FESHM 9180: HAZARD MITIGATION FOR ELECTRICAL WORKERS

WORK PRACTICES AND SELECTION AND USE OF HAZARD PROTECTIVE CLOTHING AND PERSONAL PROTECTIVE EQUIPMENT

Revision History

Author	Description of Change	Revision Date
David E. Mertz	Complete revision to conform with NFPA 70E requirements, current FESHM chapter format, and included the ESS Simplified PPE Tables as a Technical Appendix.	5 Year Review May 2019
Michael J. Utes	Section 9 Number 17 clarified that PPE is to be worn until zero voltage verification is assured.	February 2013
John Anderson Jr, and Michael J. Utes	• Updated NFPA 70E Standard name and year. • Updated ASTM standard for flame-retardant clothing. • Corrected definition for Limited Approach Boundary • Added definition of Arc Rating • Updated definition of a Qualified Electrical Worker • Updated definition of Working on Energized Live Parts • Added Division / Section / Center • Defined diagnostic and manipulative energized electrical work activities • Added reference to Electrical Safety Subcommittee Guidance Sheets for Fermilab • 10. Updated the Special Requirements and Responsibilities section	5 Year Review August 2011

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1.0 INTRODUCTION AND SCOPE

Electrical workers are often exposed to specific hazards associated with electricity that pose risk of physical injury. These hazards include shock, electrocution, arc blast, arc flash and electrical burns. These exposures are present for work activities that involve AC Power Distribution System and utilization equipment as well as DC systems.

Electrical safe work practices coupled with the selection and use of protective clothing and personal protective equipment (PPE) are the primary means of mitigating these specific hazards. Special steps of mitigation may also be specified in an individual written Hazard Analysis (HA) for work that involves a high-risk hazard, or two or more low-risk hazards as defined in FESHM Chapter 2060. non-routine or especially hazardous work activities. The purpose of this Chapter is to outline work practices and provide the requirements and guidance in the selection of PPE to reduce overall risk for the electrical worker to an acceptable level. It is imperative that any work within the limited approach and arc-flash boundaries of circuits be performed with an acceptable low risk to personnel.

The scope of this Chapter is limited to work activities on AC Power Distribution Systems that operate at 600 VAC and less (NEC "Low Voltage" Class), DC systems 50 volts or higher with a stored capacity exceeding 1kWh, and on utilization equipment that present electrical shock, arc-flash, or thermal hazards. Only qualified electricians shall perform installation, maintenance and repair of AC electrical power distribution systems. Only qualified electrical workers shall perform installation, maintenance and repair of electrical utilization equipment.

Many of these activities typically involve the 277/480 and 120/208 VAC distribution systems commonly found throughout the Laboratory. Work on systems and equipment having operating or supply voltages above 600 VAC is specific to a smaller range of work groups and is performed only by specially trained and qualified electrical workers. The work practices and recommended PPE associated with these higher voltage systems and equipment are to be developed separately by management of these selected work groups, although many of the requirements of this Chapter may be applicable.

The stated requirements, guidelines and recommendations of this Chapter have been developed consistent with the requirements found in Articles 120 and 130 of NFPA 70E "Standard for Electrical Safety in the Workplace" 2018 Edition.

2.0 DEFINITIONS

Arc Rating – The value attributed to materials that describe their performance to exposure to an electrical arc discharge. The arc rating is expressed in cal/cm^2 and is derived from the determined value of the arc thermal performance value (ATPV) or energy of breakopen threshold (E_{BT}) (should a material system exhibit a breakopen response below the ATPV value). The Arc Rating is the lower of ATPV or E_{BT}.

Energized Live Parts - Conductors, buses, terminals, or components that are electrically connected to a source of potential difference that is hazardous. Insulation or barriers normally protect such parts. Work activities frequently involve temporary removal of insulation and/or barriers thereby presenting a hazard to the worker. Electrical conductors that normally operate at a potential different than the earth is regarded as energized until proven to be de-energized.

Hazard Analysis (HA) – Hazard Analysis is a tool used to assess hazards and plan work accordingly. The anticipated phases of work are identified, as are all hazards associated with each phase, and the work processes to be employed to eliminate or reduce those hazards are determined.

Limited Approach Boundary – An approach limit at a distance from an exposed live part within which a shock hazard exists. Working inside this boundary is limited to Qualified Persons. Where there is a need for an unqualified person(s) to cross the Limited Approach Boundary, a qualified person shall advise him or her of the possible hazards and continually escort the unqualified person(s) while inside the Limited Approach Boundary. This distance is nominally within three feet six inches (3ft. 6 in.) of uninsulated or exposed non-movable energized live parts less than or equal to 750 volts phase to phase. (NFPA -70E Table 130.2(C))

Normal Operating Condition - A normal operating condition exists when all of the following conditions are satisfied (1) The equipment is properly installed (2) The equipment is properly maintained (3) The equipment is used in accordance with instructions included in the listing and labeling and in accordance with manufacturer's instructions (4) The equipment doors are closed and secured (5) All equipment covers are in place and secured (6) There is no evidence of impending failure.

Qualified Person or Qualified Electrical Worker is an individual trained and knowledgeable of the construction and operation of equipment or a specific work method and trained to recognize and avoid the electrical hazards that might be present with respect to that equipment or work method. A Qualified Person possesses the skills and techniques necessary to distinguish exposed energized electrical conductors and circuit parts from other parts of the electrical equipment; and the individual is able to determine the nominal voltage of the exposed energized electrical conductors and circuit parts. Training requirements for the Qualified Person are set forth in NFPA 70E Article 110.2 (A)(1). A person can be considered qualified with respect to certain equipment and methods yet be unqualified for others.

Working Near Energized Live Parts – Any activity inside the limited approach boundary.

Working on Energized Live Parts – Coming in contact with energized electrical conductors or circuit parts with the hands, feet, or other body parts, with tools, probes, or with test equipment, regardless of the personal protective equipment a person is wearing. There are two categories of "working on": Diagnostic and Manipulative.

Diagnostic Energized Work is work **ON** exposed energized electrical conductors or circuit parts. LOTO verification, the process where the worker determines by conclusive test that an electrical circuit is either energized or de-energized, is a common diagnostic energized work activity. Examples of other diagnostic energized work activities include troubleshooting, inspection, measurements, and testing of systems or equipment including voltage and current measurements, circuit and signal tracing, and thermal imaging. Diagnostic Energized Work does not make any physical change to the equipment.

Manipulative Energized Work is work performed **ON** exposed energized electrical conductors or circuit parts where a circuit connection is being closed or opened. Examples of manipulative energized work activities would include replacement of a bolt-on circuit breaker in an energized panel board, tightening connections, replacing a duplex receptacle, switch, or fluorescent light ballast without de-energizing the associated branch circuit. Manipulative energized work activities are allowed only under special circumstances and must be approved by the Fermilab Directorate.

3.0 RESPONSIBILITIES

Division/Section/Project Heads shall provide necessary resources to assure implementation of the requirements of this Chapter, including provision of personal protective equipment (PPE), tools, and equipment that is not stocked by the stockroom or furnished through the rubber insulating glove program. The D/S/P shall provide the periodic testing required by regulation of any PPE, tools, and equipment not part of the ES&H rubber insulating glove program.

The ES&H Section shall develop and provide training as necessary in the various elements of this Chapter and in the use and care of PPE. Electrical training requirements are found in FESHM Chapter 9100. The ES&H Section shall provide rubber insulating gloves to affected trained electrical workers and administer the periodic testing program required by regulation.

The Facility Engineering Service Section shall stock in the Fermilab stockroom Arc-Rated coveralls, electrically rated face shields, electrically rated hard hats, and double layer switching hoods.

4.0 POLICY

Any work on electrical systems or equipment that has hazardous electrical energy shall preferentially be performed with the equipment de-energized. Exceptions include troubleshooting, inspection, measurements, and testing activities that require the system or equipment under examination to be energized in whole or part. Additional steps and approvals are required for manipulative work on energized systems. These requirements are found on the Electrical Hazard Analysis and Work Permit. Signature approvals of the Division/Section/Project Electrical Coordinator, the area Division/Section/Project Head, and the Fermilab Directorate are required. The signature of the FESS Head is also required if FESS Operations Department electricians are working within or for another division/section/project. Prior to granting approval, these individuals shall assure themselves that it is necessary to work on the system in an

energized condition and not simply a matter of convenience, and that appropriate safety measures have been or will be implemented.

Only qualified workers shall perform work on or near uninsulated or exposed energized live parts.

All qualified workers shall perform work in accord with safe work practices that include the use of personal protective equipment.

All electrical work activities shall be conducted to minimize the risk of injury from credible hazards to an acceptably low level.

5.0 DISCUSSION OF ELECTRICAL HAZARDS

Primary electrical hazards include shock, electrocution, arc flash, arc blast and electrical burns. The actual risk to a worker involved in electrical work activities is determined by the particular work to be performed. Voltage and current alone do not determine the risk. Risk is determined by both the likelihood of occurrence and severity of the of an incident. The potential severity of an electrical incident is determined by voltage, available current, under both normal and fault conditions, duration of exposure, and proximity of the worker. The risk assessment process is described in the Quality Assurance Manual Chapter 12030, *iTrack Procedures and Risk Assignment*. Available current varies by design at different points in the AC power distribution circuit. Equipment design, for either power distribution or utilization equipment, can either increase or lessen exposure to electrical hazards. For example, incoming mains are separately shrouded in panelboards of newer design thereby significantly lowering the risk to the worker for energized work in the panelboard.

5.1 Electrical Shock

Protection against electrical shock, electrocution and electrical burns involves preventing any part of the body contacting exposed energized conductors whereby the body becomes part of the electrical circuit. The amount of current, path of the current and duration determine the extent of personal injury. The human body can detect AC currents as low as one milliampere. Currents over five milliamperes may interrupt respiration and pulse and may be fatal. Electric shock can induce pain, muscular contraction and paralysis, asphyxiation, heart fibrillation and paralysis, and tissue burning, depending on current magnitude, duration of the shock, and the individual's physiology. Work procedures, insulated tools and insulating PPE are the primary means of avoiding electrical shock, electrocution and electrical burns. Tools and PPE must have insulating voltage ratings in excess of the actual voltages encountered in the work activity. Types of PPE most often used to avoid these hazards include electrically rated gloves and dielectric insulating mats.

5.2 Arc Flash and Arc Blast

Arc flash presents risks different from electric shock. Untreated clothing that ignites during an arc incident will increase burn severity. Where high arc currents are involved, burns from such arcs can be debilitating and the ignition of clothing can occur even when several feet away. While arc flash can result from electrical equipment malfunction, its occurrence is often the result of inadvertent contact with exposed electrical conductors or misapplication of work practices. The level of hazard presented by arc flash is determined by available fault current, duration of the fault current and physical proximity of workers to the arc flash. Accurate quantification of the arc flash hazard can be accomplished only by an arc fault analysis of the circuit, which quantifies arc fault current and duration. Performing such an engineering analysis requires detailed knowledge of the circuit, equipment specifications, wire sizes and lengths, conduit sizes, motor loads, and fuse and circuit breaker characteristics.

Arc flash is a fault current existing in a conductive plasma of molten metal and ionized air. Exposures are measured in calories per square centimeter. Protection against arc flash involves shielding the body from the arc flash radiation. Protective clothing and/or equipment shields the hands, face, eyes, and body from arc flash. In an arc flash event, adequate protective clothing will prevent clothing ignition induced by the arc flash and limit thermal burns to the threshold between first and second degree. Shock and Arc flash PPE is not required to provide protection against the shock wave or ejecta of an arc blast, though such clothing may also offer some incidental protection against these hazards.

NFPA 70E Article 130.5(G) permits the use of the Incident Energy Analysis Method for determining correct arc-flash PPE. This method may be adopted by individual Fermilab D/S/P. D/S/Ps shall not adopt this method piecemeal but shall choose to follow either this method or the methods identified elsewhere for the entirety of their facilities and experimental equipment. A transition period executed according to a planned schedule will be permitted. D/S/Ps adopting the Incident Energy Analysis Method will be responsible for providing their employees with any of the PPE specified in NFPA 70E Table 130.5(G) that is not required under the method specified elsewhere in this Chapter.

While an incident energy analysis of the circuit is not always readily afforded, such analysis can demonstrate reduced risk. Rarely, certain situations can be more dangerous than the conservative assumptions on which the tables are based, and additional levels of PPE are appropriate.

The “two-second rule” has been a contentious matter in performing incident energy analyses. When applied, incident energy calculations are terminated at an arbitrary two seconds after the fault is initiated, regardless of whether the upstream overcurrent protective device has operated. This “rule” is meant to be applied where the fault current is low enough that the overcurrent protective device does not act within a few cycles to clear the fault but operates as if the fault were an overload current to be cleared in several seconds or minutes to prevent thermal damage to conductor insulation. The “two-second rule” acknowledges that, where

possible and able, a person close to an arc-flash event will swiftly remove themselves from close proximity to the arc-flash. The "two-second rule" shall not be used as a default condition for performing incident energy analyses at Fermilab. However, if a completed incident energy analysis has equipment for which the clearing time exceeds two seconds, this "rule" may be applied if (1) the physical location of the equipment and its surroundings permit a worker to safely and rapidly exit the vicinity of an arc-flash, (2) and the nominal system potential is less than 600 volts.

As documented in ESS Determination 2019-02, the limited range of transformer types and sizes at Fermilab and the use of conservatively long fault clearing times allows the Laboratory to establish a Default Arc Flash Boundary of 4 feet for AC power distribution systems operating at 600 volts and under. Because DC systems do not employ transformers, this default boundary does not apply to them, and the ESS Simplified Arc-Flash Guidance Table for DC Systems includes Arc Flash Boundaries based on Table 130.7(C)(15)(b) in the 2018 NFPA 70E.

5.3 Equipment Condition and Condition of Maintenance

The ability of electrical equipment to protect workers from electrical hazards is affected by its condition. Metallic components, primarily conductors, enclosures, and raceways, are compromised by physical abuse and corrosion. Non-metallic components, primarily insulation, barriers, and non-conductive structural supports are also susceptible to physical abuse, as well as temperature extremes, chemical attack, radiation, and age-related deterioration. Mechanical actions can be compromised by deterioration of lubrication. Certain components of the electrical distribution system require maintenance to help assure their correct operation. This will be addressed in a new FESHM Chapter on Safety-Related Electrical Maintenance.

Before electrical work proceeds, equipment to be serviced must be visually inspected to determine if it is in a Normal Operating Condition, if electrical equipment is not in a Normal Operating Condition, additional measures may be required to adequately protect workers.

5.4 Likelihood of Occurrence

Certain tasks are considered to have a negligible likelihood of an arc-flash event occurring while the task is being performed. Based on NFPA 70E Article and Table 130.5(C), a worker and her or his direct supervisor may together agree to waive the requirements for arc-flash PPE when performing the following tasks:

1. Reading a panel meter, including operating a phase selector switch for that meter.
2. Performing infrared thermography or other non-contact inspections while remaining outside the Restricted Approach Boundary (RAB). This does not include the opening of equipment doors or covers.
3. Working on control circuits operating at less than a nominal 125 volts AC or DC, provided there are no other exposed circuits at nominal voltages in excess of 125 volts. This includes opening and hinged doors for access.

4. Visual examination of cables provided the cables are not manipulated.
5. Insertion and removal of single or multicell units in an open-rack DC battery system.
6. Maintenance of a single cell in an open-rack DC battery system.

Certain additional tasks are considered to have a negligible likelihood of an arc-flash event occurring while the task is being performed only if the equipment on which the task is performed meets the criteria for Normal Operating Condition as given in Article 2.0 of this Chapter, and arc-flash PPE requirements may be similarly waived for them:

7. Operation of a switch, circuit breaker, or motor starter.
8. Voltage testing on individual battery cells or multi-cell units.
9. Removal and installation of covers for equipment such as raceways, junction and pull boxes, and cable trays in which there are bare energized conductors and circuit parts.
10. Opening a panelboard hinged door or cover to access dead-front fuses or circuit breakers.
11. Removal of non-conductive battery cell interconnection covers.

6.0 REQUIREMENTS

1. The conduct of any work on any electrical systems or equipment that has hazardous electrical energy shall be performed in accordance with the policy stated above.

2. All work involving electrical hazards shall be planned as described in FESHM Chapter 2060, *Work Planning and Hazard Analysis*. A written Hazard Analysis is also required when a high-risk hazard, or two or more low-risk hazards as defined in FESHM Chapter 2060 Appendix B are likely to be encountered. Refer to FESHM Chapter 9100 Section 5.2 and Chapter 9120 Section 4.3.a for circumstances in which the use of the *Electrical Hazard Analysis and Work Permit* is required or recommended. The plan should anticipate and accommodate events that have the reasonable possibility of adversely affecting the safe conduct of the work activity. Changes in the scope of work that could result in work on electrical equipment not in a safe working condition or result in exposure to other hazards shall cause work to be paused and the work plan and hazard analysis to be revised to account for the changed conditions.

3. Communicate with other members of the work group. Designate a Person in Charge. If the switching required to obtain an Electrically Safe Working Condition will be performed by anyone other than the Person in Charge or someone under her or his direct supervisions for the work to be done, the person performing this switching shall also be designated in the work plan.

4. Determine the Limited, Restricted, and Arc-Flash boundaries. Where an arc-flash hazard analysis has determined the arc-flash boundary and required PPE, this information shall be used preferentially over the Fermilab Default Arc Flash Boundary and ESS Simplified Tables for arc flash PPE based on equipment type. Mark the more distant of the Limited or Arc-Flash boundaries with cones, warning tape, or other barriers to deter unqualified persons from entering. Spaces to which unqualified persons do not have ready access,

such as fenced switchyards and dedicated electrical rooms, do not require additional barriers. Boundaries must be identified in the Hazard Analysis and made obvious to qualified workers to minimize error precursors. These shall also be marked with cones, warning tape, or other barriers, or a sign reading "RAB = NN feet" in at least 48-point type is displayed above the equipment being serviced, unless one these sets of conditions are met:

a. A single piece of equipment operating with a maximum potential of under 750 volts is being serviced by a single crew for no longer than a single day.
b. All work prior to establishing an Electrically Safe Work Condition will be done without any persons or conductive objects entering the RAB (appropriate fully insulated tools such as hot sticks are permitted).

5. Conductive articles of jewelry and clothing, such as watches, bands, bracelets, rings, necklaces, belt buckles or unrestrained metal frame glasses that could reasonably be expected to contact energized conductors are not permitted inside the RAB, unless such articles are rendered non-conductive by covering with an insulating means adequate for the maximum voltage present.

6. Handling of conductive materials, tools, and equipment within the shock and arc-flash boundaries shall be minimized and done only when non-conducting or insulated equivalents are not available. Within the RAB they must be directly part of the electrical work being performed, and within the Limited Approach Boundary they shall be handled in a deliberate manner to avoid contact with energized conductors or circuit parts. Doors and hinged panels shall be held in position during work if there is a hazard of the door or panel contacting energized parts or forcing a person into contact, or if the movement of the door or panel creates other hazards.

7. LOTO verification of zero electrical energy (zero voltage verification, or ZVV) shall follow a three-step process consisting of verifying the operation of the test instrument on a known reference source, performing voltage measurements (several measurements are likely to be required), and reverifying test instrument operation on the reference.
   a. Some equipment at Fermilab have voltage-testing contacts on the enclosure exterior. These contacts have series resistors that limit available current to non-hazardous levels. These may be used for ZVV only if measurements at the terminals confirming presence of normal voltage are made immediately prior to performing the LOTO isolation step.
   b. Permanently-mounted test devices that are listed and labeled for verifying zero voltage are permitted to be used for ZVV. The face of the device must be marked to indicate this purpose, or laboratory management must have applied an equivalent label adjacent to the device. The devices must be used in accordance with the manufacturer's instructions. Voltage indicators that are not listed and labeled for ZVV use are not to be used for ZVV, though they may be used to perform a preliminary check.
   c. Use of non-contact devices for ZVV is permitted on electrical systems normally operating at over 1000 volts, provided that an equipotential zone is established, using

temporary protective grounding equipment such as grounding cables, prior to lifting electrical hazard boundaries or workers removing shock and arc-flash PPE.

d. When the reasonable possibility exists for hazardous induced voltages of stored energy exists, temporary protective grounding equipment such as grounding cables or hard-ground sticks shall be used. The equipment used shall be sized to cause upstream overcurrent protective devices to operate or to limit voltages that could be present to non-hazardous levels.

8. Zero Voltage Verification shall be repeated anytime the personnel performing work leave the work area unattended.

9. Workers who may be exposed to the risk of electric shock shall wear adequately rated rubber insulating gloves with leather protectors. The rubber insulating gloves used shall have been issued for service within the prior six months and have been electrically tested within one year of issue for service. Insulating sleeves, gloves, and mats shall be used and periodically tested as required in 29 CFR 1910.137. Electrically insulating (EH) footwear shall be worn by workers exposed to step and touch potential hazards and should be worn by personnel exposed to potentials above 600 volts. Electrically insulating footwear shall not be considered to allow a reduction in the voltage rating of any other shock protection PPE,

10. Both capacitors and coaxial and shielded cables may carry a static charge and may experience relaxation charge buildup. Discharge them and install a shorting wire if the potential for stored energy at normal system voltage exceeds the specified energy level in Joules found in the ESS Simplified DC shock hazard table.

11. Workers who may be exposed to the risk of arc flash hazards shall wear untreated natural fiber clothing. Such clothing includes that made of cotton, wool, silk, linen, rayon, and/or leather. Incidental meltable fibers, such as threads or elastics found in underwear or socks, are allowed. It is the responsibility of the worker to bear the cost of purchase and maintenance of such clothing.

12. Workers shall inspect PPE for integrity prior to use. PPE exhibiting flaws, excessive soiling, cracks, rips or tears shall not be used. Certain workers may be issued Arc Rated clothing in the form of coveralls for arc flash protection. It is the responsibility of the worker to clean and/or launder this flame-resistant clothing in accordance with the manufacturer's requirements. PPE shall comply with relevant manufacturing standards at the time of purchase. Good references for relevant standards are found in NFPA 70E Table 130.7(C)(14).

13. The Electrical Safety Subcommittee guidance sheets included at the end of this Chapter shall be used in determining the shock and arc flash PPE for various work activities. The Incident Energy Analysis Method found in NFPA 70E 130.5(G) may be used where the arc-flash energy has been determined by an arc flash hazard analysis performed on an

electrical system model that is reasonably accurate considering that utility system voltages may vary +/- 10% from nominal.

14. Arc Flash and Limited Approach Boundaries shall be maintained during conduct of electrical work activities to keep unqualified people from entering and being exposed to electrical hazards.

15. Testing and measuring equipment, when utilized, shall be properly rated for the electrical activity and environmental conditions, used in accordance with the manufacturer's instructions and limitation, and inspected prior to use to verify the instrument, power cords, probes, and connectors are in a safe operating condition. Personnel using such equipment shall be trained in the use of such equipment.

16. Personnel performing electrical work shall have necessary skills and knowledge to perform the work safely and be acquainted with the particular hazards of the job activity. If an individual performing the work is unfamiliar with the equipment or is being trained, she or he shall be under the direct supervision of a qualified person.

17. Personnel performing energized electrical work shall have direct line of sight of the components on which they will work and adequate illumination to perform the work safely. Illumination shall be adequate, accounting for the visual impairment that arc-flash face shields or hoods may cause. Supplemental (task) lighting may be needed.

18. Good housekeeping within the Limited Approach and Arc-Flash Boundary is essential to prevent incidents, especially where PPE reduces the perception and dexterity of the workers. Inside these boundaries, only qualified personnel in appropriate PPE may perform housekeeping work. Temporary insulated or grounded barriers that prevent contact with energized equipment and sufficient to protect against arc-flash energy must be erected if unqualified workers are to perform housekeeping work within these boundaries.

19. Illness and fatigue, as well as medications and other conditions, may affect workers' alertness, reactions times, and physical performance. While the electrical safety program does not set policy regarding fitness for duty, persons performing electrical work are encouraged to evaluate if any conditions affecting their mental or physiological state may impair their ability to work safely.

20. Tools and material handling equipment used in the RAB and in the LAB where intentional or unintentional contact with energized parts is likely shall be rated for the voltage to which they may be exposed, designed for the use to which they will be put, and inspected prior to use for defects, damage, or contamination. Fuse pullers and lines, ropes, cable pulling "snakes," and the side rails of portable ladders shall be made of non-conductive materials. Live-line tools (e.g., "hot sticks" and "shotguns") shall meet applicable manufacturing standards as well.

21. Electrical demolition has specific hazards, especially when disused equipment, cables, and raceways must be removed while leaving other electrical infrastructure operational. NFPA 70E, 2018 edition, Article 130.7(E)(4) requires that unspecified "additional steps" be taken to identify conductors to be cut, removed or relocated when the cable terminations are not within sight of the work area. Effective additional steps depend on the specific work but may include additional checks with proximity or contact voltage or current sensing instruments and use of circuit identifiers such as "tick" tracers or pulsed-current fault locators. When removing heavy or stiff cables that have to be removed in segments from cable trays containing circuits that must remain active, non-conductive sleeves, such as couplings for plastic pipe, can be slid over the cable ends and pushed ahead of the cuts to maintain positive identification of the cables to be cut.

22. Multiple pieces of equipment that are similar in appearance (Look-alike equipment) pose a risk of misidentification. Examples include rows of switchgear and line-ups of redundant utilization equipment such as pumps. Countermeasures must be used to ensure the correct equipment is serviced and LOTO is applied correctly. These countermeasures include pre-job labeling of which equipment is to be serviced and which is not be serviced and inquiring with facility subject matter experts to confirm equipment identity. EFCOG Best Practice 207 is a good resource on this topic.

23. All workers are responsible to avoid storing materials or otherwise obstructing the working spaces and access to working spaces for electrical equipment as specified in NFPA 70 Articles 110.26, 110.33. and 110.34.

24. Where exposed conductors have not been proven to be de-energized, no work, including housekeeping and janitorial tasks shall be performed within the larger of the Limited Approach and Arc-flash Boundaries unless performed by qualified electrical workers wearing required PPE.

25. Unless a no-load condition has been created, only switching devices intended for operation under load, such as circuit breakers and load-rated disconnects shall be used to isolate a circuit. No-load rated devices such as fuses, plug connectors, and cable terminations may only be used to isolate a loaded circuit in emergency situations.

26. If an analysis of specific diagnostic and testing work activities indicates that use of certain PPE may actually increase the risk of accident or injury by unduly restricting bodily movements then less restrictive PPE may be acceptable. The decision to reduce PPE shall be documented in writing using risk analysis. This must be completed and approved by the worker's Department Manager before proceeding with the work.

27. Wearing of natural fiber clothing is meant to include long sleeve shirts, long pants and underwear. Arc-Rated coveralls provided by Fermilab provides an ATPV protective rating of 8.2 cal/cm^2. The addition of natural fiber clothing worn under them will increase the protection because of its protective characteristics and layering.

28. Leather gloves, while not electrically rated, provide some protection against thermal electrical hazards, such as when operating circuit breakers or disconnect switches with no energized parts exposed. Leather gloves may not be substituted for rubber insulating gloves where shock protection is required. Special leather protector gloves must be worn to protect rubber insulating gloves. When used, leather gloves should be dry and free of excessive soils, especially oils.

29. If an overcurrent device (circuit breaker or fuse) clears, it shall not be manually reset until the condition that caused it to clear has been identified and mitigated.

7.0 ELECTRICAL SAFE WORK PRACTICES

The following points are general safe work practices that apply to electrical work activities. Some are very broad in application while others relate to specific types of work activity.

1. Ensure related procedures, schematics, drawings, and manuals are available and up-to-date. Consult them if in doubt about any aspect of the work to be performed or the voltages and energies present.

2. While no standards specify a threshold at which a second person must be assigned to an electrical task, if management determines that a reasonable possibility exists that a worker could be exposed to a “no-let-go” shock hazard or an injury severe enough to preclude self-extrication and notification of first responders, a second person shall be assigned to the task. If the second person must enter the Limited Approach or Arc-Flash Boundaries, they must also be a Qualified Person and don appropriate PPE while the task is being performed.

3. Take the necessary time to perform the work safely. Don’t be rushed or take short cuts.

4. Use the one-hand rule as often as possible.

5. Assume that all power is on and that stored energy is not relieved until proven otherwise.

6. De-energize the equipment whenever possible.

7. When operating a circuit breaker or disconnect switch, face away and minimize physical exposure to the breaker or switch. Visually verify the operation of energy isolating devices where it is possible to do so without additional exposure to potentially energized cables or conductors, such as disconnect switches that have viewing windows.

8. Follow LOTO procedures (FESHM 2100) to isolate the hazardous energy source(s)

9. Be mindful of multiple electrical energy sources such as UPS and backfeed of circuits

10. Remember that verification is the most important step of the LOTO procedure. Proper Personal Protective Equipment shall be worn until zero voltage verification is assured.

11. Labels are not always accurate.

12. Be aware that failures of multipole circuit breakers and disconnects often involve mechanical failure of one of the poles to operate properly.

13. When verifying absence of voltage from the AC Power Distribution System, measure terminal-to-terminal, terminal to neutral, and terminal-to-ground.

14. Take necessary steps to disable remote control of the equipment if appropriate.

15. If testing equipment is critical to your safety, make sure it is ON and operational.

16. Plan your use of test equipment with respect to grounding, to the placement of equipment and probes, to signal levels, and with respect to identifying energized components in the equipment. Pre-connect test probes if possible.

17. Know what is grounded.

18. Install and/or maintain low impedance grounding.

19. Understand what is connected to the load and the hazards it may pose.

20. Understand the benefits of current limiting fuses in reducing the effect of arc blast hazards.

21. Observe good housekeeping practices in equipment while performing work.

22. Check the integrity of all high voltage and high current connections.

23. Use a magnet or vacuuming equipment, preferably insulated, to collect metal chips within de-energized electrical enclosures. Follow requirements for objects entering Limited and Restricted Boundaries for energized equipment.

24. Check integrity of electrical insulation and flash barriers.

25. Use and maintain color-coding, polarity, and phase rotation conventions. (FESHM 9120)

26. Keep 120/208 and 277/480 VAC services physically separated.

27. Understand the difference between resistive and non-resistive ground sticks and when to use each type. Test for continuity before use.

28. After the work is finished, inspect completed work and replace all protective covers before re-energization.

29. Closing in a circuit is generally more dangerous than opening a circuit, especially if new or modified.

30. Older equipment, especially AC power distribution equipment, is generally more dangerous to work on.

8.0 Electrical Safety Subcommittee Simplified PPE Tables

The Electrical Safety Subcommittee (ESS) has prepared Simplified PPE Tables adapted from NFPA 70E 2018, which are included in the Technical Amendment to this FESHM Chapter. These tables may be used in determining required PPE for various work activities at or below 600 VAC and 15 kVDC.

Shock protection boundaries and PPE requirements for Alternating Current Circuits of 400 Hertz at Fermilab power distribution voltage ranges and under are presented in the first table. The second table presents the shock protection boundaries and PPE requirements for DC systems. For voltages and system frequencies not presented in these tables, refer to NFPA 70 Article 130.4 and Tables 130.4(D)(a) and 130.4(D)(b).

Arc-flash PPE requirements are presented in the third ESS Table. While the 2018 NFPA 70E no longer includes a PPE Category 0 (zero), Fermilab has retained this terminology to specify PPE for electrical work that does not include an arc-flash hazard in excess of 1.2 cal/cm^2. The final three tables assign PPE Categories to work on common electrical equipment types found in Fermilab AC power distribution equipment, AC utilization equipment, and DC equipment. Arc-flash PPE requirements for electrical distribution equipment not listed in these tables may be found in NFPA 70E Table 130.7(C)(15)(a). Arc-flash PPE requirements not addressed by the ESS or NFPA 70E tables shall be determined on a case-by-case basis by Fermilab electrical SMEs prior to working on the equipment.

Alternating Current (AC) Shock Protection Boundaries and PPE Fermilab Summary for NFPA 70E, 2018 Edition. [Based on Table 130.4(D)(a).]			
System Voltage Range Phase to Phase	**Limited Approach Boundary (Fixed Parts) (LAB)**	**Restricted Approach Boundary (RAB)**	**Shock Protection Insulating PPE**
50 to 150 **Includes 120**	**3 Ft 6 In**	**Avoid Contact**	**LAB - None RAB - Wear/Use if Contact Likely**
150 to 750 **Includes 208, 240, 277 and 480**	**3 Ft 6 In**	**1 Foot**	**LAB - None RAB - Must Wear**
751 to 15K **Including 13.8K**	**5 Feet**	**2 Ft 2 In**	**LAB - None RAB - Must Wear**
345K to 362K	**15 Ft 4 In**	**9 Ft 2 In**	**LAB - None RAB - Must Wear**

Within the Limited Approach Boundary	**Non-Qualified Worker Allowed Within Only if Advised and Escorted by a Qualified Worker. Insulated Equipment/Tools if Contact Likely.**
Within the Restricted Approach Boundary	**Only Qualified Worker Allowed Within. May Not Cross Into with Conductive Objects. Conductive Objects Prohibited. Body Parts Must be Insulated.**

(New Table) Direct Current (DC) Shock Protection Boundaries and PPE Fermilab Summary for NFPA 70E, 2018 Edition [Based on Table 130.4(D)(b).]			
System Voltage Range Phase to Phase [* NFPA 70E 350.9(2)]	**Limited Approach Boundary (Fixed Parts) (LAB)**	**Restricted Approach Boundary (RAB)**	**Shock Protection Insulating PPE**
100* to 300	**3 Ft 6 In**	**Avoid Contact**	**LAB - None RAB - Wear/Use if Contact Likely**
301 to 1000	**3 Ft 6 In**	**1 Foot**	**LAB - None RAB - Must Wear**
1001 to 5K	**5 Feet**	**1 Ft 5 In**	**LAB - None RAB - Must Wear**
5K to 15K	**5 Feet**	**2 Ft 2 In**	**LAB - None RAB - Must Wear**

Within the Limited Approach Boundary	**Non-Qualified Worker Allowed Within Only if Advised and Escorted by a Qualified Worker. Insulated Equipment/Tools if Contact Likely.**
Within the Restricted Approach Boundary	**Only Qualified Worker Allowed Within. May Not Cross Into with Conductive Objects. Conductive Objects Prohibited. Body Parts Must be Insulated.**
Capacitor energy limits [NFPA 70E 350.9(3)]	**Consult with your D/S Electrical Coordinator if capaciitors operate at below 100 V and over 100 Joules, 100 to 400 volts and over 1 Joule, over 400 volts and over 0.25 Joule (1 Joule = 0.5 * C * V * V)**

Arc-Flash PPE Categories - Required Clothing - Required PPE
Fermilab Summary for NFPA 70E, 2018 Edition [Based on Table 130.7(C)(15)(c).]

Calculated Exposure from Prospective Arc-Flash	PPE Category	Minimum Required Arc-rating	Clothing Requirements	Additional PPE
Zero up to 1.2 cal/cm^2	0*	NA	Long Sleeve Cotton Shirt and Pants	Safety Glasses required, Hearing Protection and Leather Gloves recommended
More than 1.2 and up to 4 cal/cm^2	1	4 cal/cm^2	FR Coverall**	Hard Hat, Safety Glasses, Arc-rated Face Shield, Hearing Protection, Leather Gloves, Leather Work Shoes
More than 4 and up to 8 cal/cm^2	2	8 cal/cm^2	Cotton Clothing Under FR Coverall**	Hard Hat, Safety Glasses, Flash Suit Hood, Hearing Protection, Leather Gloves, Leather Work Shoes
More than 8 and up to 25 cal/cm^2	3	25 cal/cm^2	Cotton Clothing Under FR Coveralls* plus Multilayer Flash Suit Jacket & Pants	Hard Hat, FR Hard Hat Liner, Safety Glasses, Flash Suit Hood, Hearing Protection, Arc-Rated Gloves, Leather Work Shoes
More than 25 and up tp 40 cal/cm^2	4	40 cal/cm^2	Cotton Clothing Under FR Coverall* plus Multilayer Flash Suit Jacket & Pants	Hard Hat, FR Hard Hat Liner, Safety Glasses, Flash Suit Hood, Hearing Protection, Arc-Rated Gloves, Leather Work Shoes
*Fermilab policy ** Coverall Rated at 8 cal/cm^2 Available from Fermilab Stockroom				

Simplified Arc-Flash Guidance for Electrical Work on Fermilab AC POWER DISTRIBUTION Equipment

Diagnostic Work Including LOTO Voltage Testing Unless Otherwise Noted, Plus Some Additional Operations

The Fermilab Default AC Arc-Flash Boundary is 4 Feet (1.2 meters)

Equipment	Voltage	Rated Full Load Current	PPE Category	Conditions or Qualifications
Primary Panelboards SWBD DHP	480/277 VAC	More than 1,200 Amps	4	Primary Transformer Larger than 1000 KVA (Assuming More Than 25,000 ISC Available with Fault Clearing Time >2 Cycles) Take Advantage of Installed Panelboard Meter for LOTO Verification if Present.
Motor Control Centers MCC	480 VAC	Typical 600 Amps and Above	4 or 2	Category 2 permitted only if overcurrent protective device will clear fault in under two line cycles (0.03 s). Take Advantage of Installed Central Monitoring Unit for LOTO Verification if Present
Primary or Secondary Panelboards DHP PHP LP	480/277 VAC	400 to 1,200 Amps	2	Proximity to Transformer Power Source Presumed
Operating 13.8 KV Disconnects with Doors Closed	13.8 KV	NA	2	Booster Brentford or RF Anode Power Supplies are Examples
Secondary Panelboards PHP LP	480/277 VAC	100 to 225 Amps	2	More Than 200 Feet from Panelboard Sourcing Power
Work in Lighting Panelboards (LP) including LOTO Verification	480/277 VAC	100 Amps	2	More Than 100 Feet from Secondary Panelboard Sourcing Power
Work in Utility Panelboards including LOTO Verification	120/208 VAC 120/240 VAC	Below 350 Amps	1	Requirement Direct from NFPA 70E 130.7(C)(15)(a), Applies if overcurrent protective device will clear fault in under two line cycles (0.03 s).
Operating Circuit Breakers and Disconnect Switches with Covers On or Closed	480/277 VAC	NA	0	Equipment must be in Normal condition as defined by NFPA 70E Table 130.5(C)
	120/208 VAC 120/240 VAC	NA	0	Equipment must be in Normal condition as defined by NFPA 70E Table 130.5(C)

This Simplified Table for AC Power Distribution Equipment Has Been Approved by the Electrical Safety Subcommittee, based on the 2018 Edition of NFPA 70E
If Stated Conditions or Qualifications Are Not Met or the Circumstances of the Work Activity Appear Unique, Refer to NFPA 70E Table 130.7(C)(15)(a) or Consult with Your D/S Electrical Coordinator.

Simplified Arc-Flash Guidance for Electrical Work on Fermilab AC UTILIZATION Equipment

Diagnostic Work Including LOTO Voltage Testing Unless Otherwise Noted

The Fermilab Default AC Arc-Flash Boundary is 4 Feet (1.2 meters)

Equipment	Voltage	Sourcing Branch CB	PPE Category	Conditions or Qualifications
Power Supplies	480 VAC	Various	**Can Range from 1 to 3**	Ask Your Department for an Assessment. Take Advantage of Installed Panel Meters for LOTO Verification.
Various Equipment	480 VAC or 480/277 VAC	100 to Less than 400 Amps	**2**	Distance from Primary Panelboards and Feed Conductors Limit Available Fault Currents
Various Equipment	480 VAC or 480/277 VAC	Less Than 100 Amps	**1**	Distance from Primary Panelboards and Feed Conductors Limit Available Fault Currents
Sump Pump Controllers Motor Controllers HVAC Equipment	480 VAC	60 Amps and Below	**1**	Distance from Primary Panelboards and Feed Conductors Limit Available Fault Currents
Ballasts and Light Fixtures	277 VAC	30 Amps and Below	**1**	Typical Lighting Ballast
Power Supplies	208 VAC	350 Amps and Below	**0**	Equipment and branch circuit overcurrent protective device(s) must be in Normal condition as defined by NFPA 70E Table 130.5(C)
Various Equipment	120/208 VAC	350 Amps and Below	**0**	Equipment and branch circuit overcurrent protective device(s) must be in Normal condition as defined by NFPA 70E Table 130.5(C)
Various Equipment	120 VAC	30 Amps and Below	**0**	Equipment and branch circuit overcurrent protective device must be in Normal condition as defined by NFPA 70E Table 130.5(C)

This Simplified Table for AC Utilization Equipment Has Been Approved by the Electrical Safety Subcommittee, based on the 2018 Edition of NFPA 70E
If Stated Conditions or Qualifications Are Not Met or the Circumstances of the Work Activity Appear Unique,
Consult with Your D/S Electrical Coordinator.

(New Table) Simplified Arc-Flash Guidance for Electrical Work on Fermilab DIRECT CURRENT Equipment

Diagnostic Work Including LOTO Voltage Testing Unless Otherwise Noted
The Fermilab Default Arc-Flash Boundary does not apply.

Equipment	Voltage	Fault Current	PPE Category	Arc-Flash Boundary	Conditions or Qualifications

DS Batteries, Switchboards, or other sources exceeding limits on voltage, current, or both	> 600	Various	**Varies**	**Varies**	Also applies to arc durations over 2 seconds or working distance under 18 inches. Ask Your Department for an Assessment.
DS Batteries, Switchboards, or other sources	251 - 600	7 - 10 kA	**4**	**8 Feet**	Maximum arc duration of 2 seconds and working distace of not less than 18 inches
DS Batteries, Switchboards, or other sources	251 - 600	3 - 7 kA	**3**	**6 Feet**	Maximum arc duration of 2 seconds and working distace of not less than 18 inches
DS Batteries, Switchboards, or other sources	251 - 600	1.5 - 3 kA	**2**	**4 Feet**	Maximum arc duration of 2 seconds and working distace of not less than 18 inches
DS Batteries, Switchboards, or other sources	251 - 600	< 1.5 kA	**2**	**3 Feet**	Maximum arc duration of 2 seconds and working distace of not less than 18 inches
DS Batteries, Switchboards, or other sources	100 - 250	7 - 15 kA	**3**	**6 Feet**	Maximum arc duration of 2 seconds and working distace of not less than 18 inches
DS Batteries, Switchboards, or other sources	100 - 250	4 - 7 kA	**2**	**4 Feet**	Maximum arc duration of 2 seconds and working distace of not less than 18 inches
DS Batteries, Switchboards, or other sources	100 - 250	< 4 kA	**2**	**3 Feet**	Maximum arc duration of 2 seconds and working distace of not less than 18 inches

This Simplified Table for Direct Current Equipment Has Been Approved by the Electrical Safety Subcommittee, based on the 2018 Edition of NFPA 70E
If Stated Conditions or Qualifications Are Not Met or the Circumstances of the Work Activity Appear Unique,
Refer to NFPA 70E Table 130.7(C)(15)(b) or Consult with Your D/S Electrical Coordinator.