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Environment, Safety, and Health

Volume II

Part 16: Electrical

16.2
Work and Design Controls for Electrical Equipment

Recommended for approval by the ES&H Working Group

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16.2

Work and Design Controls for Electrical Equipment*

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* **Minor revision**

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Work and Design Controls for Electrical Equipment

1.0 Introduction

This document supersedes LLNL's Electrical Engineering Department Electrical Safety Policy, LED 61-00-01-A1A. It contains work and design controls for all facility, service, and programmatic electrical work performed at LLNL and is to be used in conjunction with Document 16.1, "Electrical Safety," in the *ES&H Manual*. Document 16.1 contains a general overview of electrical safety, descriptions of the various types of electricity that may be encountered at LLNL, and basic and supplementary training requirements for LLNL electrical workers.

All workers who are trained, qualified, and authorized to service, maintain, or operate electrical equipment and systems, including research and development (R&D) equipment and systems, shall comply with the work controls prescribed in this document.

A list of codes, regulations, and standards upon which this document is based can be found in Sections 7.0 and 8.3.

2.0 Hazards

Electricity is used in many different ways at LLNL. Each application has its own combination of hazards that includes the potential of electric shock, fire, and burns. Thus, it is essential for all workers to be aware of the hazards associated with electrical work and to use appropriate protective methods to minimize the risk of an injury or accident.

3.0 Work and Design Controls

Only trained, qualified, and authorized workers are to perform work on LLNL electrical equipment and circuits. These workers shall adhere to the general work controls listed below in addition to those in subsequent sections for specific types of equipment.

General Work Controls

- Know the emergency procedures to follow in case of an accident **(dial 911)**.
- De-energize the equipment prior to beginning work, then lock out and tag all hazardous energy sources. (See Document 12.6, "LLNL Lockout/Tagout

Program," in the *ES&H Manual* for details.) Make sure that the controls applied will prevent operation of the equipment and that all hazardous energy, including residual or stored energy, is blocked, discharged, or relieved prior to starting work.

IMPORTANT

If the equipment must be serviced while energized, apply the work controls in Section 3.1 and those in Table A-1, Appendix A, or prepare a special safety plan and have it approved by the appropriate levels of management before beginning the work. This plan shall be reviewed by an electrical subject-matter expert and shall clearly specify deviations from any of the work controls required by the *ES&H Manual*, the reasons for such deviations, and alternate methods or other mitigation to ensure adequate protection.

- Never enter alone into an area containing exposed electrical energy sources. Table A-1 provides further details.
- Use appropriate personal protective equipment (PPE). Be sure to check the equipment to verify its effectiveness.
- Use only the test instruments, insulated tools, and PPE rated for the voltage and current specified.

Any deviation from these controls will require management to review the operation and prepare an Operational Safety Plan (OSP).

3.1 Utility, Facility, and Programmatic Power Systems

3.1.1 Utility power systems

Utility power systems include electrical power distribution and transmission systems with more than 600 V (i.e., substations, vaults, transformers, switchgear) that furnish electrical power to buildings and facilities through an electric service entrance. These systems are to be maintained and operated *only* by qualified Plant Engineering personnel (or their designees).

3.1.2 Facility Power Systems

Facility power systems (or building wiring) have less than 600 V and can be found in buildings and facilities downstream of the weather head or service entrance. These systems usually include building lighting, outlets, and installed building equipment (i.e., heating, ventilating, and air conditioning (HVAC) systems) and are to be maintained and operated *only* by qualified Plant Engineering personnel (or their designees).

3.1.3 Programmatic Power Systems

Programmatic power systems may include electrical power distribution and transmission systems with more than 600 V (i.e., substations, vaults, transformers, switch gear) and low-voltage systems (<600 V) that supply power to programmatic equipment. These systems are to be covered by an OSP or Facility Safety Plan (FSP) and maintained and operated by programmatic personnel (or their designees). Identification and labeling requirements for these systems' electrical panels and associated equipment can be found in the Plant Engineering Panel Board and Circuit Numbering Standard, PEL-E-16196.

Work Controls. (The work controls listed below apply to utility, facility, and programmatic power systems.) It is practice at the Laboratory as well as the Electronics Engineering Department, Plant Engineering Electric Utilities Division, and the Electric Main Shop in particular to conduct work on electrical circuits and equipment while such equipment is de-energized (see Document 12.6 for details). However, if it is safer or essential to perform work while the equipment is energized, the precautions listed below and those in Appendix A are to be taken to minimize electrical hazards. Note that programmatic convenience is not sufficient cause to work on energized equipment.

- Work that is not in compliance with the guidelines in Appendix A requires an OSP. Work covered in Plant Engineering's *High Voltage Distribution System Operations Manual* is exempt from this requirement.
- The PPE specified in the OSP, FSP, or other work guidance documents shall be worn. The work supervisor or facility manager shall ensure that the equipment is inspected and tested before use. Specialized PPE (insulating gloves, hoods, hose, blankets, and sleeves) is also available from your work supervisor, the Electric Utilities Division, or the Electric Main Shop.
- Personal protective equipment shall be protected from damage during storage and use. Any damaged equipment shall be removed from service immediately and repaired or replaced. Additional information on PPE can be found in Document 11.1, "Personal Protective Equipment," in the *ES&H Manual*.
- Warning signs and barriers shall be installed when any worker may be exposed to hazards associated with electrical work. Enclosures (cabinets, panels, components, etc.) containing high-voltage equipment (>600 V) shall be labeled with the highest voltage to which a worker can be exposed in the event the panel is opened. Furthermore, enclosures with electrical sources that could expose unqualified personnel to live parts shall be locked or secured with a mechanism (e.g., bolts) that requires a tool to open it.

- Work on energized panel boards shall be conducted only when it is essential to do so. Molded-case circuit breakers opposite each other in the same panel shall not be removed at the same time if the panel board is energized. Installation hardware shall be checked for manufacturer-recommended torque requirements.

3.2 Research and Development Systems

Note: Equipment covered in this section is found predominantly in R&D systems at LLNL; however, some of this equipment is also found in other systems operated and maintained by Plant Engineering. Therefore, the work and design controls specified in this document also apply to systems maintained by Plant Engineering.

Research and Development (R&D) systems include racked research equipment, power supplies, capacitor storage banks, laser equipment, computer equipment, instrumentation systems, and control systems or, in general, any system that is purchased or fabricated for use by one or more of the Laboratory's research programs. The Engineering Directorate provides specifications for these systems as well as design, fabrication, installation, operational, and maintenance support.

There is a broad range of hazards associated with R&D systems. Many of these hazards are different from those found in facility or utility systems. This makes it difficult to establish a single set of electrical safety requirements that can be applied uniformly; therefore, general electrical safety guidelines also shall be applied to R&D systems throughout the Laboratory. Furthermore, it is important for personnel working on or around these systems to be trained and qualified and to follow the controls set forth in this document and in Document 16.1.

Research and development equipment should be examined for electrical safety as extensively as possible. Areas to be considered during this inspection include, but are not limited to the following:

- Failure modes.
- Heat effects.
- Magnetic effects.
- Grounding and bonding requirements.
- Guarding of exposed live parts.
- Leakage currents.
- Dielectric testing.

- Access to serviceable parts.
- Over-current and over-temperature protection.
- Clearances and work space.
- Design and procedural documentation.
- Signs, labels, and administrative controls.
- Stored energy.

This inspection shall be documented to include the tests performed, conditions of acceptability, standards used for equipment evaluation, and any limitations of approved usage.

3.2.1 Power supplies

Power supplies that can deliver energy in excess of 10 J at more than 50 V are considered potentially hazardous, and the hazards shall be identified. An appropriate warning sign shall identify electrical hazards in areas or equipment accessible to unqualified personnel. Internal component failure of power supplies can result in excessive voltages across components that may not be appropriately sized. An internal component short in a capacitor bank may result in excessive fault current, extremely high temperatures, over-pressurization of components, fires, and explosions. Overloading or improper cooling of power supplies can cause excessive temperatures and fires. Output circuits and components may remain energized after input power is secured. Power supplies serving more than one experiment may create additional hazards for operators unfamiliar with the equipment. Therefore, potentially hazardous power supplies shall have an integral or automatic system to discharge the stored energy to ground when the input power is turned off, lights to warn personnel that the power supplies are energized, and a positive means of disconnecting the power input. A power supply need not have a lockout device if powered by a cord and plug provided that the plug is under the positive control of the worker.

Low-voltage, high-current power supplies. R&D systems may include equipment that operates at less than 50 V. Even though this voltage level generally is not regarded as hazardous, high-current levels generated by these systems may be hazardous. Furthermore, inadvertent grounding of conductors may result in arc flashes and burns, and inductive circuits may create high-voltage hazards when interrupted. For these reasons, low-voltage, high-current systems should have adequate protective covers or barriers, appropriate warning labels, and components suitable for the intended use. Magnetic fields should be evaluated where high-current equipment is used.

Magnetic fields may pose a hazard to personnel with implants such as pacemakers.

High-voltage, low-current power supplies. Power supplies with output currents less than 5 mA pose virtually no electrical shock hazard. In hazardous locations (described in Section 3.3), however, such equipment may spark and cause an explosion. Voltage surges in excess of normal ratings may result from faults or lightning. Overcurrent protective devices (fuses or circuit breakers) for conventional applications may not be adequate for highly inductive direct-current systems. Stored energy in long cable runs may cause additional hazards. Thus, all energized parts shall be guarded or shielded or an analysis of the associated hazards shall be conducted by the program work supervisor, along with other qualified persons from the program and members of the cognizant ES&H Team, prior to starting work.

3.2.2 Batteries and Battery Systems

Design Controls

- Batteries and battery systems present certain risks to workers, including electric shock. Storage batteries in particular can cause burns, due to the high current potential present in battery systems and from electrolyte (acid) within the cells. Batteries being charged may produce a flammable gas (hydrogen) that may explode in the presence of an ignition source (i.e., sparks or flames). Therefore, battery systems shall be designed, installed, maintained, and tested in accordance with IEEE, NFPA 70, and OSHA requirements.
- A disconnecting means (or switch) is required where more than one direct-current cell-line-process power supply serves the same cell line. This switch shall be installed on the cell-line circuit side of each power supply so that it can be easily disconnected from the cell-line circuit should this become necessary.

Work Controls. The guidelines below apply when work is performed on or around batteries or battery systems. Note that these guidelines do not apply to small appliances that contain small batteries.

- Locked enclosures, accessible only to qualified personnel, shall be provided for all battery system installations. Safety guidelines for specific battery systems shall be obtained and followed.

- Warning signs shall be posted specifying the PPE (i.e., aprons, goggles, and rubber gloves) required to service batteries. In the event that an acid exposure is possible, an emergency eyewash or shower shall be available within 100 ft or a 10-second travel time from the battery system.
- To avoid the potential of an explosion, no sources of ignition (i.e., sparks or flames) shall be present nearby when charging batteries. In addition, battery areas should have adequate ventilation.
- All exposed live parts shall be guarded or insulated to prevent tools or other objects that have been dropped from shorting between polarities or terminals. The use of insulated tools is recommended for work on battery systems. Guidelines for working on energized circuits can be found in Table A-1 of Appendix A.

For further information on battery systems, including requirements for battery-charging areas, contact your ES&H Team.

3.2.3 Capacitors

Design Controls

- Until they are discharged and grounded, hazardous capacitor banks or enclosures shall have interlocks to prevent unauthorized personnel from gaining access.
- Capacitors with stored energy greater than 10 J shall have voltage indicators so that personnel can check the status before accessing the electrical enclosure. A "hot stick" voltmeter may be used to obtain measurements. Provisions shall be made to verify whether the voltage indicators are working both before and after the capacitors are tested. If the capacitor or capacitor bank requires an OSP, it shall include procedures for using and testing voltage indicators.
- Manual-grounding devices shall be installed with capacitors and used, even if automatic discharge systems are used.
- Capacitors shall be physically grounded regardless of the existence of bleeder resistors, dump switches, interlocks, or other potential de-energizing devices. Grounding devices shall be placed at low-impedance points and kept in these positions while personnel are in the enclosure. All terminals shall be grounded to ensure full discharge.

Grounding of a hot terminal while the nominal grounding terminal is floating will not ensure personnel safety.

- Discharging and grounding systems shall be designed so that personnel will not be exposed to flying molten metal from high-current electric arcs.
- The design of all capacitor banks shall include bleeder resistors. The time for decay of residual voltage to 50 V or less shall not exceed 5 minutes for capacitors rated higher than 600 V or 1 minute for capacitors rated at 600 V or less.
- A faulty capacitor in a capacitor bank may rupture, sometimes explosively. Depending on the type of dielectric used, the rupture could lead to fire or release of toxic gases. To control such hazards, special fire-suppression and ventilation systems shall be provided when designing a capacitor bank enclosure. When fault currents cannot be limited by fuses, the design shall include a barrier or enclosure around the capacitor bank to protect personnel from any projectiles.
- High-energy density capacitors are manufactured using new technology that involves series or parallel matrix of elemental capacitors. A common problem with these capacitors is that one or more of the elemental capacitors can become open-circuited while being charged. Thus, provisions shall be made to measure the capacitance of these capacitors and to identify those that have partially failed. Another complicating issue is that the aging effect for these capacitors contributes to a gradual decrease in their capacitance value due to the repeated action of "self-healing" dielectric.

  Note: Charged capacitors can fail if an internal circuit to one of the terminals is opened. Be sure to short the terminals to the case when handling faulty capacitors. Also size the shorting element to handle the maximum short-circuit current from a fully charged capacitor. Jarring or temperature changes could connect the internal open connection.

- Because a disconnected and discharged capacitor can self-charge (due to dielectric memory effects) or accumulate a charge by being placed in an electric field, all capacitors shall be short-circuited with a drain wire and grounded, if appropriate, to the case when not in use.

Work Controls

- Capacitors shall be isolated with barriers or enclosures to prevent contact with charged terminals.
- Personnel shall wear eye protection when applying manual grounding devices to all capacitors and hearing protection when the stored energy is more than 10 kJ.

3.2.4 Cathode-Ray Tubes

Work Controls. The following precautions are to be taken when handling cathode-ray tubes (CRTs):

- Don eye protection and gloves.
- Short and ground the terminals to the outer coating.
- Carefully store and transport CRTs to prevent breakage. Use the original shipping boxes, if available.

3.2.5 High-Voltage Equipment

Work Controls. Electrical equipment operated over 10 kV in a vacuum may produce x rays that can penetrate the vacuum enclosure. Furthermore, equipment that does not normally emit x rays can do so through an inadvertently heated surface by addition of a sharp point or edge to a surface, by a change in the location of a part, or by a change in material or surface treatment. Similarly, a minor change in vacuum-pumping operation may produce a hazardous situation. Therefore, particular care shall be exercised even during slight modification of high-voltage equipment.

Document 20.1, "Occupational Radiation Protection," in the *ES&H Manual* provides additional information on x rays.

3.2.6 Electrical Interlocks

Design Controls. Electrical interlocks are safety devices usually designed to de-energize electrical circuits when personnel access an electrical hazard area. Panels, doors, and other entryways that permit access to enclosures surrounding electrical hazards are to be bolted, locked, and interlocked. Interlock circuits intended for personnel protection shall be designed such that the process of bypassing or completing the interlock chain will not automatically start the equipment.

Work Controls. Interlock circuits shall be checked for proper operation after each installation or modification and semiannually thereafter. Conditions found during inspection shall be noted in the equipment log or other record.

If a lock-controlled master switch is used in the interlock chain, the same key that controls the lock shall be used to gain access to the equipment. A status panel shall be used in the following instances:

- To continually monitor interlock circuits that de-energize exposed terminals operating at 50 V or greater.
- To automatically discharge the stored energy of capacitors that operate at more than 10 J at levels greater than 50 V.

More information on capacitors can be found in Section 3.2.3 of this document. Specific information on the design, installation, and testing of personnel safety interlock systems can be found in Document 12.1, "Access Control, Safety Signs, Safety Interlocks, and Alarm Systems," in the *ES&H Manual*. Information specific to laser systems and radiation-generating devices can be found in Document 20.8, "Lasers," and Document 20.3, "LLNL Radiological Safety Program for Radiation-Generating Devices," in the *ES&H Manual*, respectively.

3.2.7 Machine Tools

Work Controls. Machine tools are defined as electrical or electronic equipment, apparatus, or systems supplied as part of nonportable industrial machinery operating at less than 600 V. The following work controls apply to machine tools:

- Only trained and qualified personnel in the Machine Tool Services (MTS) group of the Manufacturing and Materials Division (MMED) (or other designated LLNL employees or outside vendors) are authorized to service, maintain, repair, and install modifications on electrical equipment or systems used with or in machine tools.
- The MTS Group shall inspect, certify, and approve all LLNL machine tools prior to use. Certification (a work order on file that documents the inspection conducted by MTS personnel) is required for newly installed machine tools, existing machine tools that have been relocated, and any machine tool that has been repaired or modified.
- The Equipment Acquisition Section of the MTS group shall prepare specifications and acceptance test requirements for acquiring new machine tools. These specifications shall comply with all applicable electrical safety standards and requirements. If unusual safety requirements or significant electrical risks are involved, these shall be coordinated by MTS personnel with the Safety Officer for the Engineering Directorate and the Safety Programs Division of Hazards Control. Any qualified person designated by the program management purchasing the new equipment may conduct acceptance tests.

3.2.8 Power Disconnect Equipment

Design Controls. The following controls apply when designing or specifying disconnect switches and circuit breakers:

- Power disconnect switches and circuit breakers shall have a lockout device that is designed to minimize the probability of accidental removal, prevent access by unqualified personnel, and support a force of no less than 50 lb. These devices also shall be capable of being locked with a padlock in the open (off) position. The padlock functions as a positive disconnect point when applying the lockout and tag procedure described in Document 12.6.
- Circuit breakers shall be identified by their circuit number and the function to be disconnected.
- Power disconnect switches shall be installed with their handles in the down (or off) position.

Work Controls. Power disconnect equipment may be secured with a lock of suitable size for administrative or operational purposes. A yellow caution tag (Form LLNL-CNOC-30575-SLT, stock number 4280-71958) shall be attached to the equipment; a danger sticker is not required.

3.2.9 Equipment Enclosures

Design Controls. Enclosures shall be designed in full compliance with applicable codes, regulations, orders, and standards for their intended application and for use in the worst-case environment. In addition, the following design controls apply:

- Enclosures shall be installed around electrical equipment as an adequate guard (or barrier) to prevent injury or death.
- Enclosures shall be designed with adequate ventilation.
- The spacing around an enclosure shall be adequate to permit quick and safe inspections; adjustments; service; operation; and maintenance, which includes de-energizing and grounding the equipment under emergency conditions (e.g., rescue of injured personnel).
- Enclosures shall be made of materials strong enough to contain hazards, as electrical systems with sufficient energy can accelerate projectiles or start a fire. Similarly, capacitors are capable of exploding and causing significant damage.
- Circuits having an energy greater than 10 J and operating levels above 50 V shall be identified with an appropriate label. The live contact points of these circuits shall have a caution sign, barrier, or guard.

- Manual grounding devices for high-energy equipment shall be fully visible. Grounding points shall be clearly identified and color-coded.

Grounding and bonding of all noncurrent-carrying metal parts of the enclosure and its contents shall continually provide a path for leakage current to ground, eliminating the effective dielectric capacitance between the ground and metal enclosure.

Work Controls

- Warning signs shall be posted at the access points to enclosures indicating the nature of any hazards and precautions to be observed.
- Safety procedures shall be posted at the entry points to high-energy enclosures.

3.2.10 Control and Instrumentation Circuits

Design Controls

- When possible, control circuits should be designed such that the risk level will not increase without warning if one component fails. Indicator lights (pilot lights) on these circuits sometimes can be misleading because failure of a lamp might be interpreted as a de-energized circuit. For this reason, these circuits should have different color pilot lights to indicate whether a circuit that is energized or de-energized or a push-to-test provision.
- Control circuits shall not be placed in the same conduit, cable tray, or raceway as high-voltage circuits (>600 V).
- The disconnect switch for control circuits shall be installed with the handle in the down (or off) position.
- Disconnect switches and circuit breakers shall be legibly marked to indicate their purpose and position of operation.

Work Control. Records shall be maintained of all equipment design and modification drawings and other documents.

3.2.11 Laser and RF Equipment

Laser Equipment. Troubleshooting or servicing of laser equipment exposes workers to significant electrical hazards. Thus, it is important to ensure that laser systems have the following design features:

Design Controls

- Laser resonator and electro-optical elements should be designed so that no exposed metallic element is above ground.

- The frames, enclosures, and other accessible noncurrent-carrying metallic parts of laser equipment shall be grounded.
- Laser equipment shall be grounded by providing a reliable, continuous metallic connection between the parts to be grounded and the grounding conductor of the power wiring system.

RF Equipment

All RF electrical equipment shall be grounded, except where experimental conditions indicate otherwise.

Work Controls. Only suitable barriers or insulated shields shall be provided when using this type of equipment. In addition, a safety plan (OSP or FSP) or other document shall be written covering the safe operation of the experiment.

3.3 Electrical Equipment/Wiring in Hazardous Locations

Specialized equipment and wiring are required in locations classified as hazardous (i.e., areas where flammable vapors, liquids, gases, or combustible dusts may be present in flammable or combustible concentrations during normal operations [i.e., spray painting in a booth] or because of an accident or unplanned event). Personnel shall not work on energized equipment in these locations because of the hazards that may be present.

Document 17.1, "Explosives," in the *ES&H Manual* provides specific guidance for explosives work and for work in explosives area. The Hazards Control Department can provide further guidance on whether planned operations or electrical wiring presents any hazards.

3.4 Other Electrical Apparatus and Systems

Work on electrical systems not covered in this document shall be performed in full compliance with the guidelines in Table A-1, Appendix A, or in accordance with current, documented, and approved safety plans and work controls. Special procedures, responsibilities, limitations, and authorities shall be conspicuously posted.

4.0 Clearances and Work Spaces for Electrical Equipment

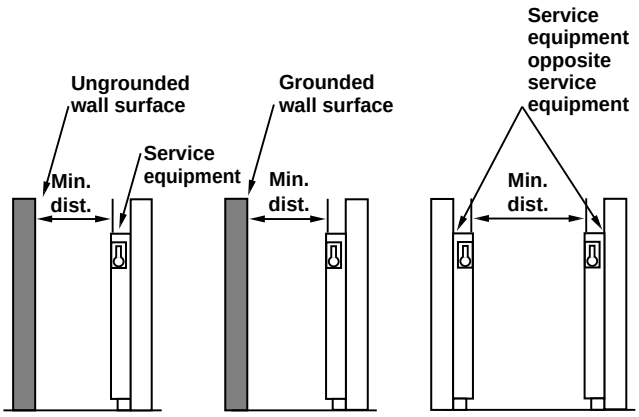
4.1 Electrical Equipment Rated at 600 V or Less

The clearance and working space around electrical enclosures (panel boards, switches, circuit breakers, controllers, power supplies, heating and air conditioning controls) shall be adequate for all anticipated activities (e.g., maintenance, operation) to ensure the

safety of personnel during emergencies (e.g., rescue of injured personnel). Section 110-16 of NFPA 70 specifies that a 30-in-wide workspace, either centered or offset in front of the equipment, is required as a minimum for electrical equipment rated at 600 V or less. The depth of the workspace shall be clear from the floor to the required height, depending on the conditions described below and as specified in Fig. 1.

- **Condition 1** means that electrical equipment is mounted or set on one wall and the wall on the opposite side is insulated (ungrounded parts).
- **Condition 2** means that electrical equipment is mounted or set on one wall and the wall on the opposite side is grounded.
- **Condition 3** means that electrical equipment is mounted or set on one wall and additional electrical equipment is mounted or set on the opposite side of the room.

There also shall be at least a 90° opening in the work area for doors or hinged panels of equipment being serviced. Working spaces may overlap.

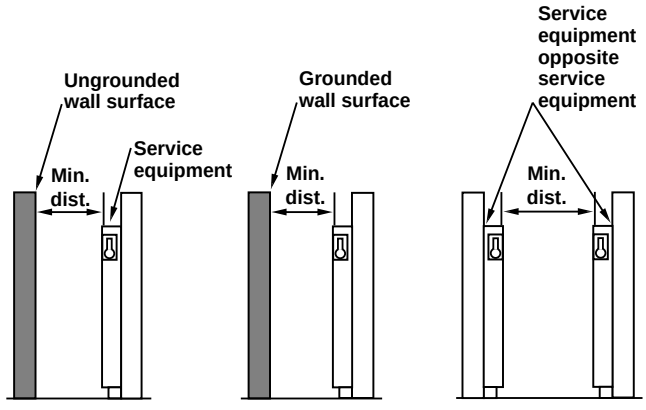


Condition 1		Condition 2		Condition 3	
Volts to ground	Min. dist.	Volts to ground	Min. dist.	Volts to ground	Min. dist.
0 - 150 V 151 - 600 V	3 ft. 3 ft.	0 - 150 V 151 - 600 V	3 ft. 3 1/2 ft.	0 - 150 V 151 - 600 V	3 ft. 4 ft.

Figure 1. Clearances for electrical equipment rated at 600 V or less. Note that a minimum clearance of 2-1/2 ft (for Condition 1) is allowed for installations completed before April 16, 1981.

4.2 Electrical Equipment Rated above 600 V

Figure 2 shows minimum clearances and work spaces for high-voltage electrical equipment such as switchboards, control panels, switches, circuit breakers, and motor controllers.



Condition 1		Condition 2		Condition 3	
Volts to ground	Min. dist.	Volts to ground	Min. dist.	Volts to ground	Min. dist.
601 - 2,500 V	3 ft.	601 - 2,500 V	4 ft.	601 - 2,500 V	5 ft.
2,501 - 9,000 V	4 ft.	2,501 - 9,000 V	5 ft.	2,501 - 9,000 V	6 ft.
9,001 - 25,000 V	5 ft.	9,001 - 25,000 V	6 ft.	9,001 - 25,000 V	9 ft.
25,001 - 75,000 V	6 ft.	25,001 - 75,000 V	8 ft.	25,001 - 75,000 V	10 ft.
above 75,000 V	8 ft.	above 75,000 V	10 ft.	above 75,000 V	12 ft.

Figure 2. Clearances for electrical equipment rated above 600 V.

Minimum work clearances are required for electrical equipment with more than 600 V when

- Exposed live components are on one side of a space and ungrounded parts are on the other.
- Exposed live components are on one side and grounded parts are on the other (e.g., concrete, brick, and tile walls).
- Exposed live components are on both sides.

5.0 High Potential Insulation Testing

High-potential testing of equipment is typically called "Hi-Pot." Hi-Pot tests are used during the design, manufacture, installation, and maintenance of equipment or for fault location testing. In any test, the manufacturer's instructions and procedures shall be followed exactly. At LLNL, Hi-Pot testing shall be performed only on de-energized equipment or during installations.

Test units built at LLNL shall have the following built-in safety features:

- Grounded metal enclosures and insulated panels.
- Safety interlocks to shut off the high voltage, if the high-voltage range switch is turned on or the system is accessed during any portion of a test.
- Shielded plug-in outlet cables.

- Limited current output.
- An output bleeder that discharges dielectric charge from both the Hi-Pot equipment and test item.
- Adjustable electronic circuit breakers in the metered-return circuit that trip at any set current leakage between 10–5000 μA.
- Secondary circuit breakers that turn off the high voltage when the output exceeds 5 mA.

To avoid an effective capacitance shock after high-potential insulation testing, a ground shall be connected solidly to drain off or discharge dielectric charge on the insulation for a period equal to four times the testing limits.

6.0 Responsibilities

All workers and organizations responsible for electrical equipment shall refer to Document 2.1, "Laboratory and ES&H Policies, General Worker Responsibilities, and Integrated Safety Management," in the *ES&H Manual* for a list of general responsibilities. Specific responsibilities are listed below each title.

6.1 Employees and Other Workers

- Only perform electrical work for which you are qualified.
- Understand the basic principles of electricity and electrical safety and the safe work controls delineated in this document.
- Use the proper tools and PPE.
- Request additional training to prevent working beyond your level of qualification.

6.2 Work Supervisor

Refer to Document 2.1 for a list of responsibilities.

6.3 Hazards Control Department

The Hazards Control Department is responsible for providing guidance on planned operations and hazards analyses of electrical equipment and systems.

6.4 Electrical Safety Advisory Board

The Electrical Safety Advisory Board (ESAB) was established on February 20 1996 to support all LLNL facilities with electrical safety issues. This includes, but is not limited to recommending safe work controls for electrical equipment; developing, reviewing, and approving electrical safety training programs; and evaluating electrical accidents to determine the root cause(s).

7.0 Work Standards

29 CFR 1910, Subpart H, "Hazardous Materials."

29 CFR 1910, Subpart J, "General Environmental Controls." (See specifically 29 CFR 1910.147, "The Control of Hazardous Energy Lockout/Tagout.")

29 CFR 1910, Subpart R, "Special Industries."

29 CFR 1910, Subpart S, "Electrical."

29 CFR 1926, Subpart K, "Electrical."

ANSI Z 136.1--2000, "American National Standard for the Safe Use of Lasers."

DOE M 440.1-1, *DOE Explosives Safety Manual* (latest revision).

NFPA 70, "National Electrical Code."

NFPA 77, "Recommended Practice on Static Electricity."

8.0 Resources for More Information

8.1 Contacts

For additional information regarding this document, contact the following:

- Safety Programs Division, Hazards Control Department
- Machine Tool Services Group
- Plant Engineering Electric Utilities Division
- Plant Engineering Electric Main Shop
- ES&H Team
- Electronics Engineering Department

8.2 Lessons Learned

Applicable Lessons Learned can be found at the following Internet address:

http://www-r.llnl.gov/es_and_h/lessons/lessons.shtml

8.3 Other Sources

ANSI/IEEE C2, "National Electrical Safety Code."

ANSI/IEEE 18, "Shunt Power Capacitors."

ANSI/IEEE 80, Guide for Safety in AC Substation Grounding."

ANSI/NEMA 250, "Enclosures for Electrical Equipment (2000 V maximum)."

ANSI/UL 16724, "Light Industrial Tools."

FIPS-94, "Federal Information Processing Standards 94."

IEEE 450, "Practice for Maintenance, Testing and Replacement of Large Lead Storage Batteries for Generating Stations and Substations."

IEEE 484, "Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations."

NFPA 70B, "Inspection Frequency."

NFPA 70E, "Electrical Safety Requirements for Employee Workplaces."

NFPA 79, "Electrical Standard for Industrial Machinery."

NFPA 110A, "Stored Energy Systems."

NFPA 30, "Flammable and Combustible Liquids Code."

NFPA 45, "Standard on Fire Protection for Laboratories Using Chemicals."

NFPA 49, "Hazardous Chemical Data."

NFPA 325M, "Fire Hazard Properties of Flammable Liquids, Gases, Volatile Solids."

NFPA 491M, "Manual of Hazardous Chemical Reactions."

NFPA 497A, "Recommended Practice for Classification of Class l Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas."

NFPA 497M, "Gases, Vapors, and Dusts for Electrical Equipment in Hazardous (Classified) Locations" (Contains a more complete list of flammable liquids, gases, and solids.)

PEL-E-16196, "Panel Board and Circuit Numbering Standard."

Underwriters Laboratories, Inc., *Hazardous Location Equipment*. [Contains a directory of listings and classifications.]

U.S. Department of Energy, *Electrical Safety Guidelines*, DOE/ID-10600 (May 1993).

Appendix A

Guidelines for Working on Energized Equipment

This appendix contains requirements for working on energized electrical systems and equipment. Additional guidance can be found in this document and in Document 42.1. Note that these requirements are not a substitute for proper supervision of persons working with hazardous electrical systems or equipment. Furthermore, it is incumbent upon both qualified workers and their work supervisor to carefully plan any work to be carried out on energized systems.

A.1 Competent Person Used as a Companion or Safety Watch

An individual may work alone on any system that is de-energized and properly locked out and tagged. However, if the equipment is energized and is a Class 2 or higher (see Table A-1 for details), another competent person (companion or safety watch) shall be present until the work is complete.

A competent person is authorized by management and qualified to take prompt corrective measures to eliminate hazards (e.g., turn off equipment), provide first aid, and notify the appropriate personnel when an accident or incident occurs. This individual therefore shall

- Be capable of identifying existing or predictable hazards.
- Understand the hazard class associated with the equipment and the procedures for de-energizing equipment in an emergency.
- Know who to contact for assistance.
- Be qualified to perform cardiopulmonary resuscitation (CPR).

The safety watch is specifically assigned to stand by within audible and visible range of workers and continually monitor the equipment and personnel for safety.

A.2 Special Precautions

It may be necessary to work on an energized system if de-energizing the system may create additional hazards, or if it is not possible to work on the system de-energized because of its design. In such cases, workers shall

- Not wear conductive articles such as watches, rings, and other jewelry while working in close proximity of electrical circuits.

- Consider all electrical equipment and conductors to be energized until otherwise verified by a qualified and authorized person.
- Wear the appropriate PPE while performing the work. Additional details on PPE can be found in Document 11.1 and Document 16.1.

Additionally, workers and their supervisors shall consider the following factors for special or unique situations:

- Are environmental issues of concern (e.g., wet or damp locations or hazardous or explosive atmospheres)?
- Are accurate schematics available?
- Do workers have experience working with the type of equipment or situation involved?

A.3 Work Controls for Energized Systems

Apply the work controls in Table A-1 to energized electrical systems and equipment.

A.4 Work Controls for Batteries

Apply the following work controls to battery systems (electrolytic cells, batteries, and uninterruptible power systems):

- For equipment with <50 V and a short-circuit current of <10 A, apply the work controls in Table A-1 for Class 1 equipment hazards. This work control also applies to typical dry-cell batteries used in flashlights and radios.
- For equipment with <50 V and a short-circuit current ≥10 A, apply the work control in Table A-1 for Class 2 equipment hazards.
- For equipment with ≥50 V, apply the work controls for the appropriate equipment hazard class specified in Table A-1.

Table A-1. Work controls for energized systems based on their hazard class. The hazard class is based on potential contact with exposed, energized parts operating at the levels specified. All system voltages are measured as RMS or DC values; pulsed systems require further analysis. Where the operating level may be in more than one hazard class, the work controls for the highest hazard class shall apply. Note that a three-phase power source is a one-branch circuit, which counts as one source. A split-phase power source with a common neutral circuit (Edison circuit) counts as two sources.

Equipment/system hazard class	Work control
Class 1: Includes systems with branch circuit voltage <140 V, branch circuit current limited to 30 A, and exposed voltage <50 V. If the exposed current is <5 mA, the exposed voltage may be ≥50V. The stored energy for these systems is <10 J.	One qualified person may work alone on the equipment with general supervision.
Class 2: Includes relatively simple systems with exposed voltage <245 V and stored energy <10 J. Workers must fully understand all hazards associated with these systems.	One qualified person may work alone on the equipment with general supervision, but another competent companion shall be positioned within visible and audible range of the worker.
Class 3: Includes systems with exposed voltage ≥245V or stored energy ≥10 J. These systems shall have no more than two exposed energy sources ≥50V. Workers must fully understand all hazards associated with these systems.	The project engineer or work supervisor shall assign two qualified persons to perform the work. These individuals shall work within audible and visible range of each other. An OSP or management-approved written procedure, specifically addressing the electrical hazards and controls, is required.
Class 4: Includes any system or equipment that is not described in one of the previous categories. These systems are complex because they have energized, exposed parts and large, dispersed arrangements of components, and may not be well understood.	Two qualified persons and a safety watch are required to perform the work. An OSP, specifically addressing the electrical hazards and controls, is required. A program leader or higher-level management shall approve the OSP.