

ADVISORY NO. 9.0: ELECTRICAL SAFETY IN THE LABORATORY

ELECTRICAL SAFETY PROCEDURES

- The careless handling of electrical equipment may result in injury, fire or explosion. Adherence to the following guidelines will minimize electrical hazards.
- Proper equipment grounding is essential. Equipment producing a "tingle" should be promptly reported for repair. Bad grounds can become progressively worse and become extremely hazardous.
- Keep the use of extension cords to a minimum and cords as short as possible. Be sure insulation and wire size of extension cords are adequate for the voltage and current to be carried and the environmental conditions in which the cord is to be used. See article 400, National Electric Code for more information. Insure connectors are of a ground configuration with blade intact.
- Work on electrical devices should be done after the power has been disconnected or shut off and suitable precautions taken to keep the power off during the work. On portable equipment the power cord should be unplugged and secured so the electricity cannot be accidentally turned on by someone else. On fixed equipment the main power switch should be shut off and locked with a padlock; shutting of and blocking starter switches is not a positive control nor safe enough since an internal short can bypass the switch and start equipment. Remove fusing when possible and tag all equipment off. **(See Advisory 2.1, Control of Hazardous Energy Sources)**
- If it is necessary to work on energized electric equipment, the person doing so should be fully knowledgeable and have a second person present that is trained in rescue, first aid and cardiopulmonary resuscitation. Never work on energized equipment alone.
- Use only tools and equipment with non-conducting handles when working on electrical devices.
- Treat all electrical devices as if they are energized.
- Drain capacitors before working near them or removing the device from service, and keep the short on the terminals during the work since some of the charge may return due to a dielectric effect.
- Never touch another person's equipment or electrical control devices unless instructed to do so. They may be working on the equipment out of your line of sight.
- After servicing electrical equipment do not turn the power back on until you are sure all persons have moved to a safe location and are aware the switch is to be activated.
- Enclose all electric contacts and conductors so that no one can accidentally come into contact with them.
- Mark all high voltage equipment with signs stating the approximate voltage with letters at least three inches high if possible.
- Wear safety glasses or a face shield where sparks or arcing may occur. When working with large vacuum tubes or cathode ray tubes, which may implode, wear safety glasses and a face shield and use a table shield if possible.
- Never use metallic pencils or rulers, or wear rings or metal watchbands when working on electrical equipment.
- Cleaning solvents for electrical equipment should be carefully chosen. The use of carbon tetrachloride or benzene should be avoided because of their toxicity. Highly toxic and/or flammable cleaning solvents require special ventilation, storage and control procedures. Chloromethane or safety solvent should be used on electrical equipment.
- All laboratory wiring should be done by electricians and should involve notification of Facilities Management's Zone Maintenance. Electronic equipment wiring should be done by trained

technicians or electronic engineers, or by students under professional supervision.

- Never handle electrical equipment when hands, feet, or body are wet or perspiring or when standing on a wet floor.
- With high voltages regard all floors as conductive and grounded unless covered with well-maintained and dry rubber matting of suitable type for electrical work.
- Whenever possible, use only one hand when working on circuits or control devices.
- When it is necessary to touch electrical equipment (for example, when checking for overhead motors), use the back of the hand. Thus, if accidental shock were to cause muscular contraction, you would not "freeze" to the conductor.
- Never use or store highly flammable liquids near electrical equipment.
- Keep in mind that on some equipment the interlocks disconnect the high voltage source when a cabinet door is opened, but power for control circuits may remain on, or be a part of an accompanying system.
- Check all electrical apparatus before use for worn or defective insulation and loose or broken connections.
- Keep all electrical wires away from hot surfaces.
- The greatest hazard from static electricity is in the winter when the air is dry. Static electricity emits sparks that can ignite flammable gases or vapors. Attempt to minimize static electricity by spraying with "Anti-Stat," using conductive materials (floors, mats, etc.), and using grounding straps on instruments and machines.

ELECTRIC CONTROL PANELS

- The exact location of the panel board for the electrical circuits to your area should be known by all laboratory personnel to facilitate remote shut-off of electrical apparatus in an emergency situation. Post location of the panel board on your equipment.
- Circuit breakers should be labeled and main circuit breakers should be prominently labeled.

WORKING SPACE AROUND ELECTRICAL EQUIPMENT (600 VOLTS OR LESS NOMINAL)

- Sufficient access and working space shall be provided and maintained around all electric control panels to permit ready and safe operation and maintenance of such equipment.
- The dimensions of the working space in the vicinity of live parts operating at 600 volts or less and contained within electric control panels shall have a **MINIMUM CLEAR DISTANCE OF 3 FEET**.
- In addition, the workspace shall **NOT BE LESS THAN 30 INCHES WIDE** in front of the electrical equipment.

NEW ELECTRICAL EQUIPMENT

- Purchase requisitions for non-fixed electrical equipment supplied by a power cord shall contain the statement that: "Exposed non-current carrying metal parts shall be grounded through a grounding type cord and plug", for any of the following:
 - Hand-held motor operated equipment;
 - Equipment used with or around moisture such as water baths, physiotherapy equipment, stirrers, and water pick-up machines;
 - Readily moveable equipment, such as centrifuges, ovens, and hot plates, which may be used around moisture, other grounded equipment, or fixed grounds such as water pipes, sinks, and

- metal hoods;
- Equipment which is explosion proof;
- Autotransformers;
- Any other item which can be procured with a grounding type cord and plug as standard item.
- Exceptions to the previous equipment are "double insulated" tools. Equipment in this category is permanently marked by the words "double insulation" or "double insulated". Units designed to meet this category shall have been tested and listed by Underwriters Laboratories, Inc., and will have the UL symbol. Many U.S. manufacturers are also using the symbol to denote double insulation.

ELECTRICAL WIRING

- Care should be taken to insure that the purchase of new electrical equipment will not place too high a demand upon the existing electrical supply.
- Fuses and over current protection devices are installed on the basis of their ability to protect a given wiring system and should not be changed except by Facilities Management after a thorough evaluation of the entire wiring system affected by the change.
- No electrical wiring, phone cable, computer cable, etc. shall be draped across doorways, taped to walls or thrown above the ceiling by building and laboratory tenants. Contact Facilities Management Zone Maintenance for proper instruction and installation.
- Eliminate all frayed or worn wiring from installation.

GROUNDING

- All laboratory electrical services should be grounded.
- Before final acceptance or use of any new or renovated laboratory facility, the entire electrical system should be tested to insure that an adequate and continuous grounding system has been installed. Contact your Facilities Management Zone Maintenance Office for inspection.
- All grounding shall be done in accordance with the standards set forth in the latest edition of the National Electric Code.
- Many older buildings do not have grounded electrical systems. The provision for an adequate grounding system should be given high priority by the principal investigator for a laboratory since the lack of a safe route to ground for electrical current produced by failures within systems creates the most severe personnel hazards.
- Where it is impractical to provide an adequate and continuous ground for the entire electrical wiring system, the following operational rules shall be established to insure that all potentially hazardous equipment is effectively grounded:
 - All electrical systems having exposed metal or current conducting parts that are normally energized or may become energized due to failure within the system shall be grounded.
 - Equipment grounding can be achieved in two ways and should only be done by qualified electricians under the direction of Facilities Management.
 - ① Attachment of a ground connection to a continuous metallic system;
 - ② Installation of a separate grounding system.

GROUND FAULT CIRCUIT INTERRUPTERS

A ground fault circuit interrupter (GFCI) is defined in the National Electrical Code® Handbook as: "A device intended for the protection of personnel that functions to de-energize a circuit or portion thereof within an established period of time when a current to ground exceeds some predetermined value that is less than that required to operate the over-current protective device of the supply circuit".

GFCI's should be installed whenever laboratory electrical outlets are located within six (6) feet of any other utility outlet (water, gas, compressed air, steam, etc.) to protect personnel from electrocution by inadvertently becoming part of the circuit to ground.

WIRING IN LABORATORY FUME HOODS

- Where feasible, outlets, switches, and lighting fixtures should not be installed within fume hoods.
NOTE: Only explosion-proof electrical equipment should be used with a hood enclosure in which flammable concentrations of vapor and air may be present.
- Wiring in hoods should be at a minimum because of corrosion.

REFRIGERATORS

- There should be no potential source of electrical sparks on the inside of a laboratory refrigerator.
- Only refrigerators "approved" for flammable liquids should be used for this purpose. Retrofitting a domestic refrigerator is expensive, and if not done properly, is hazardous, especially "Frost Free" models, which have a drain located near the compressor.
- Any domestic refrigerator found within a laboratory shall be permanently labeled **"NOT SUITED FOR FLAMMABLE LIQUIDS"** in red lettering placed near the handle.
- Laboratory refrigerators should be placed against fire-resistant walls, have a heavy-duty cord, and preferably should be protected by their own circuit breakers.
- Uncapped containers of chemicals shall not be kept in refrigerators. Containers of materials shall be capped to achieve a seal that is vapor tight and is unlikely to permit a spill if it is tipped over.

NUMBER AND LOCATION OF ELECTRICAL OUTLETS

If you are planning to renovate a laboratory the following guidelines should be followed:

- A sufficient number of electrical outlets should be provided and located so that the installation of extension cord wiring will not be necessary.
- Research laboratories should have at least four 110 VAC double outlets for each individual workstation. The number of outlets per circuit should be no more than 9 per 15 or 20-amp branch circuit.
- The outlets should be spaced so that there is no more than 1.83 m (6 ft.) from any point on any wall, bench or workspace to the nearest outlet.

OUTLET CONFIGURATIONS

- Outlets serving nominal 110V, 220V, 440V or other A/C voltages should match NEMA configurations for general-purpose non-locking plugs and receptacles as closely as possible.
- All the A/C circuits should be clearly labeled.

ELECTRICAL MOTORS

- All motors and motor installations should conform to the standards set forth in Article 430 of the National Electric Code.
- Care should be taken that 3-phase motors are properly wired for the actual voltage levels in each facility. Line voltages nominally considered as 220V by the layman may vary from 208V to 240V in fact. Consequently, failure to use the correct wiring procedures can lead to overheating, early motor failure, and possible fire.
- Installation of electric motors should be done by a qualified electrician.

- Have a competent electrician inspect and service all motors on at least an annual basis. This will prolong the service life of the motor and will allow for the detection of possible electrical faults before failure actually occurs.

ELECTRONIC EQUIPMENT

- Equipment, whether of commercial manufacture or not, should be furnished with a circuit diagram, operating instructions, and an explanation of the associated hazards and the operation of safety devices. Door interlocks should be installed (preferably in sight) to de-energize high-voltage circuits when doors are opened.
- In general, chassis and exposed metal parts should be grounded and bonded together. Conductors used for such purpose should be adequate for maximum anticipated fault current.
- High voltage connectors should be of the type on which the body of the connector contacts its mating part before the high-voltage conductor makes contact. Any voltages greater than 240 VAC should be either hard wired or connection provided by an explosion proof connecting device such as the Hubbellock "20000 series" or equivalent. If it is necessary to work on energized components, grounding should be used unless equipment damage in using such would result. The use of grounding can be at the discretion of the persons doing the work. However, if grounds are not used, the entire area should be "ground-free" and denoted as such. If grounding is desirable for safety but "noise" is objectionable, then consideration should be given to the use of a "quiet" laboratory ground, which is a separate shielded grounding conductor (independent from power ground) to provide a zero potential, free from pick-up. If such a conductor is used, it should be prominently marked.
- Bench tops in electronic laboratories should be nonconductive, and only a minimum of connected equipment should be on the bench tops.
- Conductors used to dissipate the charge on capacitors or capacitive circuits should contain sufficient copper to dissipate the calculated maximum energy without excessive temperature rise, which endangers soldered joints, etc. The length of the insulated wand should be ample for the reach and the voltages involved. Connections made with a spring clip are not recommended.
- Shorting conductor wands can be of rigid plastic or dry hardwood painted with shellac. The conductor must be a bare conductor, but transparent plastic tubing may be slipped over it. The end of the conductor should terminate in a copper hook so that it can be left hanging on a terminal of a discharged capacitor during repair work as extra protection.
- Many electronic tubes now contain radioactive materials (**Table 1**). Some of the special application tubes contain quantities, which are hazardous, when the tubes are broken and the material enters the body by inhalation, ingestion, or through cuts in the skin. Some of these tubes contain small amounts of active material, which in a single tube is not a health problem under normal conditions.

TABLE 1

Examples of Radioactive Materials in Electronic Tubes

Type	Manufacturer	Isotope	Microcurie
OA2	Raytheon	Cobalt-60	0.0067
OA2-WA	CBS-Hytron	Nickel-63	0.01-0.05
OA2-WA	Raytheon	Cobalt-60	0.0067
OB2	Raytheon	Cobalt-60	0.0067
OB2-WA	CBS-Hytron	Nickel-63	0.01-0.05
OB2-WA	Raytheon	Cobalt-60	0.0067

Selenium (in rectifiers) should be handled with caution because of its toxicity.

When a selenium rectifier burns out or arcs over, ventilate the area to remove fumes, particularly in the case of large rectifiers.

Measurement of filament voltage on power rectifier tubes should preferably be through permanently installed voltmeters rather than portable instruments. The meters should be rated for the maximum peak inverse voltage, and should be protected with a glass or plastic shield.

Metal-cased meters should only be installed on grounded panels. **NOTE:** Although it is assumed that voltmeters and ammeters will be connected to the groundside of the series resistor and the grounded side, respectively, the above two precautions are nevertheless recommended.

Filaments on some high voltage vacuum rectifier tubes, for example, IB3-GT or IV2, are capable of producing a fatal shock if the filament circuits are ungrounded.

Rectifier tubes operating in circuits in which peak inverse voltages are around 16,000 or over produce X-rays, for which shielding should be provided.

The possibility of high-frequency burns is not confined to Rf equipment, but can exist in large audio-frequency equipment due to high frequency parasitic oscillations.

Before handling cathode-ray tubes, short high-voltage terminal to outer coating and ground. Store and carry them with care to prevent breakage, and wear eye protection.

Only insulated or grounded shafts should protrude through chassis panels.

As an added precaution use short, well-recessed set screws, preferably of nylon.

Whenever technical requirements permit, install current-limiting resistors in series with the output of power supplies.

Bleeder resistors should be installed across filter capacitors in power supplies, but even with this precaution, capacitors should be manually discharged before working on them. Note, however, that under certain conditions, shorting filter capacitors improperly can result in other permanent equipment damage. When in doubt, refer such servicing to qualified personnel.

If power must be on while adjusting equipment, these precautions should be observed to minimize hazards:

- Use insulated test prods
- Have another person near you who is cognizant of hazards and familiar with artificial respiration (CPR)

- Stand on an insulating mat

PRINCIPAL HIGH VOLTAGE DANGER POINTS

- Transformer terminals
- Rectifier-tube plate caps
- Filter capacitor terminals
- Filter choke
- Rf tuning capacitors coils
- Fuse panels
- Zero adjusting screws of meters (depending on mode of installation)
- Cathode-ray tube terminals

Do not rely completely on relays because contacts may weld together. Two relays in series are an added safety feature.

If it is necessary to disable an interlock, tag it for the time it is inoperative.

FAIL-SAFE CONSIDERATIONS

- Safety circuits must be designed with normally open relays.
- When possible, install fuses in series with filter capacitors.
- Run control circuit wiring so that a short circuit causes a fail-safe situation.

IMPULSE CURRENTS

Large capacitors should be installed in barricaded locations so that all personnel are protected from bursting capacitors.

Keep capacitors short-circuited when not in use.

Floor areas around high voltage or impulse current generating equipment where operators or observers are likely to stand should be covered with a suitable kind of rubber matting. Matting should be properly maintained, kept dry, and tested per ASTM D-178-24, if visibly deteriorated.

Never put your hand on or near a condenser bank or anything attached to condensers that have to be preceded by discharging through a resistive "ground". Examples of the number of joules dissipated per foot of copper conductor, (approximately 400°C / 720°F temperature rise) are listed in **Table 2**.

TABLE 2

Energy Dissipated Per Foot of Conductor

Wire Sized	Joules
0000	44,200
000	35,100
00	27,800
0	22,200
2	13,900
4	8,700
6	5,475
8	3,450
10	2,160
12	1,370

REFERENCE:

Prudent Practices for Handling Hazardous Chemicals in Laboratories, National Research Council, National Academy Press, Washington, D.C. 1981.

CRC Handbook of Laboratory Safety, 2nd Edition, Norman V. Steere, Editor, CRC Press, Inc., Boca Raton, Florida, 1971.

National Electric code, NFPA 70 and 70A, National Fire Protection Association, Boston, MA.

LASL Health and Safety Manual, University of California, Los Alamos Laboratory, Los Alamos, New Mexico.