ELECTRICAL SAFETY AWARENESS PROGRAM

Guidance for Research Laboratory Activities

Faculty are responsible for:

- Ensuring the procurement of safe electrical equipment in their laboratories.
- Ensuring that the building of electrical equipment in the laboratory is conducted safely.
- Ensuring that students and staff's projects and tasks do not pose significant electrical risk.
- Ensuring that experiments conducted on electrical equipment that can deliver over 50V is always conducted while the system is fully de-energized.

In unlikely situations where **research experiments must be conducted on electrical equipment over 50V, while the equipment is energized,** specific precautions must be taken to ensure everyone's safety. Faculty must identify the Authority Having Jurisdiction, Qualified Electrical Persons and Safety Watch personnel prior to conducting any energized work. Consulting with the EH&S Office and the Caltech Electric Shop is strongly recommended.

Qualifications

Authority Having Jurisdiction (AHJ)

The **NFPA 70, National Electrical Code (NEC**) defies the authority having jurisdiction as 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.

The Principal Investigator may serve as AHJ for their laboratory; however, it is recommended that they consult with someone capable of conducting a thorough risk assessment for energized electrical work.

Qualified Person

The NEC defines a qualified person as:

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

Note that the qualified person not only possesses technical skills but *also must* complete NFPA 70E compliant electrical hazards safety training. Training is required prior to conducting the work and refresher training is completed every 3 years, at a minimum.

Unqualified Person

The NEC defines an unqualified person simply as a person who is not a qualified person.

Safety Watch

A safety watch is a worker who:

- Is trained in cardiopulmonary resuscitation (CPR) and use of an automated external defibrillator (AED).
- Knows the location of emergency shutoffs and power disconnects.
- Is knowledgeable about the work to be performed.

- Monitors the work area for unsafe work conditions or work practices and is capable of rendering non-work-related aid[1] if necessary.

Due to the complexity of these requirements, Principal Investigators should consider external support for these activities. Please consult with EH&S to help identify the adequate support.

When required personnel have been identified and trained, below is a list of procedures they will be required to follow, depending on the tasks and associated risk assessment.

Risk Assessment

Article 130 of NFPA 70E requires that all of the following applies whenever there is work to be done on energized electrical conductors or components operating at voltages greater than 50 V that are not in an electrically safe work condition.

- Only qualified workers are to work on electric conductors or circuit parts that are not placed in an electrically safe condition
- An electric shock risk assessment
- An arc flash risk assessment

Electric Shock Risk Assessment

The steps to performing an electric shock risk assessment are:

- Identify the shock hazards
- Estimate the likelihood and severity of an injury by considering:
  - The design of the electrical equipment
  - The operating condition of the electrical equipment and its condition
- Determine if any additional protective measures are needed:
  - If required, they should be selected based on the standard hierarchy of controls, namely elimination, substitution, engineering controls, administrative controls, and PPE.
  - When the additional measures include the use of PPE, the following need to be determined:
    - The voltage(s) to which the worker will be exposed to
    - The boundary requirements
    - The PPE and other protective equipment required to protect against electric shock
- The risk assessment must be documented

Arc Flash Risk Assessment

The steps to performing an arc flash risk assessment are:

- Identify the arc flash hazards
  - Determine if an arc flash risk exists
- Estimate the likelihood and severity of an injury by considering:
  - The environment, equipment condition, and any potential conditions that may increase risk
  - The design of the equipment, including its overcurrent protective devices and their activation time
- Determine if any additional protective measures are needed:
  - If required, they should be selected based on the standard hierarchy of controls, namely elimination, substitution, engineering controls, administrative controls, and PPE.
  - Know the appropriate safety-related work practices

[1] Examples of non-work-related aid include removing injured personnel, calling x5000, and de-energizing equipment.

- Understand the arc flash boundary and what PPE is required
- The risk assessment must be documented

Performing an arc flash calculation is complex. Most of the methods and literature are geared towards AC utility systems, whose operating voltages and currents typically exceed those encountered with laboratory equipment. Guidance for performing an arc flash calculation is given in IEEE Std 1584[2]. Estimates of the likelihood of an arc flash are given in NFPA 70E Table 130.5(C). In general, arc flash is not likely to occur in systems that operate at 120 V or less.

If the activation time of any overcurrent protective devices is unknown or if no overcurrent device is present, the so-called "two second rule" can used as a reasonable worst-case scenario for the duration of the arc flash.

Task	**Operating Condition**	**Likelihood of Occurrence**
Reading a panel meter while operating a meter switch.	Any	No
Working on control circuits with exposed energized electrical conductors or circuit parts at less than or equal to 125 V AC or DC without any other exposed energized equipment over 125 V AC or DC.	Any	No
Examination of insulated cable with no handling of the cable.	Any	No
For AC systems, work on energized electrical conductors or circuit parts, including testing	Any	Yes
Removal of instrument covers, such as front panels, battery terminal covers, to expose bare, energized electrical conductors and circuit parts.	Any	Yes
Insertion or removal of plug-in modules into or from a power backplane.	Any	Yes
Working on control circuits with exposed energized electrical conductors and circuits at greater than 120 V.	Any	Yes
Voltage testing on individual battery cells or individual multi-cell units.	Normal	No
Voltage testing on individual battery cells or individual multi-cell units.	Abnormal	Yes
Insertion or removal of UPS batteries.	Normal	No
Insertion or removal of UPS batteries	Abnormal	Yes

Table 1. Estimate of the likelihood of an arc flash incident for AC and DC systems. This includes some laboratory-related items from Table NFPA 70E 130.5(C).

Electrical Hazard Classes

Electrical hazards are classified by dividing electrical sources and energy into six general categories, based on source and waveform. These are:

[2] IEEE Guide for Performing Arc-Flash Hazard Calculations, IEEE 1584-2018. https://standards.ieee.org/ieee/1584/5802/.

- Class 1 – 50 / 60 Hz power (AC mains)
- Class 2 – DC
- Class 3 – Capacitors
- Class 4 – Batteries
- Class 5 – RF (3 kHz to 100 MHz)
- Class 6 – sub-RF (1 Hz to 3 kHz, excluding 50 / 60 Hz)

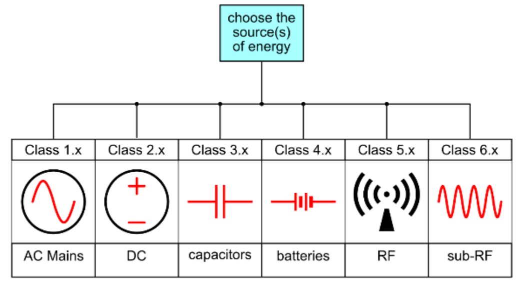

Figure 1. The electrical hazard classification system. There are six major groups. Each group is subdivided based on operating

Procedures

Approach Boundaries

Observing a safe approach distance from exposed energized electrical conductors or components is an effective means of maintaining electrical safety. As the distance between a person and the exposed energized electrical conductors or components decreases, the potential for electric accidents increases. There are three boundaries that personnel working with electrical equipment should be aware of. These are: the arc flash boundary, limited approach boundary, and the restricted approach boundary. In all cases only qualified persons may work within the three approach boundaries. Figure 1 shows the approach boundaries from an electrical element and what type of worker can work within the boundaries.

The approach boundaries for AC and DC systems are given in Table 1 and Table 2.

Arc Flash Boundary

When an arc flash hazard exists, the arc flash boundary is the distance from a potential arc source within which a person could receive a second-degree burn if an arc flash were to occur.

Unqualified persons are not allowed within the arc flash boundary unless continuously accompanied and supervised by a qualified person.

Limited Approach Boundary

The limited approach boundary is the distance from an exposed energized electrical component within which a shock hazard exists.

Unqualified persons are only allowed within the limited approach boundary if continuously accompanied and supervised by a qualified person.

When unqualified workers are working near or at the limited approach boundary, the unqualified workers must be made aware of the electrical hazard and stay outside the limited approach boundary. The alert consists of a safety sign and a physical barricade. Where a sign and a barricade is not practical, an attendant must be used. The attendant must remain present whenever the possibility of an exposure to the electrical hazard exists.

Restricted Approach Boundary

The restricted approach boundary is the distance from an exposed energized electrical component within which there is an increased risk of electric shock due to an arc combined with any inadvertent movement by qualified personnel working close to the energized electrical component.

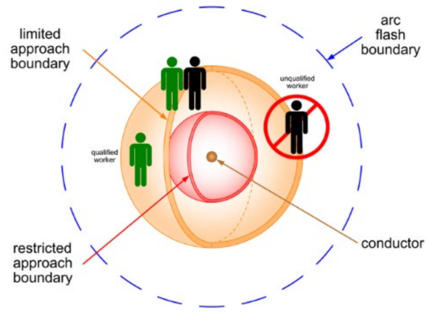

Figure 2. The approach boundaries from an exposed conductor.

Unqualified persons are not to cross the restricted approach boundary under any circumstances.

Nominal System Voltage Range, Phase-to-Phase	Limited Approach Boundary		Restricted Approach Boundary
	Exposed Movable Conductor	Exposed Fixed Circuit Conductor	
Less than 50 V	Not specified	Not specified	Not specified
50 V – 150 V	3.1 m (10 ft.)	1.0 m (3 ft. 6 in.)	Avoid contact
151 V – 750 V	3.1 m (10 ft.)	1.0 m (3 ft. 6 in.)	0.31 m (1 ft.)
751 V – 5 kV	3.1 m (10 ft.)	1.0 m (3 ft. 6 in.)	0.63 m (2 ft. 1 in.)
5.1 kV – 15 kV	3.1 m (10 ft.)	1.5 m (5 ft.)	0.65 m (2 ft. 2 in.)
15.1 kV – 36 kV	3.1 m (10 ft.)	1.8 m (6 ft.)	0.77 m (2 ft. 7 in.)
36.1 kV – 46 kV	3.1 m (10 ft.)	2.5 m (8 ft.)	0.84 m (2 ft. 10 in.)
46.1 kV – 72.5 kV	3.1 m (10 ft.)	2.5 m (8 ft.)	1.0 m (3 ft. 4 in.)
72.6 kV – 121 kV	3.3 m (10 ft. 8 in.)	2.5 m (8 ft.)	1.2 m (3 ft. 9 in.)
121.1 kV – 145 kV	3.4 m (11 ft.)	3.1 m (10 ft.)	1.3 m (4 ft. 4 in.)
145.1 kV – 169 kV	3.6 m (11 ft. 8 in.)	3.6 m (11 ft. 8 in.)	1.5 m (4 ft. 10 in.)
169.1 kV – 242 kV	4.0 m (13 ft.)	4.0 m (13 ft.)	2.1 m (6 ft. 8 in.)
242.1 kV – 362 kV	4.7 m (15 ft. 4 in.)	4.7 m (15 ft. 4 in.)	3.5 m (11 ft. 2 in.)
362.1 kV – 420 kV	5.8 m (19 ft.)	5.8 m (19 ft.)	4.3 m (14 ft.)
420.1 kV – 550 kV	5.8 m (19 ft.)	5.8 m (19 ft.)	5.1 m (16 ft. 8 in.)
550.1 kV – 800 kV	7.2 m (23 ft. 9 in.)	7.2 m (23 ft. 9 in.)	6.9 m (22 ft. 7 in.)

Table 2. Approach boundaries to exposed energized electrical conductors or circuit components for alternating current (AC) systems. This is the same as NFPA 70E (2024) Table 130.4(E)(a).

Nominal Potential Difference	Limited Approach Boundary		Restricted Approach Boundary
	Exposed Movable Conductor	Exposed Fixed Circuit Conductor	
Less than 50 V	Not specified	Not specified	Not specified
50 V – 300 V	3.1 m (10 ft.)	1.0 m (3 ft. 6 in.)	Avoid contact
301 V – 1 kV	3.1 m (10 ft.)	1.0 m (3 ft. 6 in.)	0.3 m (1 ft.)
1.1 kV – 5 kV	3.1 m (10 ft.)	1.5 m (5 ft.)	0.5 m (1 ft. 5 in.)
5.1 kV – 15 kV	3.1 m (10 ft.)	1.5 m (5 ft.)	0.7 m (2 ft. 2 in.)
15.1 kV – 45 kV	3.1 m (10 ft.)	2.5 m (8 ft.)	0.8 m (2 ft. 9 in.)
45.1 kV – 75 kV	3.1 m (10 ft.)	2.5 m (8 ft.)	1.0 m (4 ft. 6 in.)
75.1 kV – 150 kV	3.3 m (10 ft. 8 in.)	3.1 m (10 ft.)	1.2 m (3 ft. 10 in.)
150.1 kV – 250 kV	3.6 m (11 ft. 8 in.)	3.6 m (11 ft. 8 in.)	1.6 m (5 ft. 3 in.)

250.1 kV – 500 kV	6.0 m (20 ft.)	6.0 m (20 ft.)	3.5 m (11 ft. 6 in)
500.1 kV – 800 kV	8.0 m (26 ft.)	8.0 m (26 ft.)	5.0 m (16 ft. 5 in.)

Table 3. Approach boundaries to exposed energized electrical conductors or circuit components for direct current (DC) systems. This is the same as NFPA 70E (2024) Table 130.4(E)(b).

Work On Electrical Equipment

Only qualified persons and persons under the direct supervision of a qualified person should work on energized electrical equipment operating at 50 V or more. Before starting any work on electrical *equipment*, it should be placed in an electrically-safe condition[3] except when it is necessary for troubleshooting, testing, or in areas where an electrically-safe condition is not possible. ***Work on any electrical system operating at 50 V or more is not to be considered a routine activity and requires an electric shock risk assessment.*** All electrical circuits and equipment are to be considered energized until opened, locked and tagged out according to an approved lockout / tagout procedure[4], and verified with an approved, working electrical testing tool. After being de-energized, the circuit should be tested in some manner to prove that it is truly de-energized (e.g. by activating the on button).

A review of any documentation such as system drawings or schematic diagrams, or a system walkthrough should be performed to identify all potential sources of electrical energy. Where the possibility exists of the circuit becoming energized from other sources, the circuit should be grounded and shorted.

Establishing an Electrically Safe Work Condition

NFPA 70E provides a six-step process to achieving an electrically safe work condition. In summary these are:

1. Determine all possible sources of electrical supply to the equipment item being worked on. Check applicable up-to-date documentation.
2. After properly interrupting the load current, open the disconnecting device(s) for each source.
3. Where possible, visually verify that all contacts of the disconnecting device(s) are open or withdrawn to the fully disconnected position.
4. Apply lockout / tagout as per established and documented procedure.
5. Use an appropriately rated voltage detector to check for the absence of voltage on each electrical supply conductor or circuit part. Check the operation of the voltage detector prior to each use.
6. Where there is the possibility of stored or induced electrical energy, ground the conductors or circuit parts before touching them.

Modes of Work on Electrical Equipment

During regular operation of the approved electrical equipment, the user is normally protected by the engineering controls in place. When engineering controls are not yet installed, not approved, or are disabled for the purposes of testing or maintenance, work on electrical equipment falls under one of the following categories:

- Mode 0 — Electrically safe work condition
- Mode 1 — Establishing an electrically safe work condition
- Mode 2 — Energized diagnostics and testing
- Mode 3 — Energized work

[3] This is required by NFPA 70E 110.2.
[4] https://safety.caltech.edu/documents/14113/Lockout_Tagout.pdf

Mode 0 — Electrically safe work condition

An electrically safe work condition is one where the conductor(s) or circuit part(s) to be worked on, or in close proximity to, have been:

- Disconnected and isolated from hazardous energized sources or parts
- Locked out and tagged out or the equivalent of, as per a documented procedure
- Tested to verify the absence of voltage
- Grounded, if necessary

All work on hazardous electrical systems should be done in an electrically safe work condition.

Mode 1 — Establishing an electrically safe work condition

Mode 1 work is required to get to Mode 0. Mode 1 activity should be covered by standard operating procedures (SOPs) and a hazard analysis should be done. To establish Mode 1 conditions, a qualified person should:

- Determine all sources of electrical supply to the equipment
- Check all applicable documentation (system diagrams, schematics, SOPs)
- Turn off the equipment
- Wear the correct personal protective equipment (PPE) and establish barriers denoting the approach boundaries
- Open the disconnecting means (e.g. breaker, or disconnect switch)
- If possible, visually verify that the disconnecting means is fully in the disconnecting position
- Test the controls and attempt to restart the equipment
- Apply lockout / tagout (LOTO) devices, ensure any devices or controls that activate the equipment are under full control of the worker
- Verify that each normally energized conductor or circuit is de-energized
- If there is the possibility of any induced voltages on normally energized conductors or circuits, ground them before touching them
- If stored electrical energy exists, discharge or remove the stored energy and apply grounds to the normally energized conductors or circuits

Mode 2 — Energized diagnostics and testing

Mode 2 involves work with the electrical equipment energized to allow measurements, testing, diagnostics, and observation of the equipment's function. Electrical work is considered Mode 2 if proper voltage-rated instruments are used to contact energized parts. If any part of the worker's body passes through the Restricted Approach Boundary, appropriate shock PPE should be worn. If any part of the worker's body passes through the Limited Approach Boundary, this is considered to be Mode 3 Energized Work. If any part of the worker's body passes through the arc flash boundary, the appropriate arc flash PPE should be worn.

Some examples of Mode 2 work are:

- Making voltage measurements with a multimeter at various test points on a circuit board
- Adjusting voltage offsets by trimming a potentiometer
- Tuning the frequency response of a filter by adjusting a trimming capacitor
- Following the manufacturer's instructions for diagnostics and troubleshooting of energized circuits

Mode 3 — Energized work

Mode 3 involves work with moving energized conductors or circuits, or moving parts that are near energized conductors or circuits and is performed with the equipment fully energized. Work control with an approved energized electrical work permit is required.

Energized work is permissible only if:

- Equipment design or other limitations make it infeasible to perform the work in a de-energized state.
- If all exposed energized conductors and circuits operate at 50 V or less with respect to ground.
- Additional or increased hazards would exist due to establishing an electrically safe work condition.

Energized Electrical Work Permit (EEWP)

An energized electrical work permit (EEWP) is required whenever:

- Work is performed within the restricted approach boundary.
- When there is an increased chance of injury due to an arc flash hazard, even when the electrical conductors or electric circuit(s) are covered.

The work permit, at a minimum, should include the following information:

- A description of the circuit and equipment to be worked on and their location.
- A description of the work to be performed.
- A justification for why the work must be performed in an energized condition.
- A description of the work controls put in place.
- The results of any shock hazard or arc flash hazard assessment.
- Measures taken to restrict the access of unqualified workers.
- Approval of the EEWP by the AHJ.

Exemptions to an EEWP are permitted only if a qualified worker is provided with and uses the appropriate safe work practices and PPE under any of the following conditions:

- Testing, troubleshooting, or voltage measuring.
- Inspections (e.g. thermal, visual) if the restricted approach boundary is not crossed.
- General housekeeping and other non-electrical tasks if the restricted approach boundary is not crossed.
- Entering and exiting an area with energized electrical equipment provided the restricted approach boundary is not crossed.

Lockout / Tagout (LOTO)

Caltech's lockout / tagout (LOTO) program is described in Lockout/Tagout Program.[5] LOTO training is required for all personnel using a lockout / tagout locking device to control hazardous energy whilst doing their work.

For further information, see Caltech's Electrical Safety Program.

[5] https://safety.caltech.edu/documents/14113/Lockout_Tagout.pdf