, the grounds may be placed by hand without PPE.

11.5.4 In all cases, the Live-Dead-Live check is performed with a portable tester. The self-check feature in some detectors is considered a secondary indication but shall not be used for the Live-Dead-Live check of the detector.

11.6 Personal Protective Equipment

11.6.1 Shock Protection

a. In high voltage applications, primary shock protection is provided by an insulated live-line tool, usually called a hot stick. Only a hot stick of a sufficient length can provide the standoff distance necessary to safely meet the Restricted Approach Boundary requirements for the whole body.

b. Live-line tools shall conform to ASTM F711, *Standard Specification for Fiberglass-Reinforced Plastic (FRP) Rod and Tube Used in Live Line Tools*. They shall be of sufficient length that the QEW can handle the tool without having the hands enter the Restricted Approach Boundary.

11.6.2 Arc Flash Protection

a. Arc flash PPE shall be worn based on an arc flash hazard analysis in accordance with 8.1. Arc-rated gloves may be needed when using a hot stick without wearing rubber insulating gloves.

b. Note that the working distance for medium voltage switchgear is usually 36 inches. This is the typical working distance when working with a hot stick. Working closer than 36 inches raises the arc flash incident energy considerably. For example, an incident with a calculated energy of 6.2 cal/cm^2 at 36 inches becomes about 12.3 cal/cm^2 at 18 inches[8].

11.7 Temporary Personal Protective Grounding of High Voltage Circuits

11.7.1 Purpose: The installation of Temporary Personal Protective Grounds at the work location protects employees from the following hazards:

a. Accidental closing: Although all potential feeds for a deenergized circuit are required to be locked out prior to the commencement of work, the possibility of someone inadvertently energizing the circuit still remains.

b. Accidental Contact: A deenergized circuit could come in contact with another energized circuit or the deenergized circuit could be energized through human error.

c. Equipment Failure: The insulation of the switching devices opened to deenergize the circuit could either break down or track over, and energize the line on which work is being done.

[8] Assumptions: IEEE 1584 formulas with 12.47 kV switchgear, 10 kA bolted fault, 30 cycle clearing time, using EasyPower online arc flash calculator.

d. Backfeed: In addition to the primary sources, there are several secondary sources that can cause current to flow in a deenergized circuit. Some examples of these sources include tie breakers, instrument transformers, metering installations and auxiliary generators.

11.7.2 Movement of Temporary Personal Protective Grounds: The magnetic fields produced when large currents flow through grounding cables will cause the cables to whip violently. For this reason, grounding cables should be kept as short as possible and placed such that workers are not injured should whipping of cables occur. Excess length shall not be coiled, as this can add significant impedance, delay operation of the overcurrent protective device and cause explosive whipping of the cable.

11.7.3 Choosing the right type of Temporary Personal Protective Grounds

a. Only approved grounding cables and clamps shall be used for personal protective grounding. Temporary personal protective ground assemblies shall conform to ASTM F855, *Standard Specifications for Temporary Protective Grounds to Be Used on De-energized Electric Power Lines and Equipment*. Cables may be jacketed with clear or yellow jacketing. Clear jacketing allows inspection of underlying cables, while high-visibility yellow jacketing helps prevent leaving grounds applied for restoration.

b. Temporary personal protective ground assemblies shall be rated for the amount of available bolted fault current at the point of installation, in accordance with Table 11.7.3. Refer to the short circuit studies for a calculation of available bolted fault current. This is usually also listed directly next to the available arc fault current in the arc flash calculation studies.

Bolted Fault Current Rating, kA for 30 cycles at 60 Hz	Minimum Copper Cable Size (AWG)
10	#2
15	1/0
20	2/0
25	3/0
30	4/0
39	250 kcmil
54	350 kcmil

Table 11.7.3 – Minimum Size for Temporary Personal Protective Ground Assemblies. Derived from Table 1 in ASTM F855 and limited to maximum asymmetry X/R=20.

c. The magnetic fields produced when large currents flow through grounding cables will cause the cables to whip violently. For this reason, grounding cables should be kept as short as possible and placed such that workers are not injured should whipping of cables occur. Excess length shall not be coiled, as this can add significant impedance, delay operation of the overcurrent protective device and cause explosive whipping of the cable.

d. The ground position of a gas switch may be used in the place of temporary personal protective grounds.

e. When using a ground cart assembly in a breaker enclosure, the ground cart shall be locked in place. Prior to inserting the ground cart, the cover shall be locked with an HV Admin Lock in the correct position (top or bottom) to cover the side that will remain energized. Only listed ground carts from the manufacturer shall be approved for use as grounding devices.

11.7.4 Where to apply Temporary Personal Protective Grounds

a. Temporary personal protective grounds shall be applied directly downstream of the LOTO isolation, and can be applied at either end of a cable run.

b. Temporary personal protective grounds shall never be installed in series with a fuse or switch.

c. Grounding clamps shall not be installed over cable termination lugs, as these are likely to separate under the stress of a short circuit.

11.7.5 Applying Temporary Personal Protective Grounds

a. Before applying grounds to any conductor, the conductor must be isolated and locked out, then tested for the absence of voltage with an approved tester, using the Zero Voltage Verification (ZVV) procedure in 11.5. Application of grounds on an energized circuit will likely result in a serious injury or fatality.

b. The surfaces of all grounding connections must be visually checked free of surface corrosion or coating. If necessary, clean the connection point where ground clamps are to be applied using an approved live-line tool rated for the nominal line-to-line voltage of the circuit.

11.7.6 When applying Temporary Personal Protective Grounds to deenergized equipment, the grounding cables shall be connected to the ground before being brought near the conductor that is to be grounded. Temporary Personal Protective Grounds should be carefully laid out, and if necessary, tied securely so as not to present a hazard to the workers. All grounding connections should be made so they do not interfere with the work. Control of Temporary Personal Protective Grounds

a. The use and placement of all temporary personal protective grounds shall be continuously controlled by a Complex LOTO Procedure in accordance with the Lockout/Tagout Program.

11.7.7 Removing Temporary Personal Protective Grounds

a. When removing grounds, the grounding cable to each conductor shall be first removed before the ground connection point is removed.

b. PPE is not required for removing grounds.

c. Grounds may be removed temporarily for testing. When reapplying grounds after testing, follow the requirements of 11.7.5, including ZVV and PPE.

12 High Voltage/Low Current DC Systems (>1000 VDC, <40 mA)

12.1 Hazards

12.1.1 When the output current of high-voltage supplies is below 5 mA, the shock hazard to personnel is low. Where combustible atmospheres or mixtures exist, the hazard of ignition from a spark may exist. High-voltage supplies (AC or DC) can present the following hazards:

a. Faults, lightning, or switching transients can cause voltage surges in excess of the normal ratings.

b. Internal component failure can cause excessive voltages on external metering circuits and low-voltage auxiliary control circuits.

c. Overcurrent protective devices, such as fuses and circuit breakers for conventional applications, may not adequately limit or interrupt the total capacitive or inductive energy and fault currents in highly capacitive or inductive DC systems.

d. Stored energy in long cable runs can be an unexpected hazard. Safety instructions should be in place to ensure proper discharge of this energy.

e. Secondary hazards, such as startle or involuntary reactions from contact with high-voltage low-current systems, may result in a fall or entanglement with equipment.

12.2 Design Considerations

12.2.1 Personnel in R&D labs may encounter energized parts in a variety of configurations, locations, and under environmental conditions that are not usual for most electrical power personnel.

12.2.2 Sometimes the equipment can be designed to incorporate engineered controls that mitigate the hazards associated with working on such equipment. If not, safe operating procedures should be developed and used.

12.3 Safety Practices

12.3.1 An analysis of high-voltage circuits should be performed by a qualified person before work begins, unless all exposed energized parts are guarded. The analysis should include fault conditions in which circuit current could rise above the nominal rated value.

12.3.2 If the analysis concludes that the current is above 40 mA or stored high-voltage capacitive energy is above the shock thresholds for capacitors in Table 2.2.12, then the work is considered to be electrical work and shall be performed in accordance with Section 6.

12.3.3 High-voltage supplies that use rated connectors and cables, when there are no exposed energized parts, are not considered hazards. Connections shall not be made or broken with the power supply energized, unless they are designed and rated for this type of duty (e.g., load-break elbows). Inspect cables and connectors for damage and do not use if they are damaged. Exposed high-voltage parts should be guarded to avoid accidental contact.

13 Distributed Generation

13.1 Permanently connected standby generators

13.1.1 Standby generators shall have a posted single-line diagram. The diagram will not be just the manufacturer's manual drawing, as these often do not show hardwired tie-ins and isolations.

13.1.2 The diagram will include AC output to the load, AC output to the load bank, battery charging input, block heater input, and all connections to premises wiring.

13.2 Portable generator connection and operation

13.2.1 For all portable generators, the generator neutral shall be securely bonded to the generator ground bar. The generator ground bar shall be securely bonded to a reliable grounding point, preferably to an available building ground. Where a reliable building ground is not available, a grounding rod shall be driven into the ground next to the generator, except as noted in 13.2.2.

13.2.2 Under the following conditions, the frame of a portable generator need not be grounded (connected to earth) and that the frame may serve as the ground instead. If these conditions do not exist, then a grounding electrode, such as a ground rod, is required:

a. The generator supplies only equipment mounted on the generator and/or cord- and plug-connected equipment through receptacles mounted on the generator, and

b. The noncurrent-carrying metal parts of equipment (such as the fuel tank, the internal combustion engine, and the generator's housing) are bonded to the generator frame, and the equipment grounding conductor terminals (of the power receptacles that are a part of [mounted on] the generator) are bonded to the generator frame. Thus, rather than connect to a grounding electrode system, such as a driven ground rod, the generator's frame replaces the grounding electrode.

13.2.3 All temporary electrical installations connected to the portable generator shall require an equipment protection ground conductor from the generator to the final utilization equipment. The grounding conductor shall be bonded to grounding point at the generator only. Metal enclosures for intermediate distribution boxes shall also be bonded to the grounding conductor.

13.2.4 All utilization equipment powered from temporary electrical installations shall be protected with GFCI's (Ground Fault Current Interrupters). Portable GFCI's shall be installed between the distribution panel and the temporary cable feeding the utilisation equipment.

13.2.5 Electrical engineering expertise shall be consulted to obtain detailed specifications for proper grounding techniques, materials, and GFCI's.

13.2.6 When portable generators will be used, the LOTO Coordinator shall coordinate with all affected persons (including customers and contractors where applicable) to ensure that everyone knows of the possibility of electrical backfeed.

13.2.7 A Lockout Procedure shall be established in accordance with the Lockout/Tagout Program to prevent electrical backfeed prior to wiring in the portable generator. Only circuits requiring power shall be fed through the temporary generator. Other normally connected circuits shall be disconnected and locked out if they are not required to be energized.

13.2.8 The LOTO Coordinator shall review all Lockout Procedures currently in use and verify that they are adequate and take into consideration the possibility of electrical backfeed. Lockout Procedures shall be modified where required.

13.2.9 The portable generator wires must be completely removed from the enclosure prior to allowing restoration of normal power to the enclosure.

13.3 Uninterruptible Power Systems (UPS)

13.3.1 This section applies to permanently installed hardwired UPS. It does not apply to cord-and-plug desktop or rack-mounted UPS.

13.3.2 Hardwired UPS come in multiple configurations and do not have a standardized wiring scheme. The ability to bypass the UPS for maintenance includes the ability to run the UPS output and the normal power output at the same time for a short time in order to transfer power without interrupting the load. A phase monitoring and switch interlock system is normally used to prevent paralleling the UPS output breaker with the bypass breaker out of phase. Proper switching sequence is sometimes reinforced by the application of trapped key interlock systems. However, the operator should have a detailed understanding of the UPS configuration and switching requirements and should not intentionally defeat the switching interlocks.

13.3.3 The equipment owner (whether Facilities or Progam) shall be responsible for ensuring that hardwired UPS with switching have the following:

a. Posted single-line diagram. The diagram will not be just the manufacturer's manual drawing, as these often do not show hardwired tie-ins and isolations. The diagram shall include AC and DC isolations for all inputs and outputs, with breaker designations.

b. Where a mimic bus is displayed on the UPS, it shall be correct for the actual site installation.

c. Posted switching procedure. All switching procedures for the UPS, including switching from normal to bypass, bypass to normal, complete shutdown, complete startup, and other commonly used switching procedures, will be posted in the vicinity of the UPS.

14 Batteries

14.1 Scope

14.1.1 This section covers hazardous batteries that are used in the following typical applications:

a. Energy storage;

b. Voltage multipliers;

c. Filters; and

d. Isolators.

14.1.2 Hazardous batteries include the following:

a. ≤100 and > 1kW, or

b. >100 V

14.1.3 Batteries are used in multiple applications. Specialized types exist that are suitable for different applications.

14.1.4 Lead-acid storage battery types are the lead-antimony and the lead-calcium. The lead-antimony battery is low cost, high efficiency, small size and long life. Typically, the lead-calcium is chosen for use in UPS systems due to the similar characteristics of lead-antimony coupled with lower maintenance requirements. Both types use dilute sulfuric acid as the electrolyte.

14.1.5 Alkali storage battery types are the nickel cadmium and the nickel metal hydride. These batteries use compounds of nickel peroxide and iron oxide for the plate materials, and potassium hydroxide as the electrolyte. Storage batteries of this type perform well in extremes of temperature.

14.1.6 Other Batteries. Specialized batteries for applications include lithium ion, silver zinc, silver cadmium and mercury. Manufacturers' data sheets provide guidelines for safety for these and other battery types.

14.2 Qualification & Training

14.2.1 Only Qualified Electrical Workers may perform work on battery systems rated at >100 VDC.

14.2.2 All personnel working on hazardous batteries shall complete EHS0570 Battery Safety.

14.3 Hazards

14.3.1 Electrical Hazards. Electrical safety during battery operations is primarily concerned with prevention of a direct short circuit across one or more cells. Due to the large amount of stored energy in the battery cells, along with the low internal resistance of the cells, a short circuit could have catastrophic results including an explosion of the cells involved.

14.3.2 Chemical Hazards

a. For each battery type considered for use, obtain Material Safety Data Sheet (MSDS) information and understand the specific hazards involved before use.

b. Chemicals associated with battery systems may include:
   - Cadmium (Cd);
   - Lead (Pb);
   - Lead peroxide (PbO_2);
   - Lithium hydroxide (LiOH);
   - Lithium Hexafluorophosphate ($LiPF_6$) in propylene/ethylene carbonate (Flammable)
   - Potassium hydroxide (KOH);
   - Sodium bicarbonate ($NaHCO_3$);
   - Sodium hydroxide (NaOH); and
   - Sulfuric acid (H_2SO_4).

c. Many of these chemicals (and other battery components not listed here) are corrosive, poisonous and/or flammable. Possible consequences of a ruptured container or spilled electrolyte include:
   - Fire;
   - Explosion;
   - Chemical burns; and
   - Reactions to toxic fumes, solids or liquids.

14.4 Operation and Maintenance

14.4.1 Personnel conducting electrical work on battery systems are to follow the following guidelines:

a. Use insulated tools in accordance with 18.1. Insulated tools should be stored in a manner that will not expose them to degradation from battery chemicals.

b. Only instruments having a non-conductive case (e.g., the yellow rubber holster provided with some multimeters) are permitted in the vicinity of battery systems.

c. Storage battery systems may present terminal voltages of 48, 125 or 250 V DC. If the physical construction of the battery system permits, inter-cell or inter-tier cables should be disconnected when performing work on the battery system. See Fig. 14.4.1. The idea behind splitting the intercell ties in this manner is to reduce the exposed voltage in the fewest number of steps, thereby minimizing the exposure to energized parts.

d. If one terminal of the battery system is bonded to ground, an additional hazard exists. Single-point contact between an exposed battery terminal and surrounding structures could result in very large short-circuit currents and possibly lead to fires or personal injury.

14.4.2 Take care to not overcharge or exposing rechargeable batteries to higher voltages than recommended. Use of wrong charger can cause failure and possible explosion.

14.4.3 Operation and maintenance of automated battery test equipment must be performed in accordance with manufacturer's instructions. Refer to the manufacturer's operation manual for specific precautions. Ensure that the equipment is placed in an Electrically Safe Work Condition when performing maintenance inside the battery tester cabinet.

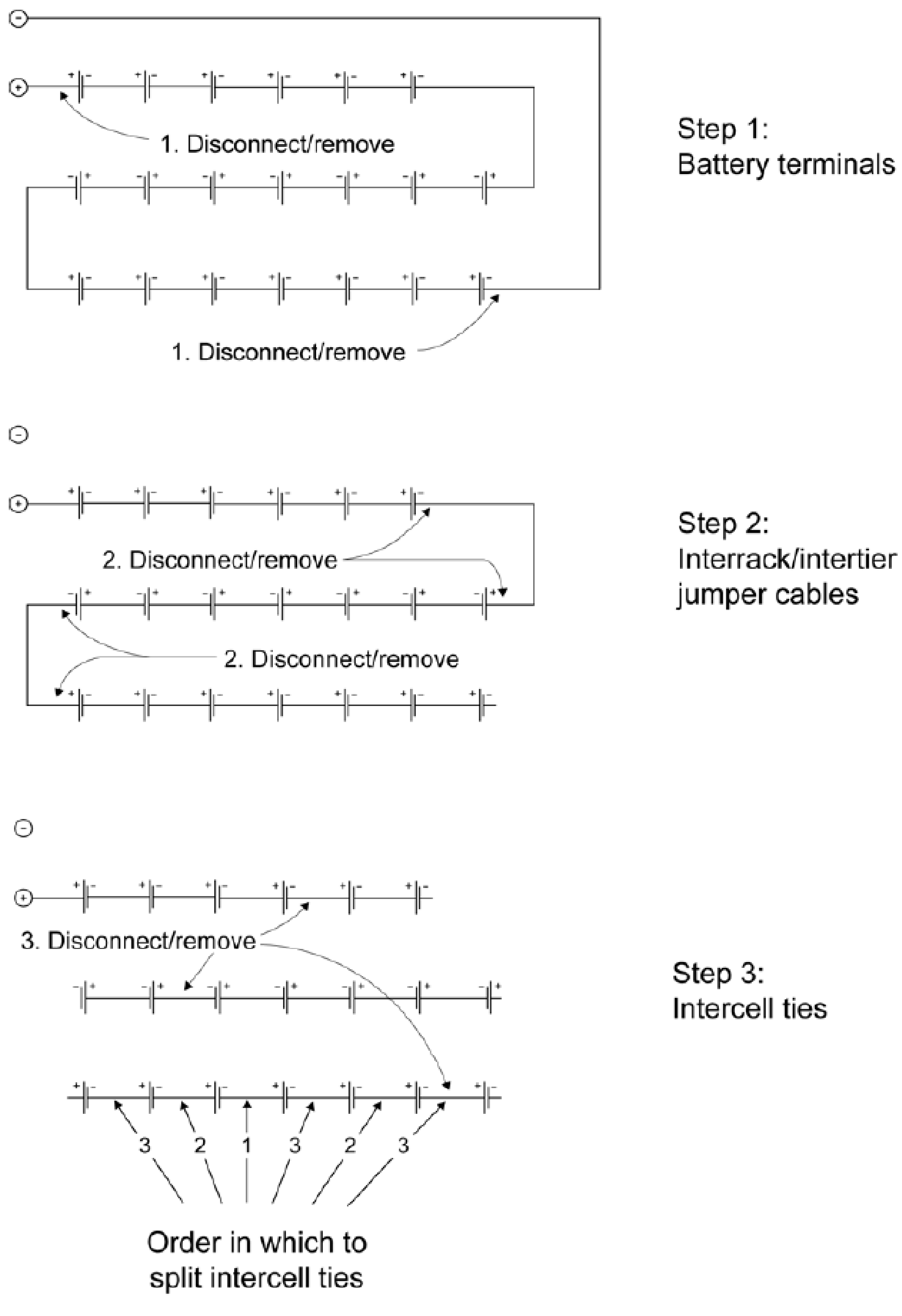


Figure 14.4.1. Example of sectionalizing a large, multi-tier battery system.

15 Capacitors

15.1 Scope

15.1.1 This section covers hazardous capacitors that are used in the following typical R&D applications:

a. Energy storage;

b. Voltage multipliers;

c. Filters; and

d. Isolators.

15.1.2 Capacitors are classified as hazardous when they exceed the shock thresholds of 2.2.12.

15.2 Qualification & Training

15.2.1 Only Qualified Electrical Workers (QEW level 1, 2 or 3) may perform work on hazardous capacitors.

15.2.2 Qualified Electrical Workers who perform work on hazardous capacitors shall complete EHS0571 Capacitor Safety.

15.3 Hazards

15.3.1 Hazardous capacitors may store and accumulate a dangerous residual charge after the equipment has been de-energized. Grounding capacitors in series may transfer rather than discharge the stored energy.

15.3.2 An additional hazard exists when a capacitor is subjected to high currents that may cause heating and explosion.

15.3.3 When capacitors are used to store large amounts of energy, internal failure of one capacitor in a bank frequently results in explosion when all other capacitors in the bank discharge into the fault. Approximately 10,000 J is the threshold energy for explosive failure of metal cans.

15.3.4 High-voltage cables should be treated as capacitors, since they have the capability to store energy.

15.3.5 The liquid dielectric and combustion products of liquid dielectric in capacitors may be toxic.

15.3.6 Because of the phenomenon of "dielectric absorption," not all the charge in a capacitor is dissipated when it is short-circuited for a short time. High voltage capacitors may build a charge in the presence of high electric fields.

15.3.7 A hazardous voltage can exist at the moment of contact across the impedance of a few feet of grounding cable at the moment of contact with a charged capacitor.

15.3.8 Discharging a capacitor by means of a grounding hook can cause an electric arc at the point of contact (see 15.7).

15.3.9 Internal faults may rupture capacitor containers. Rupture of a capacitor can create a fire hazard. Dielectric fluids may release toxic gases when decomposed by fire or the heat of an electric arc.

15.3.10 Fuses are generally used to preclude the discharge of energy from a capacitor bank into a faulted individual capacitor. Improperly sized fuses for this application may explode.

15.3.11 Capacitor polarities need to be properly understood to correctly design, install, maintain and operate safely.

15.4 Design and Construction

The following cautions in design and construction need to be considered:

15.4.1 Isolate capacitor banks by elevation, barriers, or enclosures to preclude accidental contact with charged terminals, conductors, cases, or support structures.

15.4.2 Interlock the circuit breakers or switches used to connect power to capacitors.

15.4.3 Provide capacitors with current-limiting devices.

15.4.4 Design safety devices to withstand the mechanical forces caused by the large currents.

15.4.5 Provide bleeder resistors on all hazardous capacitors not having discharge devices.

15.4.6 Design the discharge-time-constant of current-limited shorting and grounding devices to be as small as practicable.

15.4.7 Provide suitable grounding.

15.5 Automatic Discharge Devices

The following need to be considered:

15.5.1 Use permanently connected bleeder resistors when practical.

15.5.2 Have separate bleeders when capacitors are in series.

15.5.3 Automatic shorting devices that operate when the equipment is de-energized, or when the enclosure is opened, shall be employed, which discharges the capacitor to safe voltage (50 V or less) in less time than is needed for personnel to gain access to the voltage terminals. It shall never be longer than 1 minute.

15.5.4 For equipment with stored energy greater than 10 J, provide an automatic, mechanical discharging device that functions when normal access ports are opened.

15.5.5 Ensure that discharge devices are contained locally within protective barriers to ensure wiring integrity. They should be in plain view of the person entering the protective barrier so that the individual can verify proper functioning of the devices.

15.5.6 Provide protection against the hazard of the discharge itself.

15.6 Safety Grounding

The following need to be considered:

15.6.1 Fully visible, manual grounding devices shall be provided to render capacitors safe while work is being performed.

15.6.2 Grounding points shall be clearly marked.

15.6.3 Prevent transferring charges to other capacitors.

15.7 Ground Hooks

The following need to be considered:

15.7.1 Conductor terminations should be soldered or terminated in an approved crimped lug. All conductor terminations should be strain-relieved within 15 cm.

15.7.2 The resistance from the tip of the ground hook to ground should be less than 0.1 ohm.

15.7.3 The cable conductor should be clearly visible through its insulation.

15.7.4 A cable conductor size of at least #2 AWG should be used, with the conductor sized to be capable of carrying the available fault current of the system. The available fault current should be calculated from V_{peak}/0.1 ohm, including the stored energy.

15.7.5 A sufficient number of ground hooks should be used to adequately ground all designated points.

15.7.6 If they are permanently installed, ground hooks should be permanently grounded and stored in a manner to ensure that they are used.

15.7.7 Ground hooks should be designed so that equipment cannot be energized with the hook across the capacitor.

15.8 Discharge Equipment with Stored Energy in Excess of 5 Joules

The following need to be considered:

15.8.1 A discharge point with a resistance capable of limiting the current to 500A or less should be provided.

15.8.2 The discharge point should be identified with a unique marker (e.g., yellow circular marker with a red slash), and should be labeled "HI Z PT" in large, legible letters. Alternatively, a single ground hook with both a resistor and a resistor bypass can be used for the same function.

15.8.3 A properly installed grounding hook should first be connected to the current-limiting discharge point, and then to a low-impedance discharge point (< 0.1 ohm) that is identified by a unique marker (e.g., yellow circular marker).

15.8.4 The grounding hooks should be left on all of these low-impedance points during the time of safe access.

15.8.5 The low-impedance points should be provided, whether or not the HI-Z current-limiting points are needed.

15.8.6 Voltage indicators that are visible from all normal entry points should be provided.

15.9 Fusing

The following need to be considered:

15.9.1 Capacitors connected in parallel should be individually fused, when possible.

15.9.2 Caution should be used in the placement of automatic discharge safety devices with respect to fuses. If the discharge flows through the fuses, a prominent warning sign should be placed at each entry indicating that each capacitor should be manually grounded before work can begin.

15.9.3 Special knowledge of a competent person is necessary for high-voltage and high-energy fusing.

15.10 Operation and Maintenance

The following need to be considered:

15.10.1 Discharge of capacitors is normally done in conjunction with Lockout/Tagout (LOTO). Since the capacitors contain stored energy, this triggers the requirement for a written Complex LOTO Procedure. The Complex LOTO Procedure shall detail all the steps necessary to ensure the stored energy in the capacitor is fully discharged, remains discharged, and does so without damaging equipment or causing injury to the person.

15.10.2 Proper PPE shall be used when working with capacitors.

15.10.3 Access to capacitor areas shall be restricted until all capacitors have been discharged, shorted, and grounded.

15.10.4 Any residual charge from capacitors shall be removed by grounding the terminals before servicing or removal.

15.10.5 Automatic discharge and grounding devices should not be relied upon.

15.10.6 Grounding hooks shall be inspected before each use.

15.10.7 Capacitor cases are not always grounded and should be considered charged unless otherwise determined.

15.10.8 Protective devices should be tested periodically.

15.10.9 All uninstalled capacitors capable of storing 5 J or greater should be short-circuited with a conductor no smaller than #14 AWG.

15.10.10 A capacitor that develops an internal open circuit may retain substantial charge internally even though the terminals are short-circuited. Such a capacitor can be hazardous to transport, because the damaged internal wiring may reconnect and discharge the capacitor through the short-circuiting wires. Any capacitor that shows a significant change in capacitance after a fault may have this problem. Action should be taken to minimize this hazard when it is discovered.

16 Inductors

16.1 Scope

16.1.1 This section covers inductors as well as electromagnets and coils that are used in the following typical applications:

a. Energy storage;

b. Inductors used as impedance devices in a pulsed system with capacitors;

c. Electromagnets and coils that produce magnetic fields to guide or confine charged particles;

d. Inductors used in DC power supplies; and

e. Nuclear Magnetic Resonance, Electron Paramagnetic Resonance, and Magnetic Susceptibility Systems.

16.2 Hazards

Examples of inductor hazards include:

16.2.1 Overheating due to overloads, insufficient cooling, or failure of the cooling system could cause damage to the inductor and possible rupture of the cooling system.

16.2.2 Electromagnets and superconductive magnets may produce large external force fields that may affect the proper operation of the protective instrumentation and controls.

16.2.3 Magnetic fields could attract nearby magnetic material, including tools and surgical implants, causing injury or damage by impact.

16.2.4 Whenever a magnet is suddenly de-energized, production of large eddy currents in adjacent conductive material can cause excessive heating and hazardous voltages. This state may cause the release or ejection of magnetic objects.

16.2.5 The worker should be cognizant of potential health hazards.

16.2.6 Interruption of current in a magnet can cause uncontrolled release of stored energy. Engineered safety systems may be necessary to safely dissipate stored energy. Large amounts of stored energy can be released in the event of a "quench" in a superconducting magnet.

16.2.7 Current measurements in inductive circuits

a. When a current-measuring device is inserted in series with an inductive circuit, a hazard may occur if the circuit is suddenly opened (a probe falls off or a fuse opens, for example). Such sudden events can produce an inductive voltage spike across the unintentional opening of the circuit. These spikes can be many times the magnitude of the nominal voltage of the circuit, and can cause breakdown of insulation or electric shock to the worker.

b. Current-measuring devices shall not be used in series with inductive circuits, or if it is necessary to do so, then precautions shall be taken to mitigate the hazard of electric shock from the voltage spike.

16.3 Design and Construction

The following need to be considered:

16.3.1 Provide sensing devices (temperature, coolant-flow) that are interlocked with the power source.

16.3.2 Fabricate protective enclosures from materials not adversely affected by external EM fields. Researchers should consider building a nonferrous barrier designed to prevent accidental attraction of iron objects and prevent damage to the cryostat. This is especially important for superconducting magnet systems.

16.3.3 Provide equipment supports and bracing adequate to withstand the forces generated during fault conditions.

16.3.4 Appropriately ground electrical supply circuits and magnetic cores and provide adequate fault protection.

16.3.5 Provide means for safely dissipating stored energy when excitation is interrupted or a fault occurs.

16.3.6 Provide appropriate warning signs to prevent persons with pacemakers or similar devices from entering areas with fields of greater than 0.001 Tesla.

16.3.7 Personnel exposure to magnetic fields of greater than 0.1 Tesla should be restricted.

16.3.8 When a magnet circuit includes switching devices that may not be able to interrupt the magnet current and safely dissipate the stored energy, provide a dump resistor connected directly across the magnet terminals that is sized to limit the voltage to a safe level during the discharge and safely dissipate the stored energy.

17 Personal Protective Equipment

17.1 Rubber Insulating Gloves

17.1.1 Purpose. Electrical rubber insulating gloves protect personnel from electrical shock by providing an insulating barrier between equipment/conductors that could be energized and personnel. Leather protectors are worn over the gloves to prevent damage to the glove by mechanic abrasion and other means.

17.1.2 Selection.

a. Rubber insulating gloves shall conform to ASTM D120 – *Standard Specification for Rubber Insulating Gloves*. Care of rubber insulating gloves shall conform to ASTM F496 – *Standard Specification for In-Service Care of Insulating Gloves and Sleeves*.

b. Rubber insulating gloves are classified by voltage rating. The electrical properties that correspond to these classes are shown in Table 17.1. The rubber insulating glove rating shall be selected based on the equipment's line-to-line or line-to-ground (whichever is greater) nominal voltage rating.

c. Classifications. There are six classifications of rubber electrical insulating electrical gloves (voltage rated gloves). Glove selection is based upon the nominal voltage of the circuit being worked upon. Gloves are clearly marked and have color-coded labels at the cuff.

17.1.3 Leather Protectors

a. Leather protector gloves (leather protectors) shall conform to ASTM F696 – *Standard Specification for Leather Protectors for Rubber Insulating Gloves and Mittens*.

b. Leather protector gloves shall be worn over the rubber insulating gloves to prevent mechanical damage. Leather protectors shall be sized so that the rubber insulating glove is not deformed from its natural shape. A leather protector that is too small will typically be noticed by the feel of wrinkling of the rubber insulating glove at the fingertips. A leather protector that is too large will result in further loss of dexterity.

c. The top cuff of the leather protector glove shall be shorter than the top cuff of the insulating glove by at least the distance specified in Table 17.1. This is to prevent tracking of the voltage from the leather protector to the arm.

d. Protector gloves that have been used for any other purpose shall not be used to protect insulating gloves.

e. Protector gloves shall not be used if they have holes, tears, or other defects that affect their ability to give mechanical protection to the insulating gloves.

f. Care should be exercised to keep the protector gloves as free as possible from oils, greases, chemicals, and other materials that may injure the insulating gloves. Protector gloves that become contaminated with injurious materials to the extent that damage may occur to the insulating glove shall not be used as protector gloves unless they have been thoroughly cleansed of the contaminating substance.

g. The inner surface of the protector gloves should be inspected for sharp or pointed objects; this inspection should be made as often as the rubber gloves are inspected.

ASTM Class	Class Color	Proof Test Voltage AC/DC	Max. Use Voltage AC/DC	Leather Protector Cuff Distance (in)
00	Beige	2,500/10,000	**500**/750	0.5
0	Red	5,000/20,000	**1,000**/1,500	0.5
1	White	10,000/40,000	**7,500**/11,250	1
2	Yellow	20,000/50,000	**17,000**/25,500	2
3	Green	30,000/60,000	**26,500**/39,750	3
4	Orange	40,000/70,000	**36,000**/54,000	4

Table 17.1 – ASTM Class Voltage Ratings

17.1.4 Cloth Glove Liners.

a. Cloth gloves may be worn inside the rubber insulating gloves for warmth in the winter and to absorb perspiration in the hot weather.

b. Care should be exercised to keep the cloth gloves as free as possible from oils, grease, chemicals, and other materials that may damage the insulating gloves. Cloth gloves that become contaminated with damaging materials to the extent that damage may occur to the insulating glove shall not be used and shall be discarded and replaced.

c. Do not perform any work wearing only cloth liners, as this will cause the cloth glove to pick up contaminants that are likely damaging to the rubber insulating glove.

17.1.5 Inspection Before Use

a. Inspection of rubber insulating gloves shall conform to ASTM F1236 – *Standard Guide for Visual*

Inspection of Electrical Protective Rubber Products.

b. The field care and inspection of electrical insulating gloves, performed by the Qualified Electrical Worker, is an important requirement in providing protection from electric shock. Defective or suspected defective gloves and sleeves shall not be used but returned to the Electrical Safety Group for inspection and retest.

c. Rubber insulating gloves shall be visually inspected by the wearer for defects. They shall be inspected over the entire surface and shall be rolled gently between the hands to expose defects and imbedded materials.
   - Inspect glove and sleeve surface areas by gently rolling their entire outside and inside surface areas between the hands. This technique requires gently squeezing together the inside surfaces of the glove or sleeve to bend the outside surface area and create sufficient stress to inside surfaces of the glove or sleeve to highlight cracks, cuts, or other irregularities.
   - When the entire outside surface area has been inspected in this manner, turn the glove or sleeve inside-out and repeat the inspection on the inside surface (now on the outside).
   - If necessary, a more careful inspection of suspicious areas can be achieved by gently pinching and rolling the rubber between the fingers.
   - Pay special attention to the working area of the glove (Fig. 17.1.5). This includes all finger and thumb crotches, the palm (area between the wrist and the base of the finger and thumb) and the area of the finger and thumb facing the palm not extending beyond the centerline of the crotch. This is essentially the area of surface contact if a person were to firmly grasp a section of conduit.
   - Never leave a glove in an inside-out condition.
   - Stretch the thumb and finger crotches by pulling apart adjacent thumb and fingers to look for irregularities in those areas.

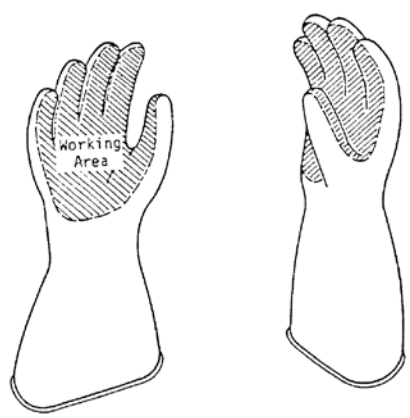


Fig. 17.1.5 – Working area of Rubber Insulating Glove

d. Gloves shall be air-tested before use each day and at other times if there is cause to suspect any damage. The glove shall be examined for punctures and other defects. Puncture detection may be enhanced by listening for escaping air or holding the gloves against the worker's cheek to feel for escaping air.

- Punctures and other small holes in rubber insulating gloves can be found by inflating the gloves with air pressure. Gloves can be inflated manually by grasping the side edges of the glove opening and stretching gently, side-by-side, to close and slightly seal the open end. Roll up the gauntlet end about 1.5 in. toward the palm by twirling the glove in a rotating motion using the rolled edges of the glove opening as an axis. Grasp the rolled up end in one hand to contain the entrapped air in the palm and fingers. Hold the inflated glove close to one ear and, with the free hand, squeeze the glove palm to increase the air pressure while listening and feeling for pinhole leaks. Release the entrapped air.
- To entrap air in heavy weight gloves, it may be necessary to lay the glove on a flat surface, palm up, and press the open end closed with the fingers. While holding the end closed, tightly roll up about 1.5 in. of the gauntlet. Grasp the rolled-up end and inspect for small holes.
- Mechanical glove inflators may also be used to inspect the surface areas of the products. Take care not to over inflate the gloves, since their physical characteristics may be adversely affected by over inflating. Type 1 gloves shall not be inflated or stretched to more than twice their normal size. Type 2 (ozone-resistant) gloves shall not be inflated or stretched to more than 1.25 times their normal size.

e. Lighting. The visual inspection of electrical protective rubber products requires good lighting and the products should be thoroughly cleaned before inspection. The light source should be at least 200 fc with a reflector and should be adjustable for different lighting conditions. Some irregularities can be more easily seen with the light shining down on the surface being examined; other irregularities require a low angle of light to allow the defect to cast a shadow in order to be seen.

f. Gloves and sleeves shall be wiped clean of any oil, grease, or other damaging substances as soon as practicable. Gloves and sleeves should be rinsed as necessary to remove perspiration. Excess water should be removed by being shaken out and the article then air dried.

g. Defective rubber insulating gloves shall not be used and shall be removed from service immediately. If a rubber insulating glove is found to be defective, then one of the fingers of the glove shall be cut off. The glove pair shall be exchanged for a new set.

h. The inner surface of the leather protector gloves should be checked for sharp pointed objects. This inspection should be made as often as the rubber insulating gloves are inspected.

i. Leather protector gloves shall not be used if they have holes, tears, or other defects that affect their ability to give mechanical protection to the rubber insulating glove.

17.1.6 Storage

a. Rubber insulating gloves that have been issued to a Qualified Electrical Worker are considered to be "in service".

b. Gloves and sleeves shall be stored in a location as cool, dark, and dry as possible. The location shall be as free as practicable from ozone, chemicals, oils, solvents, damaging vapors and fumes, and away from electrical discharges and sunlight.

c. Gloves shall be stored in their natural shape. Gloves may be kept inside of protectors or in a bag, box, or container that is designed for and used exclusively for them.

a. Gloves and sleeves shall not be stored folded, creased, inside out, compressed, or in any manner that will cause stretching or compression.

b. When stored hanging inside a canvas glove bag, rubber insulating gloves shall be kept cuff-down.

c. Clean rubber insulating gloves only with lukewarm water and mild soap detergent. Do not use solvents, oils, or grease on rubber gloves.

d. Talcum powder or baby powder may not be used inside the rubber insulating gloves. Only the following powder is approved for use with rubber insulating gloves: Salisbury Ten-Four® Glove Dust

e. Do not apply any markings to the rubber insulating glove, whether with permanent markers, paint pens or stamps. Only the test stamp applied by the certified testing laboratory is permitted.

17.1.7 6-Month Testing

a. Periodic testing of rubber insulating gloves shall conform to ASTM F 496, *Standard Specification for In-Service Care of Insulating Gloves and Sleeves*. The glove testing program is managed by the Electrical Safety Group.

b. Rubber insulating gloves shall be tested prior to being issued. A test date will be stamped or permanently marked on the cuff of the glove.

c. Rubber insulating gloves shall be exchanged every 6 months after issue. It is acceptable to retest gloves and return them to service or to replace the gloves with new gloves.

d. The shelf life of tested gloves in storage is 12 months. Gloves may be issued at any time during the 12 months. The issue date triggers a 6-month time period, at the end of which the gloves must be returned and exchanged.

17.2 Rubber Insulating Blankets

17.2.1 Rubber insulating blankets may be used to provide primary shock protection when work is being performed adjacent to exposed, energized parts (7.3.3.c). Blankets shall conform to ASTM D1048 - *Standard Specification for Rubber Insulating Blankets*.

17.2.2 Rubber insulating blankets are designed to be reusable and are subject to periodic inspection and testing requirements similar to voltage gloves.

17.2.3 Rubber insulating blankets are typically available in all ASTM classes per table 17.1.

17.2.4 Inspection of rubber insulating blankets shall conform to ASTM F1236 – *Standard Guide for Visual Inspection of Electrical Protective Rubber Products*. Defective blankets shall not be used and shall be removed from service.

a. Place rubber blankets on a clean, flat surface and roll up tightly starting at one corner and rolling toward the diagonally opposite corner.

b. Inspect the entire surface for irregularities as it is rolled up. Unroll the blanket and roll it up again at right angles to the original direction of rolling.

c. Repeat the rolling operations on the reverse side of the blanket.

17.2.5 Care of Blankets - Blankets shall be stored in a cool, dark, and dry location free from ozone, chemicals, oils, solvents, damaging vapors and fumes, and away from electrical discharges. Blankets shall be stored in a container that is designed for and used exclusively for them and shall not be kept folded, creased, distorted, or compressed in any manner that will cause stretching or compression.

17.2.6 Blankets shall be cleaned as necessary to remove foreign substances and shall be wiped clean of any oil, grease or other damaging substances as soon as practicable. Clean only with lukewarm water and mild soap detergent. Rinse thoroughly with water to remove all of the soap or detergent.

17.2.7 Do not apply any markings to the blanket, whether with permanent markers, paint pens or stamps. Only the test stamp applied by the certified testing laboratory is permitted.

17.2.8 Testing

a. Periodic testing of rubber insulating blankets shall conform to ASTM F 479, *Standard Specification for In-Service Care of Insulating Blankets*. The blanket testing program is managed by the Electrical Safety Group.

b. Rubber insulating blankets shall be tested prior to being issued. A test date will be stamped or permanently marked on the blanket.

c. Rubber insulating blankets shall be exchanged every 12 months after issue. It is acceptable to retest blankets and return them to service or to replace the blankets with new blankets.

d. The shelf life of tested blankets in storage is 12 months. Blankets may be issued at any time during the 12 months. The issue date triggers a 12-month time period, at the end of which the blankets must be returned and exchanged.

17.3 Rubber Insulating Sheeting

17.3.1 Rubber insulating sheeting may be used to provide primary shock protection when work is being performed adjacent to exposed, energized parts (7.3.3.c). Rubber insulating sheeting shall conform to ASTM F2320 - *Standard Specification for Rubber Insulating Sheeting*.

17.3.2 Rubber insulating sheeting is designed to be disposable. Precut sections may be reused but shall be discarded no more than 6 months after being cut from the parent roll.

17.3.3 Rubber insulating sheeting is available in all ASTM classes per table 17.1.

17.4 PVC Insulating Sheeting

17.4.1 PVC (Poly Vinyl Chloride) insulating sheeting may be used to provide primary shock protection when work is being performed adjacent to exposed, energized parts (7.3.3.c). PVC insulating sheeting shall conform to ASTM D1742 – *Standard Specification for PVC Insulating Sheeting*.

17.4.2 PVC insulating sheeting is designed to be disposable. Precut sections may be reused but shall be discarded no more than 6 months after being cut from the parent roll.

17.4.3 PVC insulating sheeting is typically available in ASTM classes 0 and 1 per table 17.1.

17.4.4 The primary advantage of PVC insulating sheeting over rubber insulating is that it is clear.

17.5 Arc-Rated PPE

17.5.1 Types of materials:

a. Arc-rated: any item meeting the requirements of ASTM F 1506, *Standard Performance Specification for Flame Resistant and Arc Rated Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards*

b. Flammable: any item that does not meet the requirements of ASTM F 1506.

c. Melting: materials consisting of fabrics, zipper tapes, and findings made from flammable synthetic materials that melt at temperatures below 315°C (600°F), such as acetate, acrylic, nylon, polyester, polyethylene, polypropylene, and spandex, either alone or in blends, are considered melting, unless they meet the requirements of ASTM F 1506. These materials melt as a result of arc flash exposure conditions, form intimate contact with the skin, and aggravate the burn injury.

17.5.2 All arc-rated PPE shall conform to the requirements of ASTM F 1506, Standard Performance Specification for Flame Resistant and Arc Rated Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards. Conformance shall be indicated by a tag or label on the garment. The tag or label shall also indicate the ATPV rating of the garment.

17.5.3 Clothing and Other Apparel Not Permitted. Clothing and other apparel (such as hard hat liners and hair nets) made from melting materials or made from materials that do not meet the flammability requirements shall not be permitted to be worn.

17.5.4 Layering. Non-melting, flammable fiber garments shall be permitted to be used as underlayers in conjunction with arc-rated garments in a layered system for added protection. If nonmelting, flammable fiber garments are used as underlayers, the system arc rating shall be sufficient to prevent breakopen of the innermost arc-rated layer at the expected arc exposure incident energy level to prevent ignition of flammable underlayers. Garments that are not arc-rated shall not be permitted to be used to increase the arc rating of a garment or of a clothing system.

17.5.5 Outer Layers. Garments worn as outer layers over arc-rated clothing, such as jackets or rainwear, shall also be made from arc-rated material.

17.5.6 Underlayers. Meltable fibers such as acetate, nylon, polyester, polypropylene, and spandex shall not be permitted in fabric underlayers (underwear) next to the skin.

a. Exception: An incidental amount of elastic used on non-melting fabric underwear or socks shall be permitted.

17.5.7 Coverage. Clothing shall cover potentially exposed areas as completely as possible. Shirtsleeves shall be fastened at the wrists, and shirts and jackets shall be closed at the neck. Arc-rated clothing shall cover associated parts of the body as well as all flammable apparel while allowing movement and visibility.

17.5.8 Fit. Tight-fitting clothing shall be avoided. Loose-fitting clothing provides additional thermal insulation because of air spaces. Arc-rated apparel shall fit properly such that it does not interfere with the work task.

17.5.9 Interference. The garment selected shall result in the least interference with the task but still provide the necessary protection. The work method, location, and task could influence the protective equipment selected.

17.5.10 Clothing and Other Apparel Not Permitted. Clothing consisting of fabrics, zipper tapes, and findings made from flammable synthetic materials that melt at temperatures below 315°C (600°F), such as acetate, acrylic, nylon, polyester, polyethylene, polypropylene, and spandex, either alone or in blends, are considered melting and shall not be used unless incorporated in materials that meet the requirements of ASTM F 1506. Clothing and other apparel (such as hard hat liners and hair nets) made from melting materials or made from materials that do not meet the flammability requirements shall not be permitted to be worn.

17.5.11 Where the work to be performed inside the arc flash boundary exposes the worker to multiple hazards, such as airborne contaminants, under special permission by the Electrical AHJ for Safe Work Practices and where it can be shown that the level of protection is adequate to address the arc flash hazard, non-arc-rated PPE shall be permitted.

a. Work in clean rooms necessitates wearing gear that is not arc-rated. Arc-rated clean room suits are available up to 4 cal/cm^2. Contact the Electrical Safety Group for more information. For exposures above 4 cal/cm^2, there is no PPE that meets the requirements of clean rooms and arc flash protection. Clean rooms should be designed to limit arc flash exposure to less than 4 cal/cm^2.

17.5.12 Arc-rated face shields and flash suit hoods

a. Face shields shall have an arc rating suitable for the arc flash exposure. Face shields without an arc rating shall not be used.

b. Face shields shall not be worn for exposures of greater than 12 cal/cm^2. An arc-rated hood shall be used instead.

c. Face shields shall be worn with an arc-rated balaclava for an exposure range of 4 cal/cm^2 to 12 cal/cm^2. For exposures between to 1.2 cal/cm^2 and 4 cal/cm^2, an arc-rated balaclava shall be worn where the back of the head is within the arc flash boundary.

d. Face shields shall include a wraparound guarding to protect the face, chin, forehead, ears, and neck area.

e. Eye protection (safety glasses or goggles) shall always be worn under face shields.

Fig. 17.5.12 – Arc-Rated Face Shield, Balaclava and Hood

17.5.13 Care and maintenance of Arc-Rated PPE

a. Inspection. Arc-rated apparel shall be inspected before each use. Work clothing or arc flash suits that are contaminated, or damaged to the extent that their protective qualities are impaired, shall not be used. Protective items that become contaminated with grease, oil, or flammable liquids or combustible materials shall not be used.

b. Manufacturer's Instructions. The garment manufacturer's instructions for care and maintenance of arc-rated apparel shall be followed.

c. Storage. Arc-rated apparel shall be stored in a manner that prevents physical damage; damage from moisture, dust, or other deteriorating agents; or contamination from flammable or combustible materials.

d. Cleaning, Repairing, and Affixing Items. When arc-rated clothing is cleaned, manufacturer's instructions shall be followed to avoid loss of protection. When arc-rated clothing is repaired, the same arc-rated materials used to manufacture the arc-rated clothing shall be used to provide repairs.

17.6 Other PPE

17.6.1 Hard hats shall conform to ANSI Z89.1, *Personal Protection – Protective Headwear for Industrial Workers*. Hard hats shall be of Class E (Electrical, tested to 20 kV) or G (General, tested to 2.2 kV). Class C (Conductive) hard hats are not permitted. Note that QEW 3 workers should only wear Class E hard hats, and that fiberglass hard hats are typically Class G.

17.6.2 Safety glasses shall conform to ANSI Z87.1, *Practice for Occupational and Educational Eye and Face Protection*. Safety glasses shall not be of the wireframe type.

17.6.3 Hearing protection shall consist of ear canal inserts and shall have a minimum Noise Reduction Ratio (NRR) of 20 dB. Non arc-rated earmuffs are acceptable provided they are worn under the balaclava of arc flash hood. Arc-rated earmuffs are also acceptable.

18 Electrical Tools & Equipment

18.1 Testing Equipment

18.1.1 Measurement Category

a. The measurement category is a classification system in UL 61010-2 for rating the transient overvoltage capability of testing and measuring instruments according to the type of mains circuits to which they are intended to be connected. Measurement categories take into account overvoltage categories, short-circuit current levels, the location in the building installation at which the test or measurement is to be made, and some forms of energy limitation or transient protection included in the building installation.

b. Testing equipment used on premises wiring systems (including panel boards and service disconnects) rated at less than 600 VAC shall at a minimum be rated to Measurement Category IV (CAT IV) at 600 VAC.

c. Testing equipment used on utilization equipment rated at 277/480 VAC shall at a minimum be rated to Measurement Category III (CAT III) at 600 VAC.

d. Testing equipment used on utilization equipment rated at 250 VAC or less shall at a minimum be rated to Measurement Category II (CAT II) at 300 VAC.

e. All probes and probe leads shall be rated at least to the same Measurement Category as that required for the meter.

18.1.2 Voltage Testers

a. Voltage testers shall be listed to UL 61010-2-033, *Standard for Safety, Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 2-033: Particular Requirements for Hand-Held Multimeters and Other Meters, for Domestic and Professional Use, Capable of Measuring Mains Voltage*.

b. Solenoid type detectors shall not be used at Berkeley Lab. As they are low-impedance devices, they draw a load current through a magnetic coil and displace a spring-loaded plunger. They typically have a duty rating, meaning they can only be applied to a live circuit for a limited amount of time. Although a clear favorite for electricians in the past, experience has shown that these devices have higher failure rates than high-impedance digital voltmeters.

18.1.3 Current Testers

a. Only clamp-on style ammeters shall be used for measuring power systems current (≥ 50 VAC, ≥ 5 A).

b. Clamp-on ammeters shall be listed to UL 61010-2-032, *Standard for Safety, Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 2-032: Particular Requirements for Hand-Held and Hand-Manipulated Current Sensors for Electrical Test and Measurement*.

18.1.4 All other testing equipment shall be listed to UL 61010-2-030, *Standard for Safety, Safety requirements for electrical equipment for measurement, control, and laboratory use – Part 2-030: Particular Requirements for testing and measuring circuits*.

18.2 Insulated Tools

a. Insulated tools shall meet the requirements of ASTM F 1505, *Standard Specification for Insulated and Insulating Hand Tools*. They shall be marked with the double triangle symbol and "1000 V".

b. Insulated tools and equipment shall be inspected prior to each use. The inspection shall look for damage to the insulation or damage that may limit the tool from performing its intended function or could increase the potential for an incident (for example, damaged tip on a screwdriver).

18.3 Temporary Personal Protective Grounds

18.3.1 Utility ground sets

a. Temporary personal protective grounds used for the grounding of utility equipment shall meet the requirements of ASTM F 855, *Standard Specifications for Temporary Protective Grounds to Be Used on De-energized Electric Power Lines and Equipment*.

b. Testing. Prior to being returned to service, temporary protective grounding equipment that has been repaired or modified shall be tested. Guidance for inspecting and testing safety grounds is provided in ASTM F 2249, *Standard Specification for In-Service Test Methods for Temporary Grounding Jumper Assemblies Used on De-Energized Electric Power Lines and Equipment*.

18.3.2 Other ground sets shall, such as for capacitor banks and high-voltage/low-current applications, shall be designed for the application.

18.3.3 Visual Inspection. Personal protective ground cable sets shall be inspected for cuts in the protective sheath and damage to the conductors. Clamps and connector strain relief devices shall be checked for tightness. These inspections shall be made at intervals thereafter as service conditions require, but in no case shall the interval exceed 1 year.

18.4 Other Tools

18.4.1 Fuse or Fuse Holding Equipment. Fuse or fuseholder handling equipment, insulated for the circuit voltage, shall be used to remove or install a fuse if the fuse terminals are energized.

18.4.2 Ropes and Handlines. Ropes and handlines used within the limited approach boundary of exposed energized electrical conductors or circuit parts operating at 50 volts or more, or used where an electrical hazard exists, shall be nonconductive.

18.4.3 Fiberglass-reinforced plastic rod and tube used for live-line tools shall meet the requirements of ASTM F 711, *Standard Specification for Fiberglass-Reinforced Plastic (FRP) Rod and Tube Used in Live Line Tools.*

18.4.4 Portable Ladders. Portable ladders shall have nonconductive side rails if they are used where the employee or ladder could contact exposed energized electrical conductors or circuit parts operating at 50 volts or more or where an electrical hazard exists. Nonconductive ladders shall meet the requirements of ANSI A14.5, *American National Standard for Ladders — Portable Reinforced Plastic — Safety Requirements*.

18.4.5 Rubber Insulating Equipment. Rubber insulating equipment used for protection from accidental contact with energized conductors or circuit parts shall meet the requirements of ASTM D 1048, *Standard Specification for Rubber Insulating Blankets* or ASTM D 1049, *Standard Specification for Rubber Insulating Covers*.

18.4.6 Voltage-Rated Plastic Guard Equipment. Plastic guard equipment for protection of employees from accidental contact with energized conductors or circuit parts, or for protection of employees or energized equipment or material from contact with ground, shall meet the requirements of ASTM F 712, *Standard Test Methods and Specifications for Electrically Insulating Plastic Guard Equipment for Protection of Workers*.

PART III – DEFINITIONS AND APPENDICES

Acronyms and Abbreviations

Acronym	Full Term
A	Ampere
AC	Alternating Current
AED	Automatic External Defibrillator
AHJ	Authority Having Jurisdiction
ANSI	American National Standards Institute
ARMS	Arc Reduction Maintenance Switch
ASTM	American Society for Testing and Materials
ATPV	Arc Thermal Performance Value
CFR	Code of Federal Regulations
COO	Chief Operating Officer
DC	Direct Current
DOE	Department of Energy
EBT	Breakthrough Energy
EESP	Electrical Equipment Safety Program
EETP	Energized Electrical Testing Permit
EEWP	Energized Electrical Work Permit
EHS	Environment, Health & Safety
ESA	Electrical Safety Advocate
ESD	Electrostatic Discharge
ESO	Electrical Safety Officer
ESP	Electrical Safety Program
ESWP	Electrical Safe Work Procedure
fc	Foot-Candle
GFCI	Ground Fault Circuit Interrupter
HVAC	Heating, Ventilation and Air Conditioning
Hz	Hertz
IEEE	Institute of Electrical and Electronics Engineers
ISM	Integrated Safety Management
J	Joule
kHz	Kilohertz
kV	Kilovolt
LBNL	Lawrence Berkeley National Laboratory
LOTO	Lockout/Tagout
mA	Milliampere
MCC	Motor Control Center
MHz	Megahertz

NEC	National Electrical Code
NFPA	National Fire Protection Association
NRTL	Nationally Recognized Testing Laboratory
OEM	Original Equipment Manufacturer
OSHA	Occupational Safety and Health Administration
PIC	Person in Charge
PPE	Personal Protective Equipment
PVC	Poly Vinyl Chloride
QEW	Qualified Electrical Worker
R&D	Research & Development
RF	Radio Frequency
RPT	Relocatable Power Tap
SME	Subject Matter Expert
SWD	Switching Duty
UL	Underwriter's Laboratories
UPS	Uninterruptible Power Supply
V	Volt
VAC	Volts Alternating Current
VDC	Volts Direct Current
W	Watts
ZVV	Zero Voltage Verification

Definitions

Source	Term	Definition
NEC	**Accessible (as applied to equipment)**	Admitting close approach; not guarded by locked doors, elevation, or other effective means.
NEC	**Accessible (as applied to wiring methods)**	Capable of being removed or exposed without damaging the building structure or finish or not permanently closed in by the structure or finish of the building.
NEC	**Accessible, Readily (Readily Accessible)**	Capable of being reached quickly for operation, renewal, or inspections without requiring those to whom ready access is requisite to actions such as to use tools, to climb over or remove obstacles, or to resort to portable ladders, and so forth.
UL 817	**Adapter Cord Set**	A cord set, without a switch, for use at locations such as construction sites to provide power from a single plug to a maximum of 6 outlets, convert from one contact configuration to another, or both.
NFPA 70E	**Approved**	Acceptable to the authority having jurisdiction
NFPA 70E	**Arc Flash Hazard**	A dangerous condition associated with the possible release of energy caused by an electric arc, resulting in second-degree burns to the skin or ignition of clothing.
NFPA 70E	**Arc Flash Suit**	A complete arc-rated clothing and equipment system that covers the entire body, except for the hands and feet. An arc flash suit may include pants or overalls, a jacket or a coverall, and a beekeeper-type hood fitted with a face shield.
NFPA 70E	**Arc Rating**	The value attributed to materials that describes their performance to exposure to an electrical arc discharge. The arc rating is expressed in cal/cm^2 and is derived from the determined value of the arc thermal performance value (ATPV) or energy of breakopen threshold (EBT) (should a material system exhibit a breakopen response below the ATPV value). Arc rating is reported as either ATPV or EBT, whichever is the lower value. Arc-rated clothing or equipment indicates that it has been tested for exposure to an electric arc. Flame resistant clothing without an arc rating has not been tested for exposure to an electric arc. All arc-rated clothing is also flame-resistant.
ASTM F1959/F1959M	**Arc Thermal Performance Value (ATPV)**	The incident energy (cal/cm^2) on a material or a multilayer system of materials that results in a 50% probability that sufficient heat transfer through the tested specimen is predicted to cause the onset of a second degree skin burn injury based on the Stoll curve.
NEC	**Attachment Plug (Plug Cap) (Plug)**	A male contact device that, by insertion in a receptacle, establishes a connection between the conductors of the attached flexible cord and the conductors connected permanently to the receptacle.
NFPA 70E	**Authority Having Jurisdiction (AHJ)**	An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.
NFPA 70E	**Automatic**	Performing a function without the necessity of human intervention

NFPA 70E	**Balaclava (Sock Hood)**	An arc-rated hood that protects the neck and head except for the facial area of the eyes and nose.
NFPA 70E	**Barricade**	A physical obstruction such as tapes, cones, or A-frame-type wood or metal structures intended to provide a warning and to limit access.
NFPA 70E	**Barrier**	A physical obstruction that is intended to prevent contact with equipment or energized electrical conductors and circuit parts or to prevent unauthorized access to a work area. Barriers may be permanently installed in the equipment, or placed temporarily during performance of energized work.
NEC	**Bonded (Bonding)**	Connected to establish electrical continuity and conductivity.
NEC	**Bonding Conductor or Jumper**	A reliable conductor to ensure the required electrical conductivity between metal parts required to be electrically connected.
NFPA 70E	**Boundary, Arc Flash**	When an arc flash hazard exists, an approach limit at a distance from a prospective arc source within which a person could receive a second degree burn if an electrical arc flash were to occur. A second degree burn is possible by an exposure of unprotected skin to an electric arc flash above the incident energy level of 5 J/cm^2 (1.2 cal/cm^2).
NFPA 70E	**Boundary, Limited Approach**	An approach limit at a distance from an exposed energized electrical conductor or circuit part within which a shock hazard exists.
NFPA 70E	**Boundary, Restricted Approach**	An approach limit at a distance from an exposed energized electrical conductor or circuit part within which there is an increased likelihood of electric shock, due to electrical arc-over combined with inadvertent movement, for personnel working in close proximity to the energized electrical conductor or circuit part.
NEC	**Branch Circuit**	The circuit conductors between the final overcurrent device protecting the circuit and the outlet(s).
NEC	**Building**	A structure that stands alone or that is cut off from adjoining structures by fire walls with all openings therein protected by approved fire doors.
NEC	**Cabinet**	An enclosure that is designed for either surface mounting or flush mounting and is provided with a frame, mat, or trim in which a swinging door or doors are or can be hung.
NEC	**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. The automatic opening means can be integral, direct acting with the circuit breaker, or remote from the circuit breaker.
NEC	**Classified Location**	Hazardous location, as defined in the NEC Article 500, where fire or explosion hazards may exist due to flammable gases, flammable liquid–produced vapors, combustible liquid–produced vapors, combustible dusts, or ignitible fibers/flyings.
NFPA 70E	**Conductive**	Suitable for carrying electric current.
NEC	**Conductor, Bare**	A conductor encased within material of composition or thickness that is not recognized by the NEC as electrical insulation.

NEC	**Conductor, Insulated**	A conductor encased within material of composition and thickness that is recognized by the NEC as electrical insulation.
NEC	**Controller**	A device or group of devices that serves to govern, in some predetermined manner, the electric power delivered to the apparatus to which it is connected.
UL 817	**Cord Connector**	A female contact device that is wired on flexible cord and that contains one or more receptacles.
UL 817	**Cord Set (Extension Cord)**	A length of flexible cord assembled with an attachment plug or current tap as a line fitting, and a cord connector as a load fitting.
NFPA 70E	**Current-Limiting Overcurrent Protective Device**	A device that, when interrupting currents in its current-limiting range, reduces the current flowing in the faulted circuit to a magnitude substantially less than that obtainable in the same circuit if the device were replaced with a solid conductor having comparable impedance.
NFPA 70E	**Cutout**	An assembly of a fuse support with either a fuseholder, fuse carrier, or disconnecting blade. The fuseholder or fuse carrier may include a conducting element (fuse link), or may act as the disconnecting blade by the inclusion of a nonfusible member.
NFPA 70E	**De-energized**	Free from any electrical connection to a source of potential difference and from electrical charge; not having a potential different from that of the earth.
NEC	**Device**	A unit of an electrical system, other than a conductor, that carries or controls electric energy as its principal function.
NFPA 70E	**Diagnostics**	Taking readings or measurements of electrical equipment with approved test equipment that does not require making any physical change to the equipment. Includes testing and troubleshooting.
LBNL	**Direct Field Supervision**	A designated competent QEW is present on site and is providing oversight, guidance and instruction on a specific task or set of tasks to another person.
NEC	**Disconnecting Means**	A device, or group of devices, or other means by which the conductors of a circuit can be disconnected from their source of supply.
NFPA 70E	**Disconnecting (or Isolating) Switch (Disconnector, Isolator)**	A mechanical switching device used for isolating a circuit or equipment from a source of power.
NEC	**Dwelling Unit**	A single unit, providing complete and independent living facilities for one or more persons, including permanent provisions for living, sleeping, cooking, and sanitation.
NEC	**Electrical Equipment**	A general term, including fittings, devices, appliances, luminaires, apparatus, machinery, and the like used as a part of, or in connection with, an electrical installation. Electrical equipment can be classified as premises wiring or utilization equipment.
NFPA 70E	**Electrical Hazard**	A dangerous condition such that contact or equipment failure can result in electric shock, arc flash burn, thermal burn, or blast. Class 2 power supplies, listed low voltage lighting systems, and similar sources are examples of circuits or systems that are not considered an electrical hazard.

NFPA 70E	**Electrical Safety**	Recognizing hazards associated with the use of electrical energy and taking precautions so that hazards do not cause injury or death
NFPA 70E	**Electrically Safe Work Condition**	A state in which an electrical conductor or circuit part has been disconnected from energized parts, locked/tagged in accordance with the LBNL Lockout/Tagout Program, tested to ensure the absence of voltage (Zero Voltage Verification – ZVV), and grounded if determined necessary.
LBNL	**Electrical Work**	Any job or task requiring a Qualified Electrical Worker. It includes any work that involves a shock or arc flash hazard or creates potential a shock or arc flash hazards, energized or deenergized.
IEEE	**Electrostatic Discharge (ESD)**	Electrical discharges of static electricity that build up on personnel or equipment, generated by interaction of dissimilar materials. The sudden transfer of charge between bodies of differing electrostatic potentials that may produce voltages or currents that could destroy or damage electrical components.
NEC	**Enclosed**	Surrounded by a case, housing, fence, or wall(s) that prevents persons from accidentally contacting energized parts.
NFPA 70E	**Enclosure**	The case or housing of apparatus — or the fence or walls surrounding an installation to prevent personnel from accidentally contacting energized electrical conductors or circuit parts or to protect the equipment from physical damage.
NEC	**Energized**	Electrically connected to, or is, a source of voltage.
ASTM F1959/F1959M	**Energy of Breakopen Threshold (EBT or E_{BT})**	The incident energy (cal/cm^2) on a material or a material system that results in a 50% probability of breakopen. Breakopen is a material response evidenced by the formation of one or more holes in the innermost layer of arc-rated material that would allow flame to pass through the material. Breakopen is defined as a hole with an area of 1.6 cm^2 (0.5 in^2) or an opening of 2.5 cm (1.0 in.) in any dimension.
NEC	**Equipment**	A general term, including, fittings, devices, appliances, luminaires, apparatus, machinery, and the like, used as a part of, or in connection with, an electrical installation.
NFPA 70E	**Exposed (as applied to energized electrical conductors or circuit parts)**	Capable of being inadvertently touched or approached nearer than a safe distance by a person. It is applied to electrical conductors or circuit parts that are not suitably guarded, isolated, or insulated.
NEC	**Exposed (as applied to wiring methods)**	On or attached to the surface or behind panels designed to allow access.
NEC	**Fitting**	An accessory such as a locknut, bushing, or other part of a wiring system that is intended primarily to perform a mechanical rather than an electrical function.
NFPA 70E	**Fuse**	An overcurrent protective device with a circuit-opening fusible part that is heated and severed by the passage of overcurrent through it. A fuse comprises all the parts that form a unit capable of performing the prescribed functions. It may or may not be the complete device necessary to connect it into an electrical circuit.
NEC	**Ground**	The earth

NFPA 70E	**Ground Fault**	An unintentional, electrically conducting connection between an ungrounded conductor of an electrical circuit and the normally non–current-carrying conductors, metallic enclosures, metallic raceways, metallic equipment, or earth.
NEC	**Grounded (Grounding)**	Connected (connecting) to ground or to a conductive body that extends the ground connection.
NEC	**Grounded, Solidly**	Connected to ground without inserting any resistor or impedance device.
NEC	**Grounded Conductor**	A system or circuit conductor that is intentionally grounded.
NEC	**Ground-Fault Circuit Interrupter (GFCI)**	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. Class A ground-fault circuit-interrupters trip when the current to ground is 6 mA or higher and do not trip when the current to ground is less than 4 mA. For further information, see ANSI/UL 943, *Standard for Ground-Fault Circuit Interrupters*.
NEC	**Grounding Conductor, Equipment (EGC)**	The conductive path(s) that provides a ground-fault current path and connects normally non–current-carrying metal parts of equipment together and to the system grounded conductor or to the grounding electrode conductor, or both.
NEC	**Grounding Electrode**	A conducting object through which a direct connection to earth is established.
NEC	**Grounding Electrode Conductor**	A conductor used to connect the system grounded conductor or the equipment to a grounding electrode or to a point on the grounding electrode system.
NEC	**Guarded**	Covered, shielded, fenced, enclosed, or otherwise protected by means of suitable covers, casings, barriers, rails, screens, mats, or platforms to remove the likelihood of approach or contact by persons or objects to a point of danger.
NFPA 70E	**Hazard**	A source of possible injury or damage to health.
NFPA 70E	**Hazardous**	Involving exposure to at least one hazard.
NFPA 70E	**Incident Energy**	The amount of thermal energy impressed on a surface, a certain distance from the source, generated during an electrical arc event. Incident energy is typically expressed in calories per square centimeter (cal/cm^2).
NFPA 70E	**Incident Energy Analysis**	A component of an arc flash risk assessment used to predict the incident energy of an arc flash for a specified set of conditions.
NFPA 70E	**Insulated**	Separated from other conducting surfaces by a dielectric (including air space) offering a high resistance to the passage of current. When an object is said to be insulated, it is understood to be insulated for the conditions to which it is normally subject. Otherwise, it is, within the purpose of these rules, uninsulated.
NFPA 70E	**Interrupter Switch**	A switch capable of making, carrying, and interrupting specified currents.

NEC	**Interrupting Rating**	The highest current at rated voltage that a device is identified to interrupt under standard test conditions. Equipment intended to interrupt current at other than fault levels may have its interrupting rating implied in other ratings, such as horsepower or locked rotor current.
NEC	**Isolated (as applied to location)**	Not readily accessible to persons unless special means for access are used.
LBNL	**Job (electrical)**	An assigned set of tasks to complete a certain scope of work.
LBNL	**Job Briefing**	A verbal communication of the job plan by the person in charge to the persons involved with the job. A job briefing is required for EVERY JOB.
NFPA 70E	**Labeled**	Equipment or materials to which has been attached a label, symbol, or other identifying mark of a Nationally Recognized Testing Laboratory (NRTL), and by whose labeling the manufacturer indicates compliance with appropriate standards or performance in a specified manner.
NFPA 70E	**Listed**	Equipment, materials, or services included in a list published by a Nationally Recognized Testing Laboratory (NRTL). The means for identifying listed equipment may vary for each NRTL; some NRTLs do not recognize equipment as listed unless it is also labeled. The authority having jurisdiction should utilize the system employed by the listing organization to identify a listed product.
NEC	**Luminaire**	A complete lighting unit consisting of a light source, such as a lamp or lamps, together with the parts designed to position the light source and connect it to the power supply. It may also include parts to protect the light source or the ballast or to distribute the light. A lampholder itself is not a luminaire.
UL 61010-2	**Measurement Category (CAT rating)**	A classification system in UL 61010-2 for rating the transient overvoltage capability of testing and measuring instruments according to the type of mains circuits to which they are intended to be connected. For example, typical voltmeters are rated at CAT IV, 600 V. Measurement categories take into account overvoltage categories, short-circuit current levels, the location in the building installation at which the test or measurement is to be made, and some forms of energy limitation or transient protection included in the building installation.
NEC	**Motor Control Center (MCC)**	An assembly of one or more enclosed sections having a common power bus and principally containing motor control units.
OSHA	**Nationally Recognized Testing Laboratory (NRTL)**	An organization, which is recognized by OSHA and which tests for safety, and lists or labels or accepts, equipment or materials. See 29 CFR 1910.7.
NFPA 70E	**Non-QEW**	A person who is not a Qualified Electrical Worker.
NEC	**Outlet**	A point on the wiring system at which current is taken to supply utilization equipment.

NEC	**Overcurrent**	Any current in excess of the rated current of equipment or the ampacity of a conductor. It may result from overload, short circuit, or ground fault. A current in excess of rating may be accommodated by certain equipment and conductors for a given set of conditions. Therefore, the rules for overcurrent protection are specific for particular situations.
NEC	**Overload**	Operation of equipment in excess of normal, full-load rating, or of a conductor in excess of rated ampacity that, when it persists for a sufficient length of time, would cause damage or dangerous overheating. A fault, such as a short circuit or ground fault, is not an overload.
NEC	**Panelboard**	A single panel or group of panel units designed for assembly in the form of a single panel, including buses and automatic overcurrent devices, and equipped with or without switches for the control of light, heat, or power circuits; designed to be placed in a cabinet or cutout box placed in or against a wall, partition, or other support; and accessible only from the front.
NEC	**Premises Wiring (System)**	Interior and exterior wiring, including power, lighting, control, and signal circuit wiring together with all their associated hardware, fittings, and wiring devices, both permanently and temporarily installed. This includes: (a) wiring from the service point or power source to the outlets; or (b) wiring from and including the power source to the outlets where there is no service point. Such wiring does not include wiring internal to appliances, luminaires, motors, controllers, motor control centers, and similar equipment. Power sources include, but are not limited to, interconnected or stand-alone batteries, solar photovoltaic systems, other distributed generation systems, or generators.
NFPA 70E	**Qualified Electrical Worker (QEW)**	One who has demonstrated skills and knowledge related to the construction and operation of electrical equipment and installations, has received safety training to identify and avoid the hazards involved, and who has been approved or accepted by the Electrical AHJ for Safe Work Practices.
LBNL	**QEW Supervisor**	A work lead or supervisor providing daily supervision to a QEW or group of QEWs. The QEW supervisor must be of the same level or higher than those supervised.
NEC	**Raceway**	An enclosed channel of metal or nonmetallic materials designed expressly for holding wires, cables, or busbars, with additional functions as permitted in this standard.
NEC	**Receptacle**	A receptacle is a contact device installed at the outlet for the connection of an attachment plug. A single receptacle is a single contact device with no other contact device on the same yoke. A multiple receptacle is two or more contact devices on the same yoke.
NFPA 70E	**Repair**	Any physical alteration of electrical equipment (such as making or tightening connections, removing or replacing components, etc.).
NFPA 70E	**Risk**	A combination of the likelihood of occurrence of injury or damage to health and the severity of injury or damage to health that results from a hazard.

NFPA 70E	**Risk Assessment**	An overall process that identifies hazards, estimates the potential severity of injury or damage to health, estimates the likelihood of occurrence of injury or damage to health, and determines if protective measures are required. As used in this manual, *arc flash risk assessment* and *shock risk assessment* are types of risk assessments.
LBNL	**Safety Watch**	A more stringent hazard control measure than the Standby Person that must be implemented when there are grave consequences from a failure to follow safe work procedures. The Safety Watch must be a QEW and must have no other duties other than monitoring the work of the QEW.
NEC	**Service Drop**	The overhead conductors between the utility electric supply system and the service point.
NEC	**Service Lateral**	The underground conductors between the utility electric supply system and the service point.
NEC	**Service Point**	The point of connection between the facilities of the serving utility and the premises wiring. The service point can be described as the point of demarcation between where the serving utility ends and the premises wiring begins. The serving utility generally specifies the location of the service point based on the conditions of service.
NFPA 70E	**Shock Hazard**	A dangerous condition associated with the possible release of energy caused by contact or approach to energized electrical conductors or circuit parts.
NEC	**Short-Circuit Current Rating**	The prospective symmetrical fault current at a nominal voltage to which an apparatus or system is able to be connected without sustaining damage exceeding defined acceptance criteria.
NFPA 70E	**Single-Line Diagram**	A diagram that shows, by means of single lines and graphic symbols, the course of an electric circuit or system of circuits and the component devices or parts used in the circuit or system.
NEC	**Special Permission**	The written consent of the authority having jurisdiction.
LBNL	**Standby Person**	A second person designated to fulfill the requirements of working accompanied when a QEW is performing certain types of high hazard electrical work. While the primary purpose of a second person is to initiate the emergency response system, a Standby Person is also expected to know how to deenergize electrical equipment and to safely release a QEW from contact with energized parts.
NFPA 70E	**Step Potential**	A ground potential gradient difference that can cause current flow from foot to foot through the body.
NEC	**Structure**	That which is built or constructed.
NEC	**Switch, Isolating**	A switch intended for isolating an electric circuit from the source of power. It has no interrupting rating, and it is intended to be operated only after the circuit has been opened by some other means.

NEC	**Switchboard**	A large single panel, frame, or assembly of panels on which are mounted on the face, back, or both, switches, overcurrent and other protective devices, buses, and usually instruments. These assemblies are generally accessible from the rear as well as from the front and are not intended to be installed in cabinets.
NFPA 70E	**Switchgear, Arc-Resistant**	Equipment designed to withstand the effects of an internal arcing fault and that directs the internally released energy away from the employee.
NFPA 70E	**Switchgear, Metal-Clad**	A switchgear assembly completely enclosed on all sides and top with sheet metal, having drawout switching and interrupting devices, and all live parts enclosed within grounded metal compartments.
NFPA 70E	**Switchgear, Metal-Enclosed**	A switchgear assembly completely enclosed on all sides and top with sheet metal (except for ventilating openings and inspection windows), containing primary power circuit switching, interrupting devices, or both, with buses and connections. This assembly may include control and auxiliary devices. Access to the interior of the enclosure is provided by doors, removable covers, or both. Metal-enclosed switchgear is available in non-arc-resistant or arc-resistant constructions.
LBNL	**Switching**	The manual operation (opening or closing) of any electrical isolation on energized equipment. Manual operation includes the operation of through-the-door breaker handles or other dead-front switching.
NFPA 70E	**Switching Device**	A device designed to close, open, or both, one or more electric circuits.
UL 489	**Switching Duty (SWD) Circuit Breaker**	A molded case circuit breaker intended to switch fluorescent lighting loads on a regular basis. It is marked with a “SWD”.
LBNL	**Task (electrical)**	A specific step in a work procedure; a subset of a job.
LBNL	**Temporary Use**	For construction projects, a time lasting the extent of the project. For normal use in the office, lab or other space (indoors or outdoors) not in a construction setting, this refers to an installation using extension cords, not to exceed one calendar month.
NFPA 70E	**Testing**	See **Diagnostics**
NFPA 70E	**Touch Potential**	A ground potential gradient difference that can cause current flow from hand to hand, hand to foot, or another path, other than foot to foot, through the body.
NFPA 70E	**Troubleshooting**	See **Diagnostics**
NEC	**Unclassified Location**	Locations determined to be not Classified per the NEC Article 500.
NEC	**Ungrounded**	Not connected to ground or to a conductive body that extends the ground connection.
NEC	**Utilization Equipment**	Equipment that utilizes electric energy for electronic, electromechanical, chemical, heating, lighting, or similar purposes. Typically refers to the load equipment as distinguished from generating or distribution equipment, which are part of the Premises Wiring.

	Visual Inspection	Examination of a circuit that has not been placed in an Electrically Safe Work Condition, from outside of the restricted approach boundary, without working on the circuit.
NEC	**Voltage (of a Circuit)**	The greatest root-mean-square (rms) (effective) difference of potential between any two conductors of the circuit concerned. Some systems, such as three-phase 4-wire, single-phase 3-wire, and 3-wire direct-current, may have various circuits of various voltages.
NEC	**Voltage, Nominal**	A nominal value assigned to a circuit or system for the purpose of conveniently designating its voltage class (e.g., 120/240 volts, 480Y/277 volts). The actual voltage at which a circuit operates can vary from the nominal within a range that permits satisfactory operation of equipment. See ANSI C84.1, *Electric Power Systems and Equipment — Voltage Ratings (60 Hz)*.
NFPA 70E	**Working On (energized electrical conductors or circuit parts)**	Intentionally coming in contact with energized electrical conductors or circuit parts with the hands, feet, or other body parts, with tools, probes, or with test equipment, regardless of the personal protective equipment (PPE) a person is wearing. There are two categories of "working on": **diagnostic** and **repair** (see definitions).
LBNL	**Zero Voltage Verification (ZVV)**	The practice of testing circuit parts for the absence of voltage. Includes the live-dead-live check to verify tester functionality.

Appendix A: Standards on Personal Protective Equipment

Personal protective equipment (PPE) shall conform to the standards given in the following table.

Subject	Document	Document Number
Apparel — Arc Rated	Standard Performance Specification for Flame Resistant and Arc Rated Textile Materials for Wearing Apparel for Use by Electrical Workers Exposed to Momentary Electric Arc and Related Thermal Hazards	ASTM F 1506
Aprons — Insulating	Standard Specification for Electrically Insulating Aprons	ASTM F 2677
Eye and Face Protection — General	Practice for Occupational and Educational Eye and Face Protection	ANSI/ASSE Z87.1
Face — Arc Rated	Standard Test Method for Determining the Arc Rating and Standard Specification for Face Protective Products	ASTM F 2178
Fall Protection	Standard Specifications for Personal Climbing Equipment	ASTM F 887
Footwear — Dielectric Specification	Standard Specification for Dielectric Footwear	ASTM F 1117
Footwear — Dielectric Test Method	Standard Test Method for Determining Dielectric Strength of Dielectric Footwear	ASTM F 1116
Footwear — Standard Performance Specification	Standard Specification for Performance Requirements for Foot Protection	ASTM F 2413
Footwear — Standard Test Method	Standard Test Methods for Foot Protection	ASTM F 2412
Gloves — Leather Protectors	Standard Specification for Leather Protectors for Rubber Insulating Gloves and Mittens	ASTM F 696
Gloves — Rubber Insulating	Standard Specification for Rubber Insulating Gloves	ASTM D 120
Head Protection — Hard Hats	Personal Protection — Protective Headwear for Industrial Workers	ANSI/ISEA Z89.1
Rainwear — Arc Rated	Standard Specification for Arc and Flame Resistant Rainwear	ASTM F 1891
Rubber Protective Products — Visual Inspection	Standard Guide for Visual Inspection of Electrical Protective Rubber Products	ASTM F 1236
Sleeves — Insulating	Standard Specification for Rubber Insulating Sleeves	ASTM D 1051

Appendix B: Standards on Other Protective Equipment

Other protective equipment shall conform to the standards given in the following table.

Subject	Document	Document Number
Blankets, Arc Protective	Standard Test Method for Determining the Protective Performance of an Arc Protective Blanket for Electric Arc Hazards	ASTM F 2676
Blankets, Rubber Insulating	Standard Specification for Rubber Insulating Blankets	ASTM D 1048
Covers, Rubber Insulating	Standard Specification for Rubber Insulating Covers	ASTM D 1049
Fiberglass Rods — Live-Line Tools	Standard Specification for Fiberglass-Reinforced Plastic (FRP) Rod and Tube Used in Live Line Tools	ASTM F 711
Insulated Hand Tools	Standard Specification for Insulated and Insulating Hand Tools	ASTM F 1505
Ladders	American National Standard for Ladders — Portable Reinforced Plastic — Safety Requirements	ANSI A14.5
Line Hose	Standard Specification for Rubber Insulating Line Hose	ASTM D 1050
Plastic Guard	Standard Test Methods and Specifications for Electrically Insulating Plastic Guard Equipment for Protection of Workers	ASTM F 712
PVC Sheeting	Standard Specification for PVC Insulating Sheeting	ASTM F 1742
Safety Signs and Tags	Series of Standards for Safety Signs and Tags	ANSI Z535 Series
Shield Performance on Live-Line Tools	Standard Test Method for Determining the Protective Performance of a Shield Attached on Live Line Tools or on Racking Rods for Electric Arc Hazards	ASTM F 2522
Temporary Protective Grounds — Test Specification	Standard Specifications for Temporary Protective Grounds to Be Used on De-energized Electric Power Lines and Equipment	ASTM F 855

Appendix C: In-Service Specifications for Personal and Other Protective Equipment

Personal and other protective equipment shall conform to the in-service care requirements given in the following table.

Subject	Document	Document Number
Blankets — Rubber Insulating	Standard Specification for In-Service Care of Insulating Blankets	ASTM F 479
Gloves and Sleeves – Rubber Insulating	Standard Specification for In-Service Care of Insulating Gloves and Sleeves	ASTM F 496
Rubber Protective Products — Visual Inspection	Standard Guide for Visual Inspection of Electrical Protective Rubber Products	ASTM F 1236
Line Hose and Covers	Standard Specification for In-Service Care of Insulating Line Hose and Covers	ASTM F 478
Temporary Protective Grounds	Standard Specification for In-Service Test Methods for Temporary Grounding Jumper Assemblies Used on De-Energized Electric Power Lines and Equipment	ASTM F 2249

Appendix D: Reference Sheet for the QEW Skill of the Craft Work

PLAN EVERY JOB

Step	Instruction	Manual Reference(s)
PLAN THE WORK		
1.	Designate a Person In Charge (PIC) a. Must be competent for the task b. Part of the planning process c. Responsible for the safe execution of the work	• 6.1
2.	Determine the scope of work a. Determine what needs to be performed b. Determine type of electrical work c. Always perform work in an Electrically Safe Work Condition where possible	• 4.4 • 4.1.7 • 6.3-6.7
3.	Analyze the hazards a. Perform a shock hazard analysis b. Perform an arc flash hazard analysis c. Determine approach boundaries d. Consider body positioning constraints	• 4.3.5 • 7.1 • 8.1 • 10.1
4.	Determine qualification requirements a. QEW level b. Experience level with specific equipment and/or task	• 6.2 • 6.10
5.	Select the appropriate personal protective equipment (PPE) and barriers a. Voltage gloves b. Voltage blankets c. Arc flash PPE d. Arc-rated blankets	• 0 • 7.6 • 7.9 • 8.10
6.	Determine tools required a. Listed, used for correct purpose, unmodified and in good condition b. Appropriate training received for using the tools	• 7.3.2.f • 18.1 • 18.3
7.	Determine if 2-Person Rule applies a. Standby Person b. Safety Watch	• 6.13.3 • 6.13.4
8.	Set up area access controls a. Barricades	• 10.3.2 • 10.3.3

	b. Attendants	
9.	Determine additional controls as necessary	• 4.3.6 • 4.4
10.	Obtain line management authorization to perform troubleshooting a. Who is performing the work? Are they suitably qualified and experienced? b. Who is supervising the work? Are they suitably qualified and experienced? c. Is a written procedure necessary or advised (ESWP)? d. Are any permits required and have they been approved? e. What plant operational conditions will (or should) be required? Are these accounted for in the plan? f. What could go wrong and what should be done about it? Is the level of planning and supervision appropriate for the level of risk?	• 4.5
BRIEF AND PERFORM THE WORK		
11.	PIC performs a Job Briefing a. Brief every person who participates or who is in the area b. Provide overview of hazards and controls c. Run through QEW self-control questions	• 6.9 • 4.7
12.	Control access to the work area	• 10.3
13.	PIC controls access to the work site a. Access restricted to essential personnel only b. Brief every person who comes in the area c. A QEW must escort a non-QEW within the Limited Approach Boundary d. If PIC cannot control access, designate an Attendant to perform the function	• 6.9 • 10.3 • 7.3.2.c
14.	Perform the work a. Perform work within the controls b. Always Test Before Touch c. Be alert for changes to job scope. STOP AND REASSESS. d. Maintain good housekeeping and cleanliness e. Anticipate problems f. Resist pressure to "hurry up" g. Maintain a questioning attitude	• 4.1.5 • 9.4.2
FEEDBACK		
15.	Debrief and record lessons learned for future improvement.	• 4.2.4.e

Appendix E: List of Pre-Approved Voltage Detectors for Zero Voltage Verification

Picture	Model	Specifications
	Fluke T5	T5-600: 600V ac/dc, CAT III T5-1000: 1000V ac/dc, CAT III 600V ac/dc, CAT IV
	Fluke 381	1000V ac/dc, CAT III 600V ac/dc, CAT IV Remote Display True-rms AC/DC Clamp Meter with iFlex
	Fluke 70 III	600V ac/dc, CAT II **<u>NOTE:</u>** This model has been *discontinued* and is replaced by the Fluke 115

	Fluke 115	600V ac/dc, CAT III True-rms multi-meter
	Fluke 113	600V ac/dc, CAT III 300V ac/dc, CAT IV True-rms AC/DC Utility multi-meter
	Fluke 233	1000V ac/dc, CAT III 600V ac/dc, CAT IV Remote Display True-rms AC/DC multi-meter
	Fluke 175	1000V ac/dc, CAT III 600V ac/dc, CAT IV True-rms digital multimeter

	Fluke 177	1000V ac/dc, CAT III 600V ac/dc, CAT IV True-rms digital multimeter