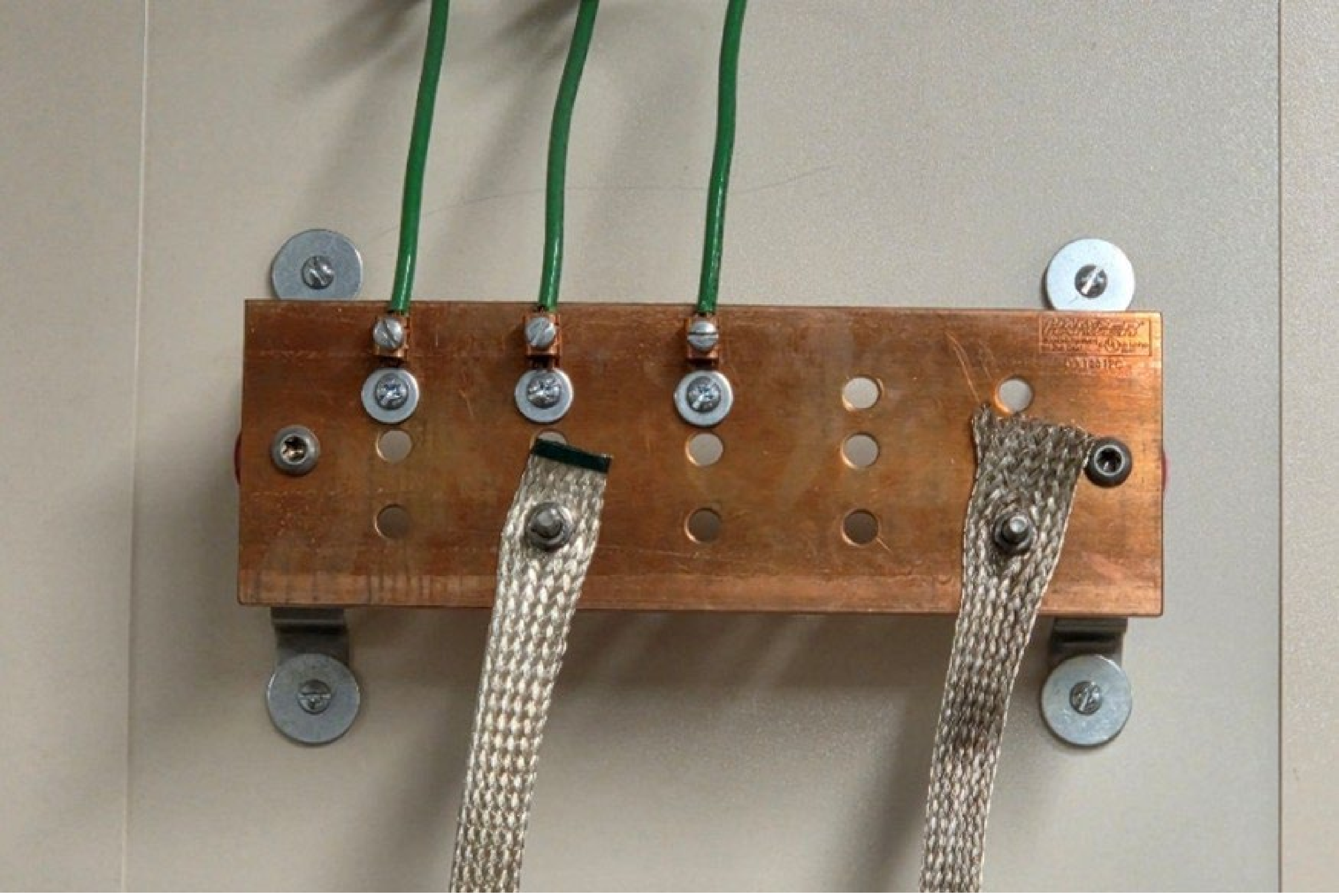

Electrical Safety Guide

2025/2026

University of Illinois Urbana-Champaign

Office of the Vice Chancellor for Research & Innovation | Division of Research Safety

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Contents

Introduction

The **Electrical Safety Guide** introduces basic safety information and best practices for laboratory and research procedures involving electrical hazards. This is a reference document for the Division of Research Safety's laboratory safety program, communicating basic requirements and campus policies, including hyperlinks to more detailed information. The Division of Research Safety (DRS) maintains this guide and updates it annually, or more often if necessary.

Scope and Applicability: This guide applies to all research laboratories, field stations, instructional labs, and other research environments at or affiliated with the University of Illinois at Urbana-Champaign.

Before working on any electrical equipment for purposes or repair, alteration or maintenance, it is critical to first establish that it is no longer energized. Refer to the Control of Hazardous Energy Program (LOTO) and contact Safety & Compliance for more information on how to establish an electrically safe working condition (ESWC). Work on live, exposed conductors, creating and approving an energized work permit or how to administer a Lockout/Tagout program in accordance with NPFA 70E are not covered here. For these situations, contact Safety & Compliance (safetyandcompliance@illinois.edu or 217-265-9828)

This guide provides information for compliance with regulations and good operating practices. Appendix A lists regulations and standards for each topic with the matching section labels for easy reference.

The associated regulations and guidance come under the legal authority granted by the Occupational Safety and Health Act of 1970. This authorized the Occupational Safety and Health Administration (OSHA), as part of the Department of Labor, to promulgate federal regulations in support of the safety of workers. Specifically, electrical safety regulations fall under Title 29 (Labor), section 1910, Subpart S with discussions of PPE in Subpart I. The National Fire Protection Association (NFPA) also promulgates documents on electrical safety. Illinois has adopted the NFPA standards as authoritative; the NFPA guidance is treated similarly to OSHA regulations. The University considers a space compliant with applicable guidance if it meets all OSHA regulations and all NFPA requirements that were active **at the time the space was commissioned** or underwent significant renovation or remodeling. DRS will make recommendations based on the most recent guidance available. The recommendations from DRS are intended to inform of potential code violations as well as educate on best practices. For questions or concerns regarding compliance with current electrical codes, contact Code Compliance & Fire Safety (CC&FS) (fandscodefire@illinois.edu) to consult with a professional engineer or qualified electrician.

Hazards

There are five main electrical hazard categories that are hazardous to the health and life of personnel:

(1) Electric shock – occurs when two parts of a person's body come in contact with surfaces at different voltages.

(2) Arc flash – an extremely high temperature discharge produced by an electrical current that flows through air. The extreme heat of the arc ionizes the air, creating an alternate path to ground. If there is sufficient voltage (around 100 V/inch) to push current across the arc, the arc will sustain itself. This can occur with an AC source capable of pushing hundreds of amps through an arc. In practice, a worker should presume that there is potential for arc flash in systems at 480 V or higher that have power-grid fault current levels (10,000 A and up). However, arc flash injuries have occurred in 208 V systems.

(3) Arc blast – the pressure wave created by a powerful arc flash.

(4) Fire hazard – fire can occur quickly from an arc flash. It can occur in any electrical connection due to heating caused by a prolonged overcurrent condition or due to extensive utilization of equipment not designed or tested for long-term use.

(5) Thermal burns – under some circumstances of lower voltage with high current, a situation can exist where metals are heated up to levels which could cause burn injuries to personnel, even though a significant shock hazard might not be present.

In any electrical system, hazards are linked to available energy. Equipment limited to voltages below 60 V, and currents limited to below 5 mA are generally safe based on human contact, but there are exceptions. Even at voltages down to about 12 V, wet conditions can help direct current through the body core leading to injuries if current limits are high. If equipment operating at 100 kV or more is limited inherently to about 1 mA, injuries are unlikely.

Guidance

General Guidance

A. Responsibilities and Expectations

The Principal Investigator has the primary responsibility to provide a safe environment and provide lab-specific training. The Division of Research Safety assists in this duty by providing consultations on request and basic training in various areas. It is the responsibility of all workers to understand and implement the safety policies as promulgated by the PI. This includes asking questions if there is something not fully understood or bringing potentially unsafe conditions to the PI's or safety contact's attention. An employer may train, audit, and retrain employees, but it is the employee who will make decisions and take actions to avoid injury and death.

B. Inspections

All electrically powered equipment shall be inspected to ensure it can be safely operated. This inspection should be done by the owner or user when the equipment is set up. If subsequent inspections are deemed necessary by the user, this should be specified in the lab safety documentation. This applies to both locally built equipment and equipment purchased from a vendor.

In accordance with the hierarchy of risk controls discussed in NPFA 70E, the top priority for work on electrical equipment, either for maintenance, repair, or to perform a detailed inspection, is to completely de-energize the equipment. Work on live or energized electrical equipment where electrical hazards are present must be avoided whenever possible but may be necessary for certain special situations. Guidance of how to conduct such operations is given in NFPA 70 and NFPA 70E but is beyond the scope of this guide.

C. Training

All employees must have electrical safety training to be aware of electrical hazards they may encounter in their work and how to protect themselves from those hazards. The level of training should be commensurate with the level of hazard exposure.

For most labs, the electrical safety information provided in the general DRS Laboratory Safety Training is adequate. For those labs with additional electrical hazards, there are three electrical safety training modules available from DRS (Fundamentals, Risk Assessment, and Recommended Practices), and PI's can assign these as additional training as they see fit. Finally, for those labs with extensive custom electrical work or equipment, additional training must be obtained in accordance with university, state, and federal regulations. For any questions, contact DRS or Facilities & Services' Division of Safety & Compliance.

As with all training, this electrical safety training shall be documented and included in the lab safety plan, whether in paper or electronic form. Visit the DRS website, or contact DRS directly, for more guidance if needed.

D. Standard Operating Procedures (SOPs)

SOPs or equivalent documents should be provided for any hazards listed in a lab's profile. Of particular interest in the context of electrical safety are: Custom Circuits – Modified Electronics, High Voltage, and Stored Electrical Energy. If any of these are present, they should be addressed in an SOP, lab-specific safety training, or similar document. Visit the DRS library page discussing SOPs for further guidance: DRS Standard Operating Procedures.

E. Consultation

For any custom electrical work, consult a qualified electrician to ensure all requirements are met. For example, on campus, a lab lost months of work because of attempts to fabricate custom components that were not appropriate for the electrical energy passing through them. A campus advisory group exists to help pool expertise and assist in custom projects. It consists of representatives from DRS, Safety & Compliance, College of Engineering Safety Office, campus electrical shops, and faculty and staff with experience in electrical design and operation. Contact this group by emailing DRS@illinois.edu.

Specific Guidance

A. Extension cords

Hazard: shock or fire due to improper use

Always follow the following precautions when using extension cords (also known as flexible cord sets):

- Consider use of a hard service cord (types S, ST, SO, STO) or junior hard service cord (types SJ, SJO, SJT, SJTO) for use with portable electric tools, appliances, and temporary/portable lights, especially in high-traffic areas.
- An extension cord's diameter is reported using the AWG (American Wire Gauge) standard. The lower the gauge number, the thicker the cord. 16-gauge or thicker should be used for industrial or laboratory use, depending on the maximum current expected to be carried by the cord, as follows:
    - 16 gauge: 10 A
    - 14 gauge: 15 A
    - 12 gauge: 20 A
    - 10 gauge: 30 A
- Note that the above values apply to a short cord (shorter than 25 feet). Longer cords have a non-negligible voltage drop along their length, which could result in a higher current through the cord. As a result, for a given current drawn by the load, a thicker gauge cord is needed. Below are recommended gauges for a few lengths of cord based on cord length and expected load current:

	0-5 A	**5-7 A**	**7-10 A**	**10-12 A**	**12-15 A**	**15-20 A**
5 ft	16	16	16	14	14	12
50 ft	16	16	14	14	12	12
100 ft	16	14	12	12	10	8

- Ensure the extension cord used is rated for the expected amperage and wattage of the load it is supplying. Information is available in the appliance's manual or measured with a multimeter or a Kill A Watt or similar device. Consult an electrician for further guidance or assistance. Keep in mind that a conductor's resistance increases with increasing temperature. If operating at or above the rating of the equipment being used, the cord will heat up, causing the resistance to change and potentially causing a fire hazard. Do the research, perform the calculation, or request a consultation before using an extension cord.
- Visually inspect extension cords before each use. Note that the **entire length of the cord** must be visible. Inspect for
  - missing, corroded, or damaged prongs on plugs
  - frayed, worn, or missing insulation
  - poorly made electrical connections
  - burns or scorch marks
- Never use a cord that feels hot or is damaged in any way. Touching even a single exposed strand can give a potentially lethal electric shock or a painful burn.
- Never use an extension cord to lift or support a tool.
- Do not plug or unplug a cord from an outlet with wet hands.
- Never alter the plug on an extension cord. This applies especially to altering or removing the ground connection.
- **Extension cords are meant to be used temporarily with portable equipment.** Extension cords should never be used for permanent power installations. If power is required for more than a short duration, a permanent electrical installation must be used. The maximum allowed is 90 days for seasonal types of installations. Unplug the equipment and extension cord when done and inspect prior to restoring to service.
- Extension cords must be protected from accidental damage. Sharp corners and projections must be avoided. When passing through pinch points, provide protection to avoid damage.
- Avoid laying extension cords across a walking path where they can become a trip hazard. If necessary, use extension cord covers to prevent a trip hazard and protect the cord.
- 29 CFR 1910.334 and 1926.416 explicitly forbid the use of staples to secure extension cords.
- If the extension cord is of a locking or twist-locking type, secure the plugs before use.
- When not in use, extension cords should be carefully rolled and stored in such a way that they cannot be damaged. Specifically, per 29 CFR 1910.305(a)(2)(ii), "Temporary wiring shall be removed immediately on completion of the project or purpose for which the wiring was installed." Keep in mind that extension cords are not designed or tested for permanent use and will deteriorate over time.

- Only buy cords approved by an independent testing laboratory, such as Underwriters Laboratories (UL), Intertek (ETL), or Canadian Standards Association (CSA). Not all cords sold in the US meet US safety standards.
- For outdoor use, choose extension cords labeled with a “W” to indicate they are weather-resistant, for example, cords marked SJTW or STJOW.

Heavy reliance on extension cords is an indication of insufficient outlets to address the needs. In consultation with facility personnel, have additional outlets installed.

B. Power Strips

Hazard: Fire, equipment damage due to improper use.

There are two types of protection that can be present-

1) Overcurrent: this is to protect against excessive current, which can result in fire or equipment damage. This is achieved with a fuse or circuit breaker.
2) Surge protection / suppression: this is to protect against a sudden voltage spike, such as that caused by a lightning strike. For electronic equipment, the transient need not be that extreme to cause damage. A varistor provides this protection to prevent equipment damage. At normal voltages, the varistor has a high resistance. This resistance drops quickly above a certain voltage, shunting the current path to ground and bypassing the normal load.

The term power strip does not imply the presence of overcurrent or surge protection, although most commercially available domestic strips do have a fuse or breaker.

When using a power strip, use the following precautions:

- Surge suppressors (and power strips with surge protection) must be UL 1449 listed and plugged directly into a wall receptacle. Relocatable power taps (RPT), also called power strips, must be UL 1363 listed and plugged directly into a wall receptacle.
- A power strip with no overcurrent protection is effectively the same as an extension cord with multiple outlets, and it should be treated as such with respect to the previous section.
- A surge suppressor may provide some protection to prevent damage to equipment in addition to the circuit breaker at the nearest upstream electrical panel. However, from a safety standpoint, a surge suppressor does not confer any more protection than an extension cord, so the guidance in the previous section for extension cords also applies to power strips.
- As with an extension cord, users must determine the current and power parameters of the load and ensure that the surge protector is rated to handle it.
- Most power strips are not designed for sustained high-power or frequently cycling loads such as space heaters, refrigerators, pumps, or microwave ovens. They are designed for long-term use with low-powered loads such as computers, peripherals, and audio or video components.
- Buy only power strips or surge protectors approved by an independent testing laboratory, such as Underwriters Laboratories (UL), Intertek (ETL), or Canadian Standards Association (CSA). Not all power strips sold in the US meet US safety standards.

C. Daisy chaining

Hazard: Using equipment in ways for which they were not designed, resulting in excessive heating, leading to a fire.

Daisy chaining refers to the practice of plugging power strips, also known as Relocatable Power Taps (RPTs), or extension cords into other power strips and/or extension cords.

- OSHA and NFPA both state the importance of following the directions of the equipment used. Guidance from Underwriters Laboratories (UL), who certifies the safety of such equipment, states that power strips and extension cords should only be plugged into **permanently installed receptacles**. There should be one power strip or extension cord between an outlet and the load under any circumstances, and refer to the previous sections, which reminds us that these are used for temporary setups only, except use of power strips for computer loads.

D. Bonding and Grounding

Hazard: danger of fire due to buildup of a static electric charge in a flammable liquid, resulting in a spark which could ignite flammable vapors.

As one material flows past another, electrons can be transferred. As a liquid is transferred from one storage container to another, a buildup of static charge can result. In some situations, this buildup could cause a spark and become a fire hazard. Bonding and grounding procedures should be used.

- If transferring flammable liquid from a container of greater than 1 gallon (~ 4 L) in volume, connect the source to the target (bonding) and then connect this to ground. DRS has guidance available, including a video, on their website: Flammable Liquids.

E. Electrical panel access

Hazard: potential shock to electricians and inability to access panel for maintenance, repair, or emergency shutoff.

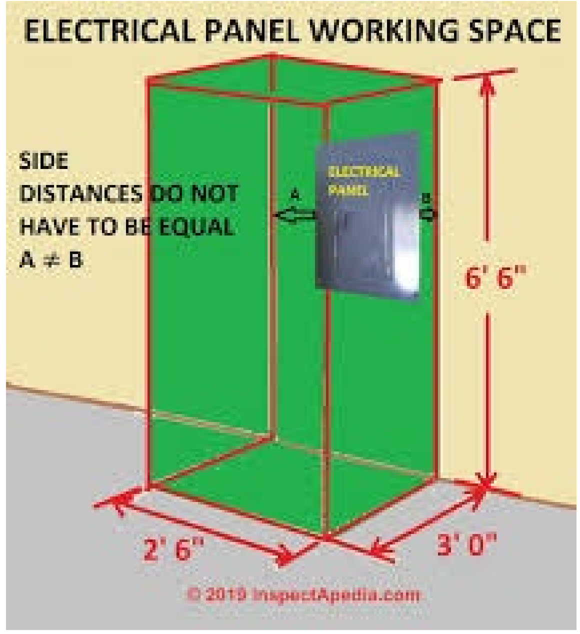
An electrical panel constitutes the central hub for distributing electricity to a facility, splitting the power from the utility company into individual circuits for different areas and protecting each circuit with a circuit breaker or fuse. Access to an electrical panel is crucial for safety, as it allows for the quick shutoff of power during an emergency such as a fire or electrical shock.

The purpose of this restriction is to allow electricians to safely use the panel under both normal and emergency conditions. This possible emergency situation is why this volume must **always** remain clear, not just for scheduled work.

- NFPA 70 and OSHA guidance requires a volume of the following dimensions be clear in front of all electrical panels: 36” to the front, 30” side-to-side, which does **not** need to be centered on the panel but must enclose the full width of the access door itself, and 6’6” from the floor. In addition, the door must be able to open at least 90 degrees.

- It is recommended to mark this area with tape (black/yellow stripes is common) to remind people to keep it clear.

- It is also critical that there is a clear, unobstructed path to the electrical panel from the entrance of the room. If the volume in front of the panel is clear but difficult to get to, you have not met the intent of the guidance and are creating a potentially unsafe condition.



F. Ground Fault Circuit Interruption (GFCI) protection

Hazard: shock hazard due to a short circuit between the electrical interior of equipment and its casing.

Keep in mind the principle involved – water as good electrical conductor can cause short circuits between energized equipment and other nearby conducting surfaces such as its housing. A person touching the housing would provide a path to ground and receive a shock. Removing the water source removes this risk.

GFCI devices protect personnel by breaking the circuit upon detection of an imbalance in current due to an unintentional path to ground. Any outlets within 6 feet of a source of water are required to be GFCI-protected, as well as any outlets into which a microwave is plugged.

These requirements apply to single-phase sources of up to 250 volts. Frequently, outlets greater than 125 volts are not protected at the outlet but by an upstream circuit breaker with GFCI protection. Three-phase GFCI devices are available commercially and can be applied to lab facilities in need of three-phase sources in damp locations.

GFCI protection may be provided by a facility-installed GFCI breaker installed upstream of the outlet in an electrical panel. In this case, the outlet should be clearly labeled as GFCI-protected.

a. GFCI receptacle type outlet (direct or upstream) – check monthly.

b. GFCI portable type outlet – check monthly.

   - These are inexpensive and available at hardware stores. These can be obtained and implemented quickly without requiring an electrician.

c. GFCI cord-connected type – check with every use.

For the above types of GFCI, verify proper operation by pressing the Test button and ensuring power is interrupted to the outlet, then restore power by pressing Reset. There are tools available to check these outlets, the simplest being a desk lamp or night light. NFPA recommends following the manufacturer-recommended frequency for checking this, which is monthly.

A lethal amount of current can be as little as 8 mA. GFCI trips occur at around 5 mA. Fuses and circuit breakers trip at 15-20 A, depending on their rating. They prevent electrical conductors from overheating and starting a fire due to too much current. They do **not** protect against electric shock due to a short circuit.

If a circuit breaker or GFCI trips repeatedly, this indicates a problem or a faulty device. In this case, contact an electrician.

G. Live Parts of Electrical Equipment

Hazard: electric shock

This guide does not address the requirements for working on energized gear. This section highlights parts of a system that may have small live parts exposed during normal operation.

There are three items to consider –

(1) Guarding against accidental contact – with a physical boundary, such as plexiglass, around the exposed part as well as placing the exposed part in an area of the room that is difficult to access unintentionally, e.g., on a high shelf or behind equipment.

(2) Prevention of physical damage – ensure that the above guarding is strong enough to withstand any possible physical damage. Ideally, place the equipment someplace where such danger of damage does not exist, if practical.

(3) Warning signs – to further enforce the provisions of guarding mentioned above, signs indicating the hazard should be placed near the hazard itself **and/or on the guarding**. Also, consider tape on the floor or a physical boundary to restrict access to the area.

H. Signage / Marking

Hazard: These signs are warnings designed to remind workers of a particularly high voltage hazard to prevent electric shock or arc flash from occurring.

For services over 600 V, signs warning of high voltage shall be posted where unqualified employees might come in contact with live parts. The entrances to all buildings, rooms, or enclosures containing live parts or exposed conductors operating at over 600 V must have posting of permanent and conspicuous warning signs reading “DANGER – HIGH VOLTAGE – KEEP OUT”.

Keep in mind that signage is not just for lab personnel. If high voltage is present when the lab is unoccupied, ensure that it is clearly marked and physical barriers are present when applicable. Protect non-lab personnel who may need to enter your space such as Building service workers (BSWs) and who are not familiar with your set-up. After hours, signage and engineering controls must be in place if a hazard exists. Also consider supplementary signage on the entrance(s) to the room.

I. High-voltage considerations

Hazard: electric shock, arc flash, equipment damage

These hazards can be mitigated by isolating the equipment when it is energized and taking precautions to limit available energy. If high voltage sources must be exposed when energized and can deliver substantial available energy, appropriate precautions from NPFA 70E and 29 CFR 1910 must be taken, which is beyond the scope of this document. Even if the setup can be enclosed and isolated from human contact, the situation might still result in damage to equipment or research material.

A. Corona discharge: In a conductor, electric fields increase at any sharp edges. If the concentration of charge driven by an electric field gets large enough, it can ionize the surrounding air, allowing current to 'leak' from the conductor. One example of this is the phenomenon popularly called St. Elmo's fire. This typically occurs above 6 kV and can be reduced significantly by minimizing sharp edges and applying insulating coatings. It tends to generate ozone, a hazardous gas.

B. Air gap across high voltage: The breakdown voltage (a.k.a. dielectric strength) of dry air is approximately 30 kV / cm. If two electrodes or surfaces are separated by only air, it is recommended to determine the distance required by that factor and double it to give a conservative margin of error. This is because angles and nonuniform shapes are likely to double the electric field near any edges. Although it is easy to enclose a setup and avoid the danger of people getting too close, an arc might form, damaging equipment or the sample under test, in addition to being a fire hazard.

J. Battery Storage

Hazard: electric shock, fire, toxic gas

Guidelines for battery storage:

- Only purchase devices that are listed by a nationally recognized testing laboratory like UL (Underwriters Laboratory).
- Ensure adequate ventilation during charging.
- Disconnect the charger when the battery has reached its full charge.
- Keep batteries at room temperature when possible.
- Do not store or charge batteries in the vicinity of flammable materials.
- Do not conduct overnight charging in unmonitored facilities.
- Ensure there is an SOP which addresses storage and charging of batteries.

See the DRS library page for information on battery use and storage: DRS Battery Safety.

K. Secondary hazards

Hazard: various

There are several hazards peripherally related to electrical safety that are not included in the list provided earlier (shock, arc flash, arc blast, fire, thermal burn).

1) Trip hazards – Unsecured cords along floors constitute a trip hazard. For longer runs involving several cables, use a cord protector as shown in the image:

This is useful for longer stretches or locations where several cables must be routed. For short distances and only one or two cords, the cables can be taped to the floor using Gaffer's tape. Sometimes, confused with duct tape, Gaffer tape is made of a different material and uses an adhesive that is more heat-resistant and is more easily removed from a surface than duct tape. Bundling multiple cords not only reduces a trip hazard but is good engineering practice. However, bundling too many cords together could hamper heat removal and potentially cause a fire. There are two aspects to consider. The tape may present a smaller trip hazard, but the protector also protects the cords. If using tape in areas of heavy foot traffic, the insulation of the cord can wear down creating a shock hazard.

If many items need to be grounded, rather than attaching each to a grounding source separately, consider attaching them to a copper block, and then routing a single wire from it to the grounding source. This serves to improve general safety by reducing trip hazards, and it can help with stray ground current issues if carefully managed.

2) Falls – if a ladder or stool must be used to perform work on or near electrical equipment, pay particular attention to the possibility of inadvertent contact, even at low voltages or currents. A minor shock that has no physiological dangers can still cause a sudden reaction resulting in a fall.

3) Other: Consider every combination of events related to electricity that can cause injury. When assessing risk, do not only consider danger due to a direct shock or arc itself, but look at the entire area and be alert to possible hazards. For example, consider the effect of contacting a low voltage that is not inherently a shock or arc hazard. The natural reaction to even a small shock is to back away from the source. Be sure the area is clear and, if this happens, that the worker is not going to step back into rotating machinery, or into a trip hazard.

Appendix A: Source / Reference Material

General

A. Responsibilities and Expectations

NFPA 70E (2024), 105.3(A) **Employer Responsibility**. The employer shall have the following responsibilities:

(1) Establish, document, and implement the safety-related work practices and procedures required by this standard.

(2) Provide employees with training in the employer's safety-related work practices and procedures.

NFPA 70E (2024), 105.3(B) **Employee Responsibility**. The employee shall comply with the safety-related work practices and procedures provided by the employer.

Campus Administrative Manual RP-17

OSHA Employer Responsibilities

B. Inspections

20 CFR 1910.303(b) Examination, installation, and use of equipment –

(1) **Examination**. Electrical equipment shall be free from recognized hazards that are likely to cause death or serious physical harm to employees. Safety of equipment shall be determined using the following considerations:

- (i) Suitability for installation and use in conformity with this subpart;
- (ii) Mechanical strength and durability, including, for parts designed to enclose and protect other equipment, the adequacy of the protection thus provided;
- (iii) Wire-bending and connection space;
- (iv) Electrical insulation;
- (v) Heating effects during all conditions of use;
- (vi) Arcing effects;
- (vii) Classification by type, size, voltage, current capacity, and specific use; and
- (viii) Other factors that contribute to the practical safeguarding of persons using or likely to come into contact with the equipment.

(2) **Installation and use**. Listed or labeled equipment shall be installed and used in accordance with any instructions included in the listing or labeling.

(6) **Deteriorating agents**. Unless identified for use in the operating environment, no conductors or equipment shall be located in damp or wet locations, where exposed to gases, fumes, vapors, liquids, or other agents that have a deteriorating effect on the conductors or equipment, or where exposed to excessive temperatures.

(8) **Mounting and cooling of equipment**.

(i) Electrical equipment shall be firmly secured to the surface on which it is mounted. Note: Wooden plugs driven into holes in masonry, concrete, plaster, or similar materials are not considered secure means of fastening electric equipment.

(ii) Electric equipment that depends on the natural circulation of air and convection principles for cooling of exposed surfaces shall be installed so that room airflow over such surfaces is not prevented by walls or by adjacent installed equipment. For equipment designed for floor mounting, clearance between top surfaces and adjacent surfaces shall be provided to dissipate rising warm air.

(iii) Electric equipment provided with ventilated openings shall be installed so that walls or other obstructions do not prevent the free circulation of air through the equipment.

C. Training

DRS Laboratory Safety Training library page

DRS Laboratory Safety Guide

DRS Electrical Safety library page

D. Standard Operating Procedures

DRS Laboratory Safety Training library page

DRS Laboratory Safety Guide

DRS Electrical Safety library page

DRS Standard Operating Procedures (SOP) library page

DRS Safety Training Page

Specific

A. Extension Cords

NFPA 1 (2024) 11.1.3.1: Multiplug adapters, such as multiplug extension cords, cube adapters, strip plugs, and other devices, shall be listed and used in accordance with their listing.

NFPA 1 (2024) 11.1.3.2: Multiplug adapters shall not be used as a substitute for permanent wiring or receptacles.

NFPA 1 (2024) 11.1.5.1: Extension cords shall be plugged directly into an approved receptacle, power tap, or multiplug adapter and shall, except for approved multiplug extension cords, serve only one portable appliance.

NFPA 1 (2024) 11.1.5.2: The ampacity of the extension cords shall not be less than the rated capacity of the portable appliance supported by the cord.

NFPA 1 (2024) 11.1.5.3: The extension cords shall be maintained in good condition without splices, deterioration, or damage.

NFPA 1 (2024) 11.1.5.4: Extension cords shall be grounded when servicing grounded portable appliances.

NFPA 1 (2024) 11.1.5.5: Extension cords and flexible cords shall not be affixed to structures; extend through walls, ceilings, or floors, or under doors or floor coverings; or be subject to environmental or physical damage.

NFPA 1 (2024) 11.1.5.6: Extension cords shall be permitted to be used on portable appliances to the nearest receptacle where receptacle spacing is in accordance with NFPA 70.

NFPA 70 (2023) 590.6(B)(2): **Assured Equipment Grounding Conductor Program**: A written assured equipment grounding conductor program continuously enforced at the site by one or more designated persons to ensure that equipment grounding conductors for all cord sets, receptacles that are not a part of the permanent wiring of the building or structure, and equipment connected by cord and plug are installed and maintained in accordance with the applicable requirements of 250.114, 250,138, 406.4(C), and 590.4(D). *The article continues by describing the required tests.*

NFPA 70E (2024) 110.9: Portable **Cord-and-Plug-Connected Electric Equipment**. This section applies to the use of cord- and plug-connected equipment, including cord- and plug-connected test instruments and cord sets (extension cords)
Handling and Storage. Portable equipment shall be handled and stored in a manner that will not cause damage. Flexible electric cords connected to equipment shall not be used for raising or lowering the equipment. Flexible cords shall not be fastened with staples or hung in such a fashion as could damage the outer jacket or insulation.

29 CFR 1910.304(b)(3)(ii)(B) Receptacles other than 125 volt, single-phase, 15-, 20-, and 30-ampere receptacles that are not part of the permanent wiring of the building or structure and that are in use by personnel shall have ground-fault circuit-interrupter protection for personnel.

29 CFR 1910.304(b)(3)(ii)(C)(4) The following tests shall be performed on all cord sets and receptacles which are not a part of the permanent wiring of the building or structure, and cord- and plug-connected equipment required to be grounded:

(i) All equipment grounding conductors shall be tested for continuity and shall be electrically continuous;

(ii) Each receptacle and attachment cap or plug shall be tested for correct attachment of the equipment grounding conductor. The grounding conductor shall be connected to its proper terminal; and

(iii) All required tests shall be performed before first use; before equipment is returned to service following any repairs; before equipment is used after any incident which can be reasonably suspected to have caused damage (for example, when a cord set is run over); and at intervals not to exceed 3 months, except that cord sets and receptacles which are fixed and not exposed to damage shall be tested at intervals not exceeding 6 months

29 CFR 1910.305(g)(1)(iv) Unless specifically permitted otherwise in paragraph (g)(1)(ii) of this section (*29 CFR 1910.305(g)*), flexible cords and cables may not be used:

(A) As a substitute for the fixed wiring of a structure;

(B) Where run through holes in walls, ceilings, or floors;

(C) Where run through doorways, windows, or similar openings;

(D) Where attached to building surfaces;

(E) Where concealed behind building walls, ceilings, or floors; or

(F) Where installed in race3ways, except as otherwise permitted in this subpart.

29 CFR 1910.334(a)(1) ***Handling.*** Portable equipment shall be handled in a manner which will not cause damage. Flexible electric cords connected to any equipment may not be used for raising or lowering the

equipment. Flexible cords may not be fastened with staples or otherwise hung in such a fashion as could damage the outer jacket or connection.

B. Power Strips

29 CFR 1910.303(b)(2) **Installation and use**. Listed or labeled equipment shall be installed and used in accordance with any instructions included in the listing or labeling.

29 CFR 1910.304(b)(4) **Outlet devices.** Outlet devices shall have an ampere rating not less than the load to be served…

TRIPP-LITE How to Choose the right surge protector

UL guidance for power strips and surge protectors

C. Daisy Chaining

NFPA 1 (2024) 11.1.4.4: The relocatable power taps (a.k.a. power strips) shall be directly connected to a permanently installed receptacle, except as permitted by 11.1.4.5.

NFPA 1 (2024) 11.1.4.5: The relocatable power tap (a.k.a. power strips) cords shall not extend through walls, ceilings, or floors; under doors or floor coverings; or be subject to environmental or physical damage.

UL 1363 1.7: A cord-connected RTP (Relocatable Power Tap, a.k.a. a power strip) is not intended to be connected to another cord-connected RPT.

NFPA 70 (2023) 110.3(B) **Installation and use**. Equipment that is listed, labeled, or both, or identified for a use shall be installed and used in accordance with any instructions included in the listing, labeling, or identification.

29 CFR 1910.303(b)(2) **Installation and use**. Listed or labeled equipment shall be installed and used in accordance with any instructions included in the listing or labeling.

29 CFR 1910.305(g)(1)(ii) Flexible cords and cables may only be used for:

(A) Pendants;

(B) Wiring of fixtures;

(C) Connection of portable lamps or appliances;

(D) Portable and mobile signs;

(E) Elevator cables;

(F) Wiring of cranes and hoists;

(G) Connection of stationary equipment to facilitate their frequent interchange;

(H) Prevention of the transmission of noise or vibration;

(I) Appliances where the fastening means and mechanical connections are designed to permit removal for maintenance and repair;

(J) Data processing cables approved as a part of the data processing system

(K) Connection of moving parts;

(L) Temporary wiring as permitted in paragraph (a)(2) of this section.

29 CFR 1910.305(g)(1)(iii) If used as permitted in paragraphs (g)(1)(ii)(C), (g)(1)(ii)(G), (g)(1)(ii)(I) of this section (quoted above), the flexible cord shall be equipped with an attachment plug and shall be energized from an approved receptacle outlet.

D. Bonding and Grounding

NFPA 77 (2024) 3.3.2: Bonding: For the purpose of controlling static electric hazards, the process of connecting two or more conductive objects together by means of a conductor so that they are at the same potential, but not necessarily at the same potential as the earth.

NFPA 77 (2024) 6.8.2: Grounding: the process of bonding one or more conductive objects to the earth so they are all at zero electrical potential.

Bonding refers to electrically connecting two materials to allow charge to be shared and ensure that a potential difference does not develop between them. This is important but not enough to ensure safety. For that we need to add grounding.

Grounding refers to electrically connecting something to the earth, ensuring it is at a constant zero voltage. If a system is properly bonded and grounded, there are no voltage differences between parts of the transferring containers or between the containers and ground, reducing the probability of a spark forming to ignite flammable vapors.

OSHA categories for flammable liquids (same as categories in the Globally Harmonized System (GHS)):

29 CFR 1910.106 (19): Flammable liquid means any liquid having a flashpoint at or below 199.4 °F (93 °C). Flammable liquids are divided into four categories as follows:

(i) Category 1 shall include liquids having flashpoints below 73.4 °F (23 °C) and having a boiling point at or below 95 °F (35 °C).

(ii) Category 2 shall include liquids having flashpoints below 73.4 °F and boiling point above 95 °F. *(Examples include isopropyl alcohol and acetone)*

(iii) Category 3 shall include liquids having flashpoints at or above 73.4 °F (23 °C) and at or below 140 °F (60 °C). When a Category 3 liquid with a flashpoint at or above 100 °F is heated for use within 30 °F (16.7 °C) of its flashpoint, it shall be handled in accordance with the requirements for a Category 3 liquid with a flashpoint below 100 °F (37.8 °C).

(iv) Category 4 shall include liquids having flashpoints above 140 °F (60 °C) and at or below 199.4 °F (93 °C). When a Category 4 liquid is heated for use within 30 °F (16.7 °C) of its flashpoint, it shall be handled in accordance with the requirements for a Category 3 liquid with a flashpoint at or above 100 °F (37.8 °C).

(v) When liquid with a flashpoint greater than 199.4 °F (93 °C) is heated for use to within 30 °F (16.7 °C) of its flashpoint, it shall be handled in accordance with the requirements for a Category 4 flammable liquid.

Per 29 CFR 1910.106(h)(7), "Category 1 or 2 flammable liquids, or Category 3 flammable liquids with a flashpoint below 100 °F (37.8 °C), shall not be dispensed into containers unless the nozzle and container are electrically interconnected."

NFPA 30 (2024), Article 4, categories for flammable liquids:

- Class IA: flashpoint below 73 °F and boiling point below 100 °F
- Class IB: flashpoint below 73 °F and boiling point at or above 100 °F

- e.g., isopropyl alcohol, acetone

- Class IC: flashpoint at or above 73 °F and below 100 °F
- Class II: flashpoint at or above 100 °F and below 140 °F
- Class IIIA: flashpoint at or above 140 °F and below 200 °F
- Class IIIB: flashpoint at or above 200 °F

NFPA 45 (2024) 9.3.3 states "Class I liquids shall not be transferred between conductive containers of greater than 4L (1 gal) capacity unless the containers are electrically interconnected by direct bonding or by indirect bonding through a common grounding system."

NFPA 45 (2024) 9.3.4 states "When dispensing Class I liquids involves nonconductive containers larger than 4 L (1 gal), which can be difficult to bond or ground, special dispensing procedures commensurate with the electrical characteristics of the liquid shall be developed and implemented."

For further information, see the DRS library page on Electrical Safety in the Research Laboratory, which includes a video demonstrating Illinois' bonding & grounding procedures and resources.

E. Electrical panel access

29 CFR 1910.303(g): what is quoted here applies for equipment containing voltage up to 150V. Higher voltages may require greater clearances, depending on what is exposed. See the quoted article for more details.

(1)(i)(A): The depth of the working space in the direction of access to live parts may not be less than indicated in Table S-1. Distances shall be measured from the live parts if they are exposed or from the enclosure front or opening if they are enclosed.

- Table S-1 gives this distance as 36" in all cases where voltage is 150 volts or less.
- This value also applies for nominal voltages up to 600 volts, provided there are exposed live parts on one side and no live or grounded parts on the other side of the working space, or exposed live parts on both sides are effectively guarded by suitable wood or other insulating material.

(1)(i)(B): The width of working space in front of the electrical equipment shall be the width of the equipment or 30 inches, whichever is greater. In all cases, the working space shall permit at least a 90-degree opening of equipment doors or hinged panels.

(1)(i)(C): The work space shall be clear and extend from the grade, floor, or platform to the height required by paragraph (g)(1)(vi) of this section. *(quoted below)*

(1)(ii): Working space required by this standard may not be used for storage.

(1)(iii): At least one entrance of sufficient area shall be provided to give access to the working space about electrical equipment.

(1)(vi): The minimum headroom of working spaces about service equipment, switchboards, panelboards, or motor control centers shall be as follows:

(A) For installations built before August 13, 2007, 1.91 m (6.25 ft); and

(B) For installations built on or after August 13, 2007, 1.98 m (6.5 ft), except that where the electrical equipment exceeds 6.5 ft in height, the minimum headroom may not be less than the height of the equipment.

NFPA 70 (2023)

110.26 **Spaces About Electrical Equipment**. Working space, and access to and egress from working space, shall be provided and maintained about all electrical equipment to permit ready and safe operation and maintenance of such equipment. Open equipment doors shall not impede access to and egress from the working space. Access or egress is impeded if one or more simultaneously opened equipment doors restrict working space access to be less than 24 inches wide and 6.5 feet high.

(A)(1) **Depth of working space**. The depth of the working space in the direction of live parts shall not be less than that specified in Table 110.26(A)(1).

- That table gives the same information as summarized above, which is 3 feet (36 inches) for most cases we will encounter.

(b) Low Voltage. By special permission, smaller working spaces shall be permitted where all exposed live parts operate at not greater than 30 volts rms, 42 volts peak, or 60 volts DC.

(A)(2) **Width of Working Space**. The width of the working space in front of the electrical equipment shall be the width of the equipment or 30 inches (2’6”), whichever is greater. In all cases, the work space shall permit at least a 90-degree opening of equipment doors or hinged panels.

Regardless of the width of the electrical equipment, the working space cannot be less than 30 inches wide. This space allows an individual to have at least shoulder-width space in front of the equipment.

(A)(3) **Height of Working Space**. The work space shall be clear and extend from the grade, floor, or platform to a height of 6.5 ft or the height of the equipment, whichever is greater.

(A)(6) **Grade, Floor, or Working Platform**. The grade, floor, or platform in the required working space shall be kept clear, and the grade, floor or platform in the working space shall be as level and flat as practical for the entire

(B) **Clear Spaces**. Working spaces required by this section shall not be used for storage.

(C) Entrance to and Egress from Working Space.

(1) **Minimum Required**. At least one entrance of sufficient area shall be provided to give access to and egress from working space about electrical equipment.

The requirements in this section provide access to and egress from electrical equipment. However, the primary intent is to provide egress from the area so that workers can escape if an arc-flash incident occurs.

F. GFCI Protection

NFPA 70 (2023): 210.8(B): All 125-volt through 250-volt receptacles supplied by single-phase branch circuits rated 150 volts or less to ground, 50 amperes or less, and all receptacles supplied by three-phase branch circuits rated 150 volts or less to ground, 100 amperes or less, installed in the following locations shall be provided with GFCI protection: ... Installed in the following locations shall be provided with GFCI protection:

(7) Sinks where receptacles or cord-and-plug connected fixed or stationary appliances are installed within 6 ft from the top edge of the inside bowl of the sink …

(12) Unfinished areas of basements

(13) Aquariums … where receptacles within 6 ft from the top inside edge or rim or from the conductive support framing of the vessel or container

(14) Laundry areas"

NFPA 70 (2023): 210.8(D): GFCI protection shall be provided for the branch circuit or outlet supplying the following appliances rated 150 volts or less to ground and 60 amperes or less, single- or 3-phase: …

(11) Clothes dryers

(12) Microwave ovens”

G. Live parts of Electrical Equipment

NFPA 70 (2023): 110.27: **Guarding of Live Parts**.

(A) Live Parts Guarded Against Accidental Contact. Except as elsewhere required or permitted by this *Code (National Electric Code – NFPA 70)*, live parts of electrical equipment operating at 50 to 1000 volts nominal shall be guarded against accidental contact by approved enclosures or by any of the following means:

- **(1)** By location in a room, vault, or similar enclosure that is accessible only to qualified persons.
- **(2)** By permanent, substantial partitions or screens arranged so that only qualified persons have access to the space within reach of the live parts. Any openings in such partitions or screens shall be sized and located so that persons are not likely to come into accidental contact with the live parts or to bring conducting objects into contact with them.
- **(3)** By location on a balcony, gallery, or platform elevated and arranged so as to exclude unqualified persons.
- **(4)** By elevation above the floor or other working surface as follows:
  - **a.** A minimum of 2.5 m (8 ft) for 50 volts to 300 volts between ungrounded conductors
  - **b.** A minimum of 2.6 m (8 ft 6 in) for 301 volts to 600 volts between ungrounded conductors
  - **c.** A minimum of 2.62 m (8 ft 7 in) for 601 volts to 1000 volts between ungrounded conductors.

(B) Prevent Physical Damage. In locations where electrical equipment is likely to be exposed to physical damage, enclosures or guards shall be so arranged and of such strength as to prevent such damage.

(C) Warning Signs. Entrances to rooms and other guarded locations that contain exposed live parts shall be marked with conspicuous warning signs forbidding unqualified persons to enter. The marking shall meet the requirements in 110.21(B).

NFPA 70 (2023): 110.21(B): Field-Applied Hazard Markings. Where caution, warning, or danger hazard markings such as labels or signs are required by this *Code*, the markings shall meet the following requirements:

- **(1)** The marking shall be of sufficient durability to withstand the environment involved and warn of the hazards using effective words, colors, symbols, or any combination thereof.
- **(2)** The marking shall be permanently affixed to the equipment or wiring method and shall not be handwritten.

Exception to (2): Portions of the markings that are variable, or that could be subject to changes, shall be permitted to be handwritten and shall be legible.

H. Signage / marking

20 CFR 1910.303(e) **Marking** –

(1) **Identification of manufacturer and ratings**. Electric equipment may not be used unless the following markings have been placed on the equipment:

(i) The manufacturer's name, trademark, or other descriptive marking by which the organization responsible for the product may be identified; and

(ii) Other markings giving voltage, current, wattage, or other ratings, as necessary.

(2) **Durability**. The marking shall be of sufficient durability to withstand the environment involved.

20 CFR 1910.303(f) **Disconnecting means and circuits** –

(2) **Motors and appliances.** Each disconnecting means required by this subpart for motors and appliances shall be legibly marked to indicate its purpose, unless located and arranged so the purpose is evident.

NFPA 70E (2024): 130.5(H) **Equipment Labeling.** Electrical equipment such as switchboards, panelboards, industrial control panels, meter socket enclosures, and motor control centers that are in other than dwelling units and that are likely to require examination, adjustment, servicing, or maintenance while energized shall be marked with a label containing all the following information:

(1) Nominal system voltage

(2) Arc flash boundary

(3) At least one of the following:

a. Available incident energy and the corresponding working distance, or the arc flash PPE category in Table 130.7(C)(15)(a) or Table 130.7(C)(15)(b) for the equipment, but not both

b. Minimum arc rating of clothing

c. Site-specific level of PPE

I. High-voltage considerations

29 CFR 1910.303(d) **Arcing parts**. Parts of electric equipment that in ordinary operation produce arcs, sparks, flames, or molten metal shall be enclosed or separated and isolated from all combustible material.

NFPA 70 (2023): 110.18 Arcing Parts: identical to OSHA (CFR) wording above

J. Battery Storage

There is no authoritative guidance from OSHA or NFPA regarding the storage of lithium-ion batteries. However, such guidance is being developed.

DRS Battery Safety Guidance

OSHA Fact Sheet for Lithium-ion Battery Safety

NFPA Guidance for Lithium-ion Batteries

US Chemical Storage guidance

K. Secondary Hazards

OSHA Field Safety and Health Management System (SHMS) Manual, Chapter 11 (expands and clarifies guidance from 29 CFR 1910 and 1926):

V. Procedures

A. Keep all worker areas, aisles, and passageways, including stairs, doorways, electrical panels and exits, free and clear of obstructions, and maintain them in a clean, orderly, and sanitary fashion.

C. All trip hazards must be eliminated. Common hazards include damaged carpeting, cords in walking areas, and projecting floor electrical outlet boxes.

E. Ladders

5. Always face the ladder when climbing or descending. Use both hands – never carry anything in your hands. You have climbed too high if your knees are above the top of the ladder or if you cannot maintain a handhold on the ladder.

7. Do not use metal ladders if there is the possibility of contact with electrical conductors.