CHAPTER 4 ISOLATION OF HAZARDS

4.1 HIGH-VOLTAGE EQUIPMENT ISOLATION REQUIREMENTS

Energized parts of high-voltage (above 600 V ac or dc) equipment and circuits shall be isolated from surfaces exposed to personnel by two acceptable, independent energy barriers, one of which shall be designed to survive any credible failure mode, i.e., having a probability of 1 x 10^{-6}/yr or more. Two acceptable, independent energy barriers are required between all ungrounded conducting parts that extend from high-voltage energy sources or enclosures to areas or devices that are accessible to personnel. A safety barrier may be used in lieu of one of the above energy barriers.

4.2 LOW-VOLTAGE EQUIPMENT ISOLATION REQUIREMENTS

Energized parts of low-voltage (600 V ac or dc and below) equipment and circuits shall be isolated from personnel by at least one acceptable energy or safety barrier.

4.3 ENERGY BARRIERS AND SAFETY BARRIERS

Barriers are isolating features that provide protection against direct contact from any usual direction of access. They are features that minimize effects on personnel by electric shock, arcs and arc-discharge (overpressure).

4.3.1 Energy barriers depend on physical integrity, insulation, or conduction to either contain or shunt the energy away from personnel. Safety barriers depend on separating personnel from the energy source by time and distance.

4.3.2 Energized parts of electrical equipment and circuits shall be guarded against accidental human contact through the use of either energy barriers, safety barriers, or both. When electrical systems and equipment are in an operating mode, all barriers shall be permanently in place and functioning. When electrical systems and equipment are in a test or maintenance mode and permanent energy barriers are removed, approved temporary safety barriers may be substituted or added to protect personnel, provided the requirements of this Section 2.0 are satisfied. Electrical equipment under test with permanent energy barriers removed shall be energized only with approved test procedures in the presence of a Qualified Person acting as the Director of the Test.

4.3.3 Energy Barriers

The design objective of energy barriers is to prevent an unwanted transfer of energy between an energy source and a target. Acceptable energy barriers shall be designed with adequate physical integrity to withstand the maximum credible energy that can be delivered by the energy sources to which the barriers are exposed. Energy barriers may be:

A. Insulating - Having adequate clearance in air, oil, or some other insulating medium.

B Conducting - Such as an effectively grounded metal enclosure. Conducting energy barriers shall have a sufficiently low-ohmic value to ground that the maximum credible fault current shall not expose personnel to any of the following conditions (see Figure 4.3.3.B):

1. Any voltage above 600 V for any period of time.

2. Any voltage between 50 V and 67 V for more than three seconds.

3. Between the 67 V and 600 V the voltage shall not exceed the value of 116 divided by the square root of the exposure time in seconds.

a) These limits are based on ANSI/IEEE Standard 80, Section 4 - fibrillation thresholds. Representative values are listed in Table 4.3.3.B. The values listed for ac circuits are conservative for both dc and impulse circuits.

b) Based on a total body, skin, and contact resistance of 1000 ohms, survivable fibrillation energy may be as low as 27 J in 60-Hz circuits and 50 J in dc and impulse circuits. The energy values for the ac circuit limits shown in Table 4.3.3.B do not exceed 14 J. Extrapolation of the voltage values beyond three seconds is not recommended.

4. The requirements in 1, 2, and 3 will not ensure protection of personnel from shock reaction or induced muscular paralysis. For precautions in this regard, see Table 4.3.3.B, also Chapter 3, paragraph 3.3..5 (CRT power supplies), paragraphs 4.13 and 4.14 (temporary operations), and paragraph 4.7 (protective rubber products).

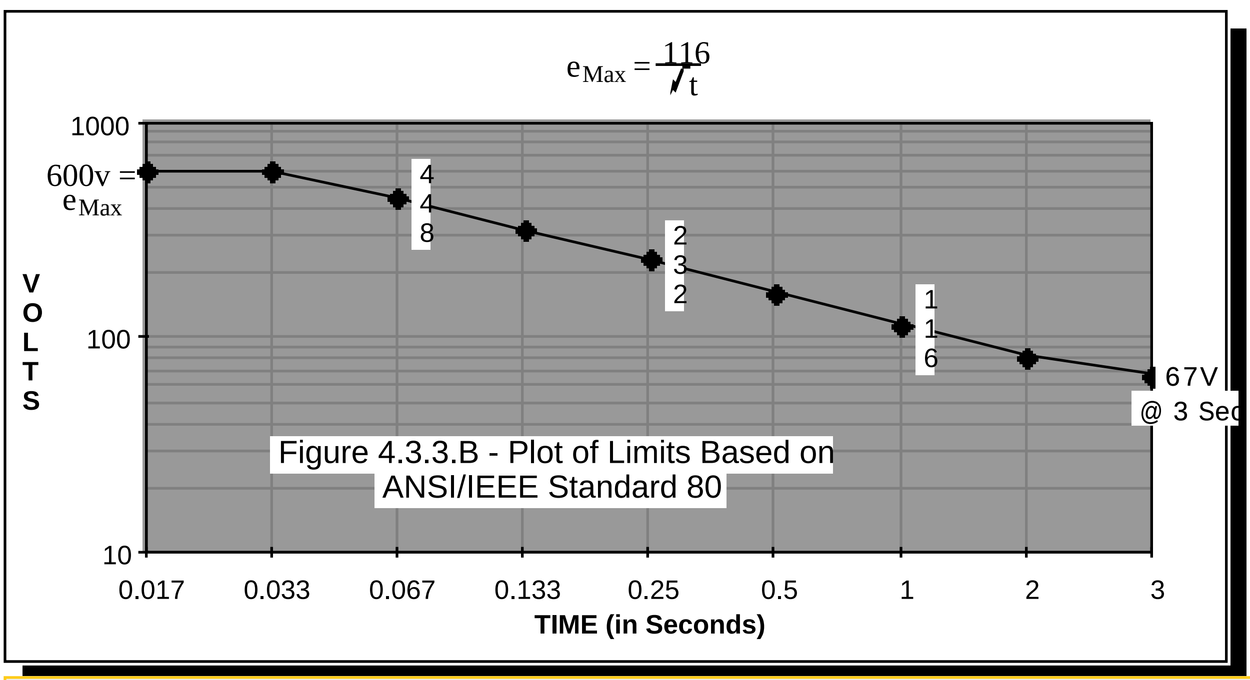

Figure 4.3.3.B - Plot of Limits Based on ANSI/IEEE Standard 80

Table 4.3.3.B - Permissible Body Current Limits
Based on ANSI/IEEE Standard 80

T_{clear} in cycles	T_{clear} in Seconds	I_{B50} in Amps	E_t, E_m, E_{tfrd} in Volts
1	0.017	*0.898	*600
2	0.033	*0.639	*600
4	0.067	0.448	448
8	0.133	0.318	318
15	0.250	0.232	232
30	0.500	0.164	164
60	1.000	0.116	116
120	2.000	0.082	82
180	3.000	0.067	67

* Upper Limit

T_{clear} = Maximum ground-fault clearing time required by the circuit-protective device.

I_{B50} = Maximum rms nonfibrilating current through the body for a 110 lb. (50-kg)

E_t (Touch V) = The potential difference between the ground-potential rise (GPR) and the surface potential at the point where a person is standing while in simultaneous contact with a grounded structure.

E_m (Mesh V) = Maximum touch voltage within the mesh of a ground grid.

E_{tfrd} (Transferred V) = A special case of E_t where voltage is transferred into or out of a substation ground grid.

Note: For a more detailed desciption of the above terms, see IEEE Standard 80.

4.3.4 Safety Barriers

Safety barriers shall be designed to restrict the time and manner in which Qualified Personnel may gain access to energy sources and to prevent or inhibit access by unqualified personnel. Safety barriers may be either of permanent or temporary construction as follows.

A. Permanent safety barriers (such as rooms, vaults, partitions, or screens) shall have sufficient structural integrity to withstand all electrical and mechanical failure modes of the enclosed energy source(s). Their access doors shall be lockable.

B. Temporary safety barriers (such as safety ropes and tapes, snow fences, or approved wooden barricades) shall be spaced far enough from unguarded live parts to prevent accidental contact by unqualified personnel. Minimum clearances specified in paragraph 4.17 shall be permitted for temporary safety barriers around areas that are accessible to Qualified Personnel only. All temporary safety barriers shall be provided with either warning devices as required by paragraph 4.13 or approved safety signs. See paragraph 4.18 for arc effects.

4.3.5 Analysis Requirements for Barriers

A. Excluding type-tested or listed equipment described in paragraph 4.5, the failure modes and effects of energy barrier designs shall be analyzed for all credible failures. Single failures and their consequences, and cascaded failures shall be considered. Consequences such as arc-over between live parts, motion of conductors due to fault-current forces, as well as inductive, capacitive, and conductive effects shall be included. The consequences of missile propagation from explosion and/or rapid energy release shall also be taken into account. The results of these analyses shall be documented.

B. Postulated failures shall be analyzed using the following criteria, which is derived from the single failure criterion of IEEE Standard 379. A barrier shall be capable of performing the desired protective function in the presence of a single failure within the barriered space, concurrent with all common-mode failures, i.e., failures occurring as a result of the single failure.

C. If analysis indicates that the energy barrier designs are unable to withstand the maximum credible fault energy, then safety barriers shall be used to exclude personnel whenever the energy source is operational.

D. The failure modes and effects of safety barriers shall be analyzed for all credible failures.

4.3.6 Examples of Acceptable Energy Barriers

A. Isolation transformers conforming to NEMA Standard ST-20 requirements and having the following features meet the requirement for two energy barriers:

1. Minimum dc isolation voltage, as measured winding-to-winding and winding-to-ground, shall equal the maximum source-voltage transient. Adequate isolation shall be verified by a successfully applied dc over-potential factory-test conducted at two times working voltage plus 1000V.

2. Grounded interwinding energy barriers having adequate clearance in air, oil, or some other insulating medium.

B. Fiber-optic links having the minimum creepage distance required by NEMA ICS-1 or NEC Table 490-24, and with dielectric clearance not subject to common-mode failure or having a grounded metal barrier between their transmitters and receivers also meet the requirements for two independent energy barriers.

C. Voltage-limiting devices (such as zener devices, thyrites, etc.) may be used as an energy barrier provided they are rated and tested to repeatedly survive the maximum credible source fault energy and peak voltage without either failing or exposing personnel to voltages exceeding those in Table 4.3.3.B. When such devices are used as an energy barrier, they must be demonstrated to retain their capability as the intended energy barrier even if they fail, i.e., they shall be designed to fail as a detectable short circuit rather than as an undetectable open circuit.

D. Resistors used as voltage dividers in high-voltage circuits shall comply with the safety criteria of Chapter 12 to meet the requirements for one energy barrier.

E. Effectively grounded metal raceways and metal cable trays installed with top and bottom covers may be used as energy barriers if they meet the analysis requirements of paragraphs 4.3 and 4.3.1. See NEC Articles 310 and 318 for ampacity correction factors for tray cable installed in covered trays.

F. Administrative controls may serve as temporary substitutes for the design features of energy barriers. Administrative controls include the use of protection on the worker such as:

1. Non-conductive hard hats conforming to ANSI Z89.2 near exposed live parts.

2. Protective devices such as flame resistant clothing for the body and safety glasses for the eyes and arc rated face shields where there is a possibility of electric arcs or flashes. The face shield shall be rated appropriate for the arc hazard that is present. Safety glasses shall be nonmetallic framed conforming to ANSI Standard Z87.1 used as primary eye protection. Nonconductive hard hats and safety glasses are issued at the C-Site Stockroom.

CAUTION
Plastic face shields are secondary eye protection and are not approved for use where there is a possibility of arcs & flying molten metal

3. Currently tested protective rubber goods, insulated tools and insulating live-line tools. Order rubber goods and tools on purchase requisitions under your cost center (see paragraphs 4.7 & 4.8). Insulated tool replacements and V-rated rubber goods are provided and tested by Electrical Safety. Insulated tools, Line tools and Ground sticks are purchased by your department and tested and replaced by Electrical Safety.

4.4 HIGH-CURRENT EQUIPMENT

Regardless of operating voltage, non-type-tested equipment and circuits rated in excess of 50 A. shall be guarded by at least one energy barrier capable of surviving any credible fault. Examples of hazards are as follows:

A. Electric-arc welding equipment and its use shall comply with Section 5.0 of this PPPL Environment, Safety, and Health Manual and Article 630 of the NEC.

B. Protect workers from arcs in conductor joints and between conductors (including ultraviolet eye burns). See paragraph 4.18, “Arc Effects.” The use of flame-resistant clothing shall be required.

C. Protect workers from the effects of fields on magnetic materials such as loose tools and inductively heated surfaces. See Chapter 9 regarding security and credit cards in high fields.

D. Conductors shall be secured to prevent hazardous movement during a short circuit or ground fault as explained in Chapter 7.

4.5 TYPE-TESTED AND LISTED EQUIPMENT

A. Commercially available equipment having a representative sample successfully tested to verify the adequacy of its design is considered type-tested. Listed equipment is approved per NEC Article 110-2. Either type-tested or listed equipment installed in accordance with the recommended industry codes and standards referenced in Chapter 3, paragraph 3.2, shall not be required to be analyzed with the barrier criteria of paragraph 4.1 or 4.2. In addition, such equipment shall be considered to have met the requirements of paragraph 4.3.

B. Unlisted and non type-tested equipment, which may be considered acceptable on the basis of documented, successful operating experience or mathematical analysis, shall be analyzed with the barrier criteria of paragraph 4.1 or 4.2 and shall meet the requirements of paragraph 4.3.

4.6 COMPLIANCE CRITERIA FOR NEW AND EXISTING ELECTRICAL SYSTEMS

A. All new high-voltage equipment installations are required to meet the isolation criteria of paragraphs 4.1 and 4.3.

B. High-voltage equipment installations that are in operation prior to May 1, 1995, are not required to meet the requirements of paragraph A. However, significant revisions or modifications to the installed equipment shall require that the entire system be analyzed and upgraded to meet the criteria of paragraphs 4.1 or 4.2 and 4.3.

4.7 PROTECTIVE RUBBER PRODUCTS

4.7.1 The use of protective rubber gloves is mandatory when working on energized circuits above 50 volts, until the circuits have been positively de-energized. Positively de-energized criteria are specified in paragraph 3.3.1 (A) in Chapter 3. Guidelines for the selection, care, inspection, testing, storage, and the use of gloves and other protective equipment for electrical work are in ASTM Specification F 1236. Employees shall visually inspect and air-test all protective rubber gloves before use as indicated below.

A. FIELD CARE AND INSPECTION OF GLOVES

1. General: Insulating equipment shall be visually inspected for damage before each use and given an air test along with the inspection. Gloves shall be returned to Electrical Safety for testing if any defects are found.

2. Perform Visual Inspection
   - a. Check for nicks, holes, tears, punctures, abrasions, or cuts.
   - b. Ozone cracks, pitting, burns
   - c. Imbedded foreign objects
   - d. Texture changes: swelling, softening, hardening, sticky, or inelastic
   - e. Other defects such as color changes in insulating material, oil, grease.

3. Perform air test
   a. Roll the cuff tightly toward the palm in such a manner that air is entrapped inside the glove. A visual inspection shall be performed for defects listed above and for leakage of air.

4. Storage of gloves and rubber products
   a. Gloves shall be stored in as cool, dark, and dry an area as possible.
   b. The location shall be free from ozone, chemicals, oils, solvents, damaging vapors or fumes, and away from sunlight and electrical discharges.
   c. Gloves shall be stored in their natural shape inside their protectors in the storage bag furnished with the gloves.

5. Glove Protectors
   a. Shall be worn over insulating gloves except for class "o" when good finger dexterity is required.
1. Rubber gloves used without protectors must be returned to Electrical Safety and retested after use.
2. When using rubber gloves without protectors personnel must use one class level higher than required for the voltage level being worked on.

4.7.2 The maximum use voltage recommended by the International Electrotechnical Commission (IEC) for each class of glove is designated as follows:

Class	ac voltage, r.m.s.	dc voltage
0	1000	1500
1	7500	11,250
2	17,000	25,500
3	26,500	39,750
4	36,000	54,000

4.7.3 Electrical Safety coordinates the testing of protective rubber products and the application of the ASTM Specifications listed below. The frequency of tests for each product category is as follows:

Product	ASTM Spec.	Frequency (months)
Gloves	F496	6
Sleeves	F496	12
Blankets	F479	12
Line Hose	F478 & this Section 2.0	12
Covers	F478 & this Section 2.0	12
(for Bushings, etc.)		

4.7.4 Rubber insulating floor matting manufactured to ASTM standard D178 is available three-eighths inch thick with anti-skid backing and non-oil resistant, corrugated surface, initially rated at 50 kV. Matting is manufactured in widths of 24, 30, 36, and 48 inches. The application should determine both the need and width. A PPPL, in-service retest specification cannot be established since no industry-consensus retest standard exists at this time. Floor matts in front of High Voltage equipment shall be provided by home cost center. Electrical Safety shall provide 4 foot sections for use by electricians to be used in lieu of insulated overshoes.

4.8 INSULATED HAND-TOOLS

Criteria for the use of insulated hand tools is specified in paragraph 3.3.3 (E) in Section 2, Chapter 3. Damaged tools will be replaced when turned in to Electrical Safety. Personnel shall return all insulated hand tools to Electrical Safety for replacement when the indicator insulation is showing through the outer jacket insulation.

4.9 LOCAL LIGHTING SWITCHES

General-use snap switches that are permitted by NEC Section 380-14 and -15 to be used on inductive loads such as electric-discharge lamps and ballasts operated over 120 V shall be clearly and permanently identified for the purpose, i.e., listed and externally labeled for the intended nominal operating voltage.

4.10 GUARDING OF LIVE PARTS

4.10.1 Live parts of equipment designed to operate above 50 V, but less than 600 V (ac or dc), shall be guarded in accordance with paragraph 110-27 of the NEC. In terminal boxes and control enclosures having circuits operated under 130 V, live parts operated over 130 V shall be guarded by barriers or cover plates requiring a screwdriver or similar tool for their removal. These barriers or cover plates shall be clearly marked to indicate the circuit voltage .

4.10.2 Live parts of equipment designed to operate over 600 V are considered high voltage and shall be guarded and labeled in accordance with Section 110-30 of the NEC.

4.10.3 High-voltage parts may be located within a vault, room, or closet, or in an area surrounded by a wall, screen, or fence. To ensure that the parts are de-energized prior to entry, either a Kirk®-type key interlock system shall control the availability of the door key or the door shall be equipped with a “fail-safe” electrical interlock. See Chapter 5, Personnel Safety Interlocks (PSI) Systems for guidelines.

4.11 HIERARCHY OF HAZARD-REDUCTION METHODS

Some hazard-reduction methods are more efficient than others. They range from the most preferred to the least acceptable method in the following sequence:

4.11.1 Design safety features utilizing energy barriers and other protective devices, which are incorporated into the design to minimize personnel-safety hazards and risks of damage to equipment.

4.11.2 Safety barriers such as rooms, grounded-metal screens, snow fences, safety tapes, insulated gloves, and insulated tools are used to separate personnel from hazards not eliminated by design features.

4.11.3 Warning devices alert personnel to the presence of hazards. Examples include annunciators, audible alarms, indicating lights, and instrumentation such as voltmeters.

4.11.4 Administrative controls include management direction and control over operations, maintenance, inspections, surveillance, and other activities that pose potential safety hazards. Examples include written procedures and verbal instructions.

4.12 REQUIREMENTS BY AREA SAFETY CLASSIFICATIONS

4.12.1 General-Access Areas

General-access areas shall meet the following criteria:

A. There are no exposed live electric parts or mechanical hazards that may cause injury in the event of accidental contact by any personnel.

B. There is no hazard to personnel in the event of equipment faults such as an explosion of capacitors.

C. “CAUTION” signs shall be placed at metal-enclosed switchgear, unit substations, power transformers, and Class E pull boxes where located in General-Access areas.

4.12.2 Limited-Access Areas

A. Limited-Access areas have live parts over 50 V and/or have insulated conductors over 300 V that are not guarded in accordance with NEC 110-27 or NEC 110-34.

B. “WARNING” signs shall be placed on the less hazardous side of entrances to Limited-Access areas from General-Access areas.

C. Limited-Access areas shall:

1. Be kept locked when authorized or Qualified Personnel are not present.
2. Have keys that are available to authorized or Qualified Personnel.
3. Be identified by warning signs.
4. Have unguarded live parts positively de-energized before unauthorized or unqualified personnel may enter for any reason. Exception: When performing observations while supervised by an Authorized / Qualified Person.

4.12.3 Interlocked-Access Areas

A. Interlocked-Access areas are potentially dangerous areas having experimental devices with unguarded live parts operating above 600 V and having 50 J or more of stored energy. Personnel access to these areas is restricted while hazardous equipment is operating or hazardous environmental conditions exist.

B. “DANGER” signs shall be placed on the less hazardous side of entrances to Interlocked-Access areas from General-Access areas or Limited-Access areas.

C. Interlocked-Access areas with energy-storage devices, when opened by normal procedures, may revert to Limited-Access areas.

4.13 TEMPORARY HAZARDOUS OPERATIONS IN GENERAL-ACCESS AREAS: PERSONNEL PROTECTION

Whenever conditions are introduced into a General-Access area such that it no longer meets the criteria for General-Access, the following precautions shall be taken:

4.13.1 Access to the area shall be guarded by a safety-barrier rope or fence placed around the perimeter of the temporarily hazardous area.

4.13.2 Adequate disconnects shall be provided in the immediate vicinity of the hazardous area so that the hazardous operation can be quickly de-energized.

4.13.3 Standard “DANGER - (state voltage) - AUTHORIZED PERSONNEL ONLY” safety signs shall be clearly displayed.

4.13.4 A Safety Watch shall be provided for the area and only Qualified Personnel shall be allowed inside the area.

4.13.5 Temporary grounding conductors shall be used to connect all ungrounded panels and exposed metal structures of portable test equipment to the nearest suitable grounding cable or bus. Due to the phenomenon of “skin effect,” grounding conductors in extension cords should not be relied upon for this purpose if the equipment being tested has a fast rise-time fault characteristic (in excess of 10kHz). Such equipment shall be grounded with braid or ribbon-type copper conductor. See paragraph 4.15.5 for additional information.

4.13.6 Approval of the cognizant engineer or Accountable Technical Individual (ATI) shall be obtained before energizing equipment.

4.13.7 The area shall meet requirements of a general-access area when the Safety Watch leaves.

4.13.8 A Hazard Analysis shall be performed and an approved procedure describing the temporary operation shall be written by the cognizant engineer and concurred with by the respective Division Head and ES&H Division Head or designee.

4.14 TEMPORARY HAZARDOUS OPERATIONS IN OTHER THAN GENERAL-ACCESS AREAS: PERSONNEL PROTECTION

The cognizant engineer or lead technician may permit temporary operations, with personnel in a limited-access or an interlocked area, under the following conditions:

4.14.1 The cognizant engineer or lead technician has determined with approval from the Division Head that it is absolutely necessary to enter and troubleshoot or test equipment in an energized condition.

4.14.2 At least two qualified persons shall be assigned to the temporary operations, both of whom are completely familiar with emergency procedures and one of whom shall be designated as Safety Watch.

4.14.3 A statement defining the reasons for entry shall be recorded in the operating log of an interlocked area or otherwise posted at the entrance(c) to an area. The statement shall include the names of all personnel permitted entry and shall designate a Safety Watch. The number of personnel authorized to enter shall be restricted to the minimum essential to do the work including the Safety Watch.

4.14.4 A Hazard Analysis shall be performed and the work shall be thoroughly planned beforehand by the cognizant engineer or lead technician and the technical personnel assigned to the temporary operations. An approved procedure shall be used.

4.14.5 Current operational restrictions of the device or system being tested shall not be exceeded.

4.14.6 Readily accessible emergency egress shall be provided (e.g., blocked-open door, kick-out panel, or other means concurred with by the ES&H Division Head or designee).

4.14.7 All emergency-shutdown pushbuttons (E-STOPs) related to the systems within the interlocked area shall be satisfactorily tested in accordance with Chapter 5, paragraph 5.8.4, before the temporary operations begin.

4.15 GROUNDING

4.15.1 The general requirements for grounding and bonding of electrical-wiring systems and equipment are covered in NEC Article 250 and NESC Section 9.0 with the following exceptions and additions:

A. Isolated equipment-grounding conductors traceable to a single-point ground may be used in experimental-device power, control, and diagnostic systems, after a technical specification and fault analysis have been provided by the cognizant engineer to the ES&H Division Head or his designee for review and approval.

B. In addition to the equipment grounding conductor, which is routed with its associated circuit,

1. a bonding conductor shall be installed between the facility ground grid and fixed electrical equipment operated between 480 V and 2 kV.
2. A redundant bonding conductor should be installed on such equipment operated over 2 kV.
3. The bonding conductor preserves at least one low-impedance path to the power source should a grounding-conductor connection disconnect. The bonding conductors reduce potential differences between equipment and conductive surfaces of the working area.

C. Guidelines for ac power substation grounding practices, including procedures for calculating maximum step-and-touch potentials, are in IEEE Standard 80. Recommended practices for grounding industrial and commercial power systems are in IEEE Standard 142. Recommended grounding practices for emergency-power and standby-power systems are in IEEE Standard 446.

D. Requirements for effective lightning protection systems are in NFPA-780 and UL-96A.

E. Requirements for the control of static electricity may be found in NFPA-77.

F. The NEC Section 250-146, permits the use of spring-type mounting straps of receptacles as a grounding conductor. Due to their unreliability, all new receptacle installations shall use a bonding jumper between the ground (green screw) terminal and the equipment grounding conductor within the outlet box.

4.15.2 Equipment supplied from an energy-storage unit is capable of delivering high-level potential wave fronts to its cases or enclosures. Considering skin-effect in a grounding conductor, described in paragraph 4.15.5, particular care shall be exercised to provide proper low-impedance return-path grounding. The potential between enclosures and nearby building ground shall be limited to less than 50 V, even under fault conditions. The path to ground from circuits, equipment, and conductor enclosures shall:

A. Be permanent and continuous.

B. Have capacity to conduct safely any fault current likely to be imposed on it but in no case shall it be smaller than indicated in NEC Table 250-122 or equivalent for frequencies above 60Hz.

C. Have sufficiently low impedance to limit the voltage to ground and to facilitate the operation of the circuit-protective devices in the circuit.

D. Be designed to prevent excessive voltage between structures and equipment accessible to personnel. The paths of grounding conductors to the grounding electrode(s) shall be separated based on class as required by NESC Rule 97.

4.15.3. When a control or metering console, rack, or other enclosure having a single ground connection interfaces with remote high-voltage equipment, an extremely hazardous condition could prevail if the grounding conductor is removed either accidentally or deliberately. The possibility of accidental loss of a grounding connection shall be virtually eliminated by physical arrangement or mechanical construction. If a ground is intentionally removed for any purpose, the power system shall be positively deenergized and shall be locked-out and tagged-out in accordance with PPPL ESH-016 tagging procedures using the criteria for positively-deenergized circuits and equipment specified in Chapter 3, paragraph 3.3.2 (A).

Exception: For certain tests, if it is absolutely necessary to turn on the high voltage with the ground removed, it may be done only with the specific prior approval of the Cognizant Engineer or Accountable Technical Individual (ATI) of the device or system, who then becomes directly responsible for personnel safety during these tests. The tests shall follow the requirements of paragraph. 4.14.

4.15.4 To meet NEC splicing requirements for grounding electrode conductors (NEC Article 250-50 and 250-64c) when neither exothermic welding nor listed grounding conductor connections are feasible, the PPPL silver brazing process shall be considered an approved alternative when it is performed by a person who is qualified in the technique.

4.15.5 Due to "skin effect," circuits having fast rise-times, i.e., the discharge circuits of charged capacitors or inductors, require flat rather than round cross-section grounding conductors. The depth of current flow in a copper conductor as a function of frequency is given by :

$$d = \frac{2.6}{\sqrt{\mu \times f}}$$

Where d = depth of current (mils); µ= permeability = 1; and f = frequency in MHz; temperature is considered to be constant.

A. Then, at: 60 Hz, d = 335 mils
1 kHz, d = 82 mils
10 kHz, d = 26 mils
40 kHz, d = 13 mils
100 kHz, d = 8.2 mils

B. Compare the current penetration depth to the cross-section area of standard cable sizes at different frequencies. A 500 kcmil copper wire is about 800 mils in diameter. The ratio of current penetration area to the conductor cross-sectional area (in kcmil) at 60 Hz is 449/500, or about 90 percent. Smaller conductors have a 100 percent ratio, i.e., having no change in impedance characteristics due to "skin effect." At 10 kHz, a #12AWG would have a current penetration ratio of 2124 cmil/6650 cmil or about 32 percent. If used in circuits having fast rise times, the diminishing current penetration depth effectively increases the impedance in the fault current return path and slows the functioning of the overcurrent protective device. Either a flat, solid conductor or a flat, braided conductor would be more appropriate for equipment grounding purposes at higher fault-current frequencies.

C. Based on the above, grounding conductors with round cross-sectional area shall be limited to use on systems where the fault currents have rise-times of 10 kHz and less.

4.16 WORKING ON GROUNDED METAL SURFACES

Grounded metal surfaces of electrical enclosures, tanks, vacuum or pressure vessels, structures, etc., are well grounded and considered good conductors relative to other floor surfaces such as dry concrete or vinyl tile. Before stepping onto metal surfaces or entering into metal enclosures, the following precautions shall be taken:

4.16.1. Ground-fault circuit interrupters (GFCIs) shall be provided for portable electrical equipment in use by personnel. GFCI's shall be tested prior to use.

4.16.2 Portable hand-lamp cords shall have step-down transformers to restrict lamp operating voltage to 50 V ac or less. The operating voltage of a typical portable hand-lamp is 24 Volts.

4.16.3 Shoes shall be visually inspected to ensure they are made with rubber soles and heels, which have not picked up any metal objects such as pins, nails, or tacks.

4.17 CLEARANCES

Adequate clearances are required to safely perform construction, operation, and maintenance tasks. The following documents define safe access, working, and egress clearances which will reduce shock hazards:

A. Around electrical equipment operated at 600 V and below when exposed parts are energized- NEC Article 110-26 and NESC Rule 125A.

B. Around electrical equipment operated above 600 V, either energized or de-energized - NEC Article 110-34 and NESC Rule 125B.

C. Means of exit from rooms and spaces where electrical-supply conductors or equipment are installed - NESC Rule 113: Electrical equipment inside switchgear rooms - NESC Section 18, Rule 180.

D. Outside, overhead electrical-supply and communication lines - NESC Section 23 and OSHA 29 CFR 1926.950 through 1926.960.

E. Outside, underground (UG) electrical-supply and communication lines and equipment:

1. UG conduit systems - NESC Rule 320B.

2. Manholes, handholes, and vaults - NESC Rule 323.

3. Direct-burial cables - NESC Rule 352 through 354.

4.18 ARC EFFECTS

Clearances sufficient to reduce shock hazards may not be adequate to avoid the hazards of electric arcs that occur over greater distances. The effects include overpressure and thermal stress. Nonionizing radiation in the visible and ultraviolet spectrum may be present in sufficient amounts to be a concern in very large arcs. If a task involves the live-line work method performed on high energy circuits operated over 250 Volts or non-type-tested high current circuits, a flash hazard analysis should be included in the procedures required in paragraph 3.3.3 in Chapter 3. Sample calculations of flash protection boundaries may be found in Attachment F in Chapter 17, and NFPA 70E, Chapter 2, paragraph 2-1.3.3.2 and Part II, Appendix D.

The effects of electric arcs are discussed in detail in the Attachments to this Section 2.0 and NFPA 70E.

To minimize risk during a switching operation, ensure that all protective energy barriers are in place and secured and the proper PPE (Personal Protective equipment) including FR clothing is worn. Stand to the side of the enclosure and open or close the device with a smooth and continuous motion on its operating handle. An erratic motion may cause unnecessary and potentially damaging arcing across blade contacts. PPPL policy shall be to perform switching operations in a de-energized state or remotely when possible.

4.19 LOCKOUT/TAGOUT PROCEDURES

Generic lockout/tagout (LO/TO) procedures are described in ESH-016. Chapter 3, paragraph 3.3.2 (A), in this Section 2.0 identifies the proper steps to positively de-energize energy isolation devices in electric circuits. Use the isolation criteria in Chapter 4 together with verified single-line diagrams and circuit directories to decide how many and what kind of isolation devices are appropriate to the risk. Examples of equipment failure and human error are given in attachment 1 of Chapter 17, Section 2..

4.20 SAFETY SIGNS/TAGS

Authorized persons with jurisdiction over electrical systems and equipment having live parts shall ensure appropriate facility safety signs and tags are used to alert employees to possible hazards or special alignment of system components. Criteria for the use of signs are in ESH-002. Criteria for the use of tags are in ESH-001. All tags are to be filled out completely and are not to be removed without the consent of the cognizant person or their supervisor. Danger tags shall not be removed without the consent of the cognizant individual or in his absence his supervisor along with safety shall walk the system down prior to removal of a Danger tag.

4.21 AS-BUILT DRAWINGS

Drawings, that are important for safe operation or maintenance of electrical systems or equipment, shall be kept up-to-date, as-built or as-installed. Single line diagrams and panelboard circuit-directories are considered important electrical drawings. It is the policy of this Laboratory that the AC Power Section shall be advised of all proposed changes to switchboards, panel-boards, lighting or receptacle panels, and other load centers that are typically shown on either the single line diagrams or panel-board circuit-directories. Failure to comply with the above will result in de-energization and tagging out of the unauthorized changes.

4.22 DEACTIVATING AND DECOMMISSIONING

A. When equipment is deactivated (shut down with no definite plans for future use), the following precautions shall be taken:

1. Circuits shall be positively de-energized, and individual capacitors shall be shorted.

2. “Out of Service” signs shall be conspicuously applied to equipment involved to provide guidance in the event of an emergency.

3. All nonessential safety signs shall be removed from the equipment.

B. In addition to the above, when equipment is decommissioned, all cables shall be either removed or left in a safe condition so that no live part is exposed in compliance with PPPL Policy No. P-046. A safe condition exists when power, lighting, and NEC Class 1 nonpower limited cables which are either not in use or abandoned in place have:

1. Both ends of each conductor properly taped or properly secured on enclosed terminal blocks.

2. An accident prevention tag at both ends of power cables above 50 volts. Use " WARNING" tag if conductors are subject to common mode failure with adjacent active energized cables (this represents a hazard level between "CAUTION" and "Danger"...ref 29CFR 1910.145(f)(7)); all other circumstances use a "CAUTION" tag per procedure ESH-001. Where practical, conductors and cables may be gathered together as one or more bundles using one tag per bundle.

3. Note the location of the other end of the cable on the tag and what procedure number authorized its decommissioning and disconnection.. Also note that the cable is Out-Of-Service (OOS).

4.23 SAFING FOR REMOVAL OF ELECTRICAL EQUIPMENT / WIRING

The safe removal of Electrical equipment and associated wiring requires a well thought out method for removing the hazards associated with some adjacent equipment that may be energized. An assessment of all the work and the associated hazards that may be present is required prior to commencing the work. All personnel must be familiar with the hazards present and have been trained in the tasks that are to be performed. Below are the minimum requirements for the removal of electrical equipment.

A. Prerequisites for safing, disconnection, and removal of equipment .

1. A Hazards assessment shall be conducted by the cognizant person, ES & H representative, and AC Power, to establish special safety/ job requirements.

2. A procedure shall be issued identifying the equipment to be removed, sources of power and safing steps to be taken prior to the equipment removal sequence. The associated drawings, and permits for the work shall be provided and a job walkdown with the technical staff to review special safety/job requirements shall be performed prior to the start of work.

3. All wires are to be considered energized until they have been tested and removed following the guidelines in paragraph 3.3.2 (A) of ES & HD 5008, Section 2, chapter 3.

4. Any abnormal situations encountered in the field (live wires, unidentified wires), shall be addressed by contacting the field electrical supervisor or engineer.

B. Minimum requirements for the safing and removal of wiring and equipment

1. Locate and identify power sources to equipment to be removed.

2. Insulated gloves and tools, FR clothing, hard hats and Safety glasses shall be used with energized equipment. See paragraph 3.3.3 of this section for added requirements for working on energized equipment.

3. Verify testing equipment is working before and after testing.

4. Check to see if the equipment to be removed has a ground wire attached. If not, ground the equipment prior to removal of existing wiring.

5. Turn off power at the source and test wires at the load end for the absence of voltage. Disconnect/cut the wires immediately at both ends and tape the ends. The rule is to test all cables prior to cutting or removing. DO NOT REMOVE GROUND WIRES until all other wires have been removed.

6. Insulate all cut or removed cable ends. Construction schedules may leave jobs incomplete, therefore ends of cables shall be taped so that no "uninsulated pigtails" are out in the field.

7. If cables are to remain in cable trays or conduits, the taped ends of the cables must have a tag attached to each end of the cable. See para. 4.22 B for tagging instructions. Approval of the Engineering Department Head is required to abandon cables in place. The foregoing is required by PPPL Policy P-046.

8. When all cables have been removed from the equipment, the only cable remaining shall be the equipment ground wire which is the last wire to be removed.

9. All changes to panelboards at PPPL must be coordinated through the AC Power Section. See para 4.21 above for as- built drawings. All circuits that have been disconnected shall be labeled as spare in the circuit index and a copy sent to AC Power for drawing and panel schedule updates.