

EUV

An NSF Engineering Research Center

Colorado State University

High Voltage Safety Manual

INTRODUCTION

General information about electricity and the human body:

More than one thousand people are killed each year in the U.S. due to generated electric current, and several thousand more are injured. Current flowing inside the body can cause deep burns and cardiac arrest. Frequently, the individual cannot let go of the power source due to involuntary muscle contraction. The brain and heart are the most sensitive organs. For effects of current on the human body, see table 1. An alternating current (ac) with a voltage potential greater than 550 V can puncture the skin and result in immediate contact with the inner body resistance. A 110-V shock may or may not result in a dangerous current, depending on the circuit path, which may include the skin resistance. A shock greater than 600 V will always result in very dangerous current levels. The most severe result of an electrical shock is death.

Conditions for a serious, yet still potentially lethal, shock across a critical path, such as the heart, are

1. More than 30-V root mean square (rms), 42.4-V peak, or 60 V dc at a total impedance of less than 5000 ohms.
2. 10 to 75 mA.
3. More than 10 J.

Conditions for a potentially, but more than likely, lethal shock across the heart are

1. More than 375 V at a total body impedance of less than 5000 ohms.
2. More than 75 mA.
3. More than 50 J.

The worst possible frequency for humans is 60 Hz, which is commonly used in utility power systems. Humans are about five times more sensitive to 60-Hz alternating current than to direct current. At 60 Hz, humans are more than six times as sensitive to alternating current than at 5000 Hz--and the sensitivity appears to decrease still further as the frequency increases. Above 100-200 kHz, sensations change from tingling to warmth, although serious burns can occur from higher radio-frequency energy.

At much higher frequencies (e.g., above 1 MHz), the body again becomes sensitive to the effects of an alternating electric current, and contact with a conductor is no longer necessary; energy is transferred to the body by means of electromagnetic radiation.

Table 1: Effects of electric current on the human body

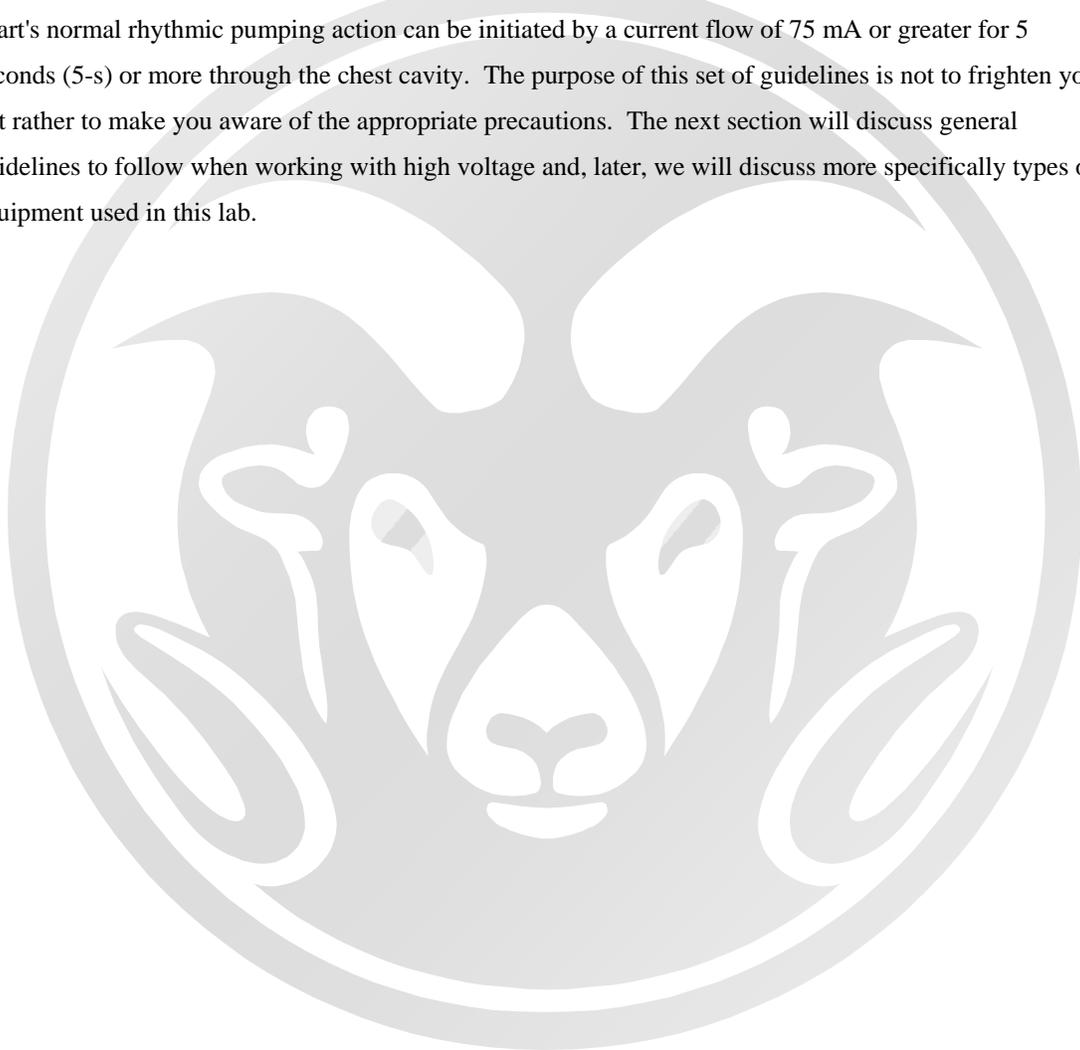
| Effect/feeling | Direct current (mA) | | Alternating current (mA) | | | | Incident severity |
|------------------------------|---------------------|--------|--------------------------|--------|-----------|--------|------------------------------|
| | 150 lb | 115 lb | 60 Hz | | 10,000 Hz | | |
| | | | 150 lb | 115 lb | 150 lb | 115 lb | |
| Slight sensation | 1 | 0.6 | 0.4 | 0.3 | 7 | 5 | None |
| Perception threshold | 5.2 | 3.5 | 1.1 | 0.7 | 12 | 8 | None |
| Shock not painful | 9 | 6 | 1.8 | 1.2 | 17 | 11 | None |
| Shock painful | 62 | 41 | 9 | 6 | 55 | 37 | Spasm, indirect injury |
| Muscle clamps source | 76 | 51 | 16 | 10.5 | 75 | 50 | Possibly fatal |
| Respiratory arrest | 170 | 109 | 30 | 19 | 180 | 95 | Frequently fatal |
| ≥ 0.03 -s vent. fibril. | 1300 | 870 | 1000 | 670 | 1100 | 740 | Probably fatal |
| ≥ 3 -s vent. fibril. | 500 | 370 | 100 | 67 | 500 | 340 | Probably fatal |
| ≥ 5 -s vent. fibril. | 375 | 250 | 75 | 50 | 375 | 250 | Probably fatal |
| Cardiac arrest | -- | -- | 4000 | 4000 | -- | -- | Possibly fatal |
| Organs burn | -- | -- | 5000 | 5000 | -- | -- | Fatal if it is a vital organ |

Life-Threatening Effects:

- Currents in excess of a human's "let-go" current (≥ 16 mA at 60 Hz) passing through the chest can produce collapse, unconsciousness, asphyxia, and even death.
- Currents (≥ 30 mA at 60 Hz) flowing through the nerve centers that control breathing can produce respiratory inhibition, which could last long after interruption of the current.
- Cardiac arrest can be caused by a current greater than or equal to 1 A at 60 Hz flowing in the region of the heart.
- Relatively high currents (0.25-1 A) can produce fatal damage to the central nervous system.

- Currents greater than 5 A can produce deep body and organ burns, substantially raise body temperature, and cause immediate death.
- Serious burns or other complications can cause delayed reactions and even death.

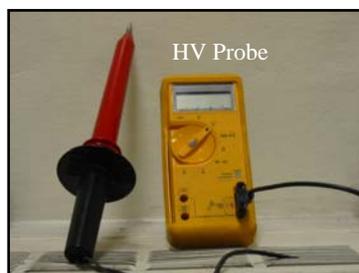
The most dangerous current flow via the chest cavity is through the heart when the shock occurs in the time relative to the normal heart rhythm. This current may cause ventricular fibrillation, which is defined as repeated, rapid, uncoordinated contractions of the heart ventricles. Ventricular fibrillation that alters the heart's normal rhythmic pumping action can be initiated by a current flow of 75 mA or greater for 5 seconds (5-s) or more through the chest cavity. The purpose of this set of guidelines is not to frighten you but rather to make you aware of the appropriate precautions. The next section will discuss general guidelines to follow when working with high voltage and, later, we will discuss more specifically types of equipment used in this lab.



GUIDELINES FOR HIGH VOLTAGE WORK

General Work Controls:

- Don't work alone - in the event of an emergency another person's presence may be essential.
- Know the emergency procedures to follow in case of an accident (**dial 911**).
- De-energize the equipment at least twice prior to beginning work. 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.
- After you have discharged everything, only touch the circuit with the back of your hand first. This allows you to let go if you need to.
- Never enter alone into an area containing exposed electrical energy sources.
- Use only the test instruments, and insulated tools rated for the voltage and current specified.
- Always keep one hand in your pocket when anywhere around a powered line-connected or high voltage system.
- Wear rubber bottom shoes or sneakers.
- Don't wear any jewelry or other articles that could accidentally contact circuitry and conduct current, or get caught in moving parts.
- Set up your work area away from possible grounds that you may accidentally contact.
- Know your equipment.
- If you need to probe, solder, or otherwise touch circuits with power off, discharge (across) large power supply filter capacitors (at least 2 times). Monitor while discharging and/or verify that there is no residual charge with a suitable voltmeter.
- If you must probe live, put electrical tape over all but the last 1/16" of the test probes to avoid the possibility of an accidental short, which could cause damage to various components. Clip the reference end of the meter or scope to the appropriate ground return so that you need to only probe with one hand.



- Perform as many tests as possible with power off and the equipment unplugged.
- Don't attempt repair work when you are tired. Not only will you be more careless, but also your primary diagnostic tool - deductive reasoning - will not be operating at full capacity.
- Finally, never assume anything without checking it out for yourself! Don't take shortcuts!

High-voltage supplies (ac or dc) and trigger generators can present the following hazards:



- Faults, lightning, or switching transients can cause voltage surges in excess of the normal ratings.
- Internal component failure can cause excessive voltages on external metering circuits and low-voltage auxiliary control circuits.
- Overcurrent protective devices such as fuses and circuit breakers for conventional applications may not adequately limit or interrupt the total inductive energy and fault currents in highly inductive dc systems.
- Stored energy in long cable runs can be an unexpected hazard. Procedures must be in place to ensure proper discharge of this energy.
- Involuntary reactions from contact with high-voltage low-current systems may result in a fall or entanglement with equipment.

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

Low-voltage, high current power supplies:

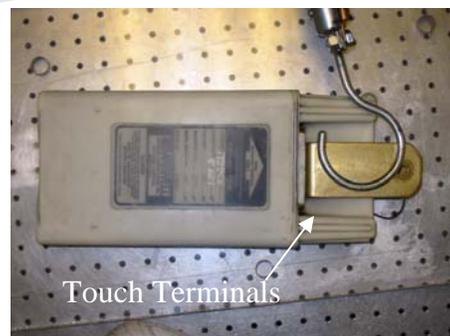
R&D systems may include equipment that operates at less than 50 V. Even though this voltage level generally is not regarded as hazardous, high-current levels generated by these systems may be hazardous. Furthermore, inadvertent grounding of conductors may result in arc flashes and burns, and inductive 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.

High-voltage, low current power supplies:

Power supplies with output currents less than 5 mA pose virtually no electrical shock hazard. In hazardous locations, 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.

Capacitors

- Manual-grounding devices shall be installed with capacitors and used, even if automatic discharge systems are used.
 - To ground, simply use a grounding rod (properly grounded), and touch both terminals of the HV capacitor.

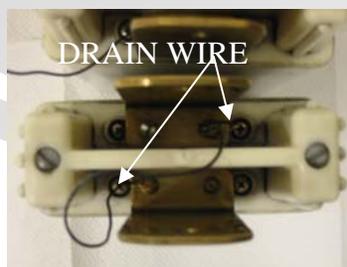


- Capacitors shall be physically grounded regardless of the existence of bleeder resistors, dump switches, interlocks, or other potential de-energizing devices. Grounding devices shall be placed at low-impedance points and kept in these positions while personnel are in the enclosure. All terminals shall be grounded, at least 2 times, 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 fuses cannot limit fault currents, the design shall include a barrier or enclosure around the capacitor bank to protect personnel from any projectiles.
- 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.



- Connections shall not be made or broken with the power supply energized unless they are designed and rated for this type of duty (e.g., load-break elbows).
- Inspect cables and connectors for damage and do not use if they are damaged.

EXAMPLES OF WHAT NOT TO DO

* A student, working on a doctorate degree, received an electrical shock while assisting a fellow student.

- The doctoral student contacted an insulated high voltage wire and ground.
 - The student received 10 kV dc hand-to-hand (fore arm) at an ampere rating between 1-2 amps.
 - The entry point was the middle and ring finger of the left hand and exit was from the right forearm.
 - The wire may have been previously damaged.
 - The individual was taken directly to Valley Medical Center, treated and released.
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* An employee received a 6 kV at 5 mA shock.

- He turned off the wrong power supply and opened an enclosure to access a cooling fan on a 10 kV duoplasmatron (Ion Gun).
 - He had opened the power supply to move a wire that was rubbing against a fan motor.
 - The employee did not verify that the power supply was de energized or locked out. Treated and released from medical.
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* Shock and second-degree burn:

- An electronics technologist was troubleshooting a power supply and had de-energized the chassis.
- He was removing a circuit board that contained three capacitors when his right thumb contacted leads from one of the capacitors.
- He received a 470vdc <10J shock and second degree burn to his thumb.
- The employee failed to discharge the capacitors prior to removing the circuit board.

** All examples took place at Lawrence Livermore National Labs (LLNL).