HAZARD MITIGATION FOR ELECTRICAL WORKERS

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

INTRODUCTION

Electrical workers are often exposed to specific hazards associated with electricity that pose risk of physical injury. These hazards include shock, electrocution, 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 Hazard Analysis (HA) for 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 so as to reduce overall risk for the electrical worker to an acceptable level. It is imperative that any work on or near energized 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 is powered by such distribution systems. Only qualified electricians shall perform installation, maintenance and repair of AC electrical power distribution systems.

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 NFPA 70E "Standards for Electrical Safety Requirements for Employee Workplaces" 2000 Edition.

POLICY

Any work on electrical systems or equipment that have 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 work on energized systems operating at voltages exceeding 130 VAC terminal-to-ground or 250 VAC terminal-to-terminal. These requirements are found on the backside of the Permit form found in FESHM 5042. Note that signature approvals of the D/S Electrical Coordinator and the area division/section Head are required. The signature of the FESS Head is also required if FESS Operations Department electricians are working within or for another division/section. 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 in such a way so as to reduce risk of injury from credible hazards to an acceptably low level.

DEFINITIONS

Arc Thermal Performance Exposure Value (ATPV) – The protective clothing characteristics as tested (ASTM P S58 standard) for flame resistant/retardant (FR) fabrics and expressed as the incident energy that would just cause the onset of a second-degree burn (1.2 cal/cm^2).

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.

Hazard Analysis (HA) - The process by which hazards are identified for all anticipated phases of work, all hazards associated with each, and the work processes to be employed to eliminate or reduce those hazards.

Limited Approach Boundary – A hazard protection boundary to be crossed only by qualified persons, and that is not to be crossed by unqualified persons unless escorted by a qualified person. This distance is nominally within three feet six inches (3ft. 6 in.) of uninsulated or exposed non-movable energized live parts and (10) feet if the exposed live part is movable. (NFPA -70E Table 2-1.3.4) This distance may be modified to a greater or lesser distance in accord with the specific magnitude of electrical hazards actually present.

Qualified Electrical Worker – An individual who:

- Is knowledgeable in the fundamental concepts of electricity
- Is familiar with the electrical hazards involved in work activities
- Knows how to recognize and avoid electrical hazards
- Is familiar with the construction and operation of the equipment
- Knows how to identify energized parts
- Knows how to determine the nominal voltage
- Performs safe work practices in performing assigned work
- Applies training to the work at hand
- Has taken "Electrical Safety for Qualified Workers" (FN000234)

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

Working On Energized Live Parts – Coming in contact with energized live parts with the hands, feet, body parts, tools, probes, or test equipment.

ELECTRICAL WORK ACTIVITIES

Electrical work activities on either the AC power distribution system or electrical utilization equipment commonly involve both energized and de-energized circuits. While most electrical work activities preferentially involve de-energized circuits, some activities necessarily involve energized circuits. For purposes of this Chapter and in the practical sense, work on energized circuits is classified or described as four distinct types of work.

Verification is the process where the worker determines by conclusive test that an electrical circuit is either energized or de-energized. In the performance of lockout/tagout (LOTO), verification is performed to determine that an electrical circuit is de-energized and isolated from a hazardous electrical energy source. Verification typically involves actual contact with electrical conductors that either are or have the potential to be energized with metering instrumentation and/or AC proximity detectors. Verification is a very common work activity performed by a wide variety of qualified electrical workers.

Troubleshooting, Inspection, Measurements, and Testing frequently requires that the system or equipment under examination be energized in whole or part. Examples

include voltage and current measurements, circuit and signal tracing, and thermal imaging. Such work activities are commonly practiced and allowed when performed by qualified electrical workers.

Energized Work is practically interpreted as work **NEAR** exposed energized conductors where there is a lack of an adequate insulating barrier and where there is reasonable probability of inadvertent contact with energized conductors. Examples of energized work on the AC Power Distribution System include changeout of a stab-on circuit breaker in an energized panelboard, and pulling and connection of conductors to a circuit breaker in an energized panelboard. Such work is less common and may be performed only by qualified electricians with a job specific work permit as mandated by FESHM Chapter 5042. Energized work on utilization equipment might include replacement of socketed circuit components.

Hot Work generally conveys working **ON** energized conductors where a circuit connection is closed or opened. An example of an authorized hot work activity would be replacement of a screw-on circuit breaker in an energized panel board. Examples of unauthorized hot work include replacing a duplex receptacle or switch without de-energizing the associated branch circuit, replacing a fluorescent light ballast without de-energizing the circuit, or soldering a 120 VAC connection. Hot work is the least common of work activities and is allowed only under special circumstances authorized by special permit with the knowledge and consent of supervisory personnel. Personnel performing hot work must be qualified electrical workers knowledgeable of the equipment and trained in or aware of special precautions required to perform the hot work safely.

DISCUSSION OF ELECTRICAL HAZARDS

Primary electrical hazards include shock, electrocution, arc flash and electrical burns. The actual risk to a worker involved in electrical work activities is highly subjective to the work at hand. Determination of risk cannot be done on the basis of voltage or current alone. Rather, risk involves the combination of current and voltage; more simply stated as available power. Duration of exposure is also an important contributing factor to risk. The AC Power Distribution System is marked by its capability of being able to provide large amounts of power. However, available power 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.

Protection against electrical shock, electrocution and electrical burns involves not having any part of the body coming into contact with exposed energized conductors so as to have the body become part of the electrical circuit. The amount of current, path of the current and duration are the critical parameters that determine the extent of

personal injury. The human body is sensitive to AC currents as low as one milliampere. Currents above this level can induce painful shock, muscular contraction and paralysis, asphyxiation, heart fibrillation and paralysis, and tissue burning. 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.

Arc flash itself is a much less common occurrence. The most serious arc flash injuries result when untreated clothing is ignited during an arc incident and this can lead to second and third degree burns. 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 carelessness or misapplication of proper work practices. The level of hazard presented by arc flash is determined by available fault current, duration of the fault current, and physical proximity to the arc flash. Accurate quantification of the arc flash hazard can be accomplished only by a short circuit analysis of the circuit. Performing such an engineering analysis requires detailed knowledge of the circuit, equipment specifications, wire sizes and lengths, conduit sizes, motor loads and fuse characteristics.

Arc flash can be described as either a fault current or short circuit current supported by a conductive plasma of molten metal. Its energy is measured in calories per square centimeter. Protection against arc flash involves shielding the body from the arc flash event. Such shielding involves wearing of protective clothing and/or equipment to protect the hands, face and body from arc flash. Protective clothing, either natural fiber and flame resistant/retardant (FR), is worn to protect the worker from second degree burns and clothing ignition induced by the arc flash. Such clothing may also offer some protection against shock. However, due to the explosive effect of some arc events, physical trauma injuries may occur. The PPE requirements do not provide protection against physical trauma.

REQUIREMENTS

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

2. Workers who are subject to non-incidental risk of exposure to arc flash hazards shall wear untreated natural fiber clothing. Such clothing includes that made of cotton, wool, silk, and/or leather. Incidental meltable fibers, such as 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.

3. Workers shall inspect supplied PPE for integrity prior to use. PPE exhibiting flaws, excessive soiling, cracks, rips or tears shall not be used. Certain workers may be issued FR 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 accord with manufacturer's requirements.

4. The Hazard Risk Category Classification Matrix and the Protective Clothing and Personal Protective Equipment Matrix included at the end of this Chapter shall be used in determining the required PPE for various work activities.

5. Limited approach boundaries shall be maintained during conduct of electrical work activities so as to protect workers from credible electrical hazards.

SPECIAL REQUIREMENTS and RESPONSIBILITIES

Division/Section Heads shall provide necessary resources to assure implementation of the requirements of this Chapter.

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 provided PPE.

The Business Service Section shall provide in Fermilab stores FR coveralls, electrically rated gloves, electrically rated face shields and dielectric mats.

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. Organize a work plan before starting work. The plan should anticipate and accommodate events that have the possibility of adversely affecting the safe conduct of the work activity.

2. Know that a written Hazard Analysis is required for non-routine work. Read it, understand it and use it.

3. 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.

4. If the hazards justify the need, follow the two-person rule with at least one experienced person who has knowledge of the equipment or similar equipment.

5. Communicate with other members of the work group. Establish who is in charge.

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

7. Wear protective clothing and PPE as determined by hazard category to reduce risk of injury from credible hazards. Inspect PPE before using.

8. Do not wear 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 come in contact with energized conductors, unless such articles are rendered non-conductive by covering with an insulating means.

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

10. Clear slip and trip hazards and clutter from the work area.

11. Secure the work area as appropriate to ensure the safety of both the workers and passers-by. Observe limited approach boundaries of 3 ft. 6 in. when working with exposed energized parts that are not movable and 10 feet if the parts are movable.

12. Assume that all power is on and that stored energy is not relieved.

13. De-energize the equipment whenever possible.

14. When operating a circuit breaker or disconnect switch, turn away and minimize physical exposure to the breaker or switch.

15. Follow LOTO procedures (FESHM 5120) to isolate the hazardous energy source(s).

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

17. Remember that verification is the most important step of the LOTO procedure.

18. Labels are not always accurate.

19. Be aware failures of multiphase circuit breakers and disconnects involve failure of one of the poles to operate properly.

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

21. Beware of static charge and relaxation charge buildup in capacitors. Beware of charge in coaxial cables.

22. Take necessary steps to isolate remote control of the equipment if appropriate.

23. Energized work and hot work can be performed only when absolutely necessary and appropriate authorizations are obtained. If parts of the equipment being worked on can be de-energized, do so.

24. Be sure that personnel performing the work have necessary skills and knowledge to perform the work safely and are acquainted with the particular hazards of the job activity. If the individual performing the work is unfamiliar with the equipment or is being trained, adequate supervision or expertise should be provided.

25. Testing and measuring equipment, when utilized, shall be properly rated for the activity and in good condition. Personnel using such equipment shall be adequately trained in the proper use of such equipment.

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

27. Plan to use test equipment with respect to grounding, to the placement of equipment and probes, to signal levels, and with respect to identifying equipment hot spots. Pre-connect test probes if possible; use special caution if this is not possible.

28. Know what is ground.

29. Install and/or maintain proper low impedance grounding.

30. Understand what is connected to the load.

31. Understand the benefits of current limiting fuses in reducing the affect of arc blast hazards.

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

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

34. Use a magnet, preferably insulated, to collect metal chips within electrical enclosures – especially when drilling into energized enclosures.

35. Check integrity of electrical insulation and flash barriers.

36. Use and maintain proper color-coding, polarity, and phase rotation conventions. (FESHM 5042)

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

38. Understand the difference between resistive and non-resistive ground sticks and when to use each type.

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

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

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

USE of the PPE MATRIX

The following matrices shall be used in determining required PPE for various work activities at or below 600 VAC. Table 1 identifies the hazard risk associated with the task. From there, Table 2 will identify the required clothing and PPE. Performing an engineering analysis to determine the risk category is an acceptable alternative to the use of the Hazard Risk Category Classification Matrix. If an engineering analysis is preformed to determine incident energy exposure in calories per square centimeter then NFPA 70-E Table 3-3.9.3 may be used. While an engineering analysis of the circuit is not always readily afforded, such analysis can demonstrate reduced risk. Conversely, certain situations can be more dangerous than the norm and additional levels of PPE are appropriate.

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 is acceptable. This should be documented in the hazard analysis. Also, when appropriate meters and testing techniques are used, the likelihood of an arc flash happening during diagnostic testing is low compared to working on exposed live parts, as with tools.

Wearing of natural fiber clothing is meant to include long sleeve shirts, long pants and underwear. FR coveralls provided by Fermilab provides an APTV 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.

Leather gloves, while not electrically rated, provide some protection against electrical hazards. Leather gloves are often worn to protect electrically rated gloves. When used, leather gloves should be dry and relatively free of excessive soils, especially oils.

TRAINING

Training in the required and recommended elements of this Chapter is largely accomplished by having qualified electrical workers read and understand the Chapter. Area Division/Section ES&H Departments, in cooperation with the ES&H Section, shall provide subject matter experts to clarify issues that may arise related to interpretation and implementation. With the assistance of the ES&H Section, clarifications shall be effectively communicated to workers, safety personnel and management.

Table 1. Hazard Risk Category Classification

Task (Assumes Equipment is Energized, and Work Is Done Within the Flash Protection Boundary)	Hazard/ Risk Catgery	V-rated Gloves	V-rated Tools
Panelboards rated 240 V and below - Notes 1 and 3			
Circuit breaker (CB) or fused switch operation with covers on	0	N	N
CB or fused switch operation with covers off	0	N	N
Work on energized parts, including voltage testing	1	Y	Y
Remove/install CBs or fused switches	1	Y	Y
Removal of bolted covers (to expose bare, energized parts)	1	N	N
Opening hinged covers (to expose bare, energized parts)	0	N	N
Panelboards or Switchboards rated >240 V and up to 600 V (with molded case or insulated case circuit breakers) — Notes 1 and 3			
CB or fused switch operation with covers on	0	N	N
CB or fused switch operation with covers off	1	N	N
Work on energized parts, including voltage testing	2*	Y	Y
600 V Class Motor Control Centers (MCCs) – Notes 2 (except as indicated) and 3			
CB or fused switch or starter operation with enclosure doors closed	0	N	N
Reading a panel meter while operating a meter switch	0	N	N
CB or fused switch or starter operation with enclosure doors open	1	N	N
Work on energized parts, including voltage testing	2*	Y	Y
Work on control circuits with energized parts 120 V or below, exposed	0	Y	Y
Work on control circuits with energized parts >120 V exposed	2*	Y	Y
Insertion or removal of individual starter “buckets” from MCC — Note 4	3	Y	N
Application of safety grounds, after voltage test	2*	Y	N
Removal of bolted covers (to expose bare, energized parts)	2*	N	N
Opening hinged covers (to expose bare, energized parts)	1	N	N
600 V Class Switchgear (with power circuit breakers or fused switches) — Notes 5 and 6			
CB or fused switch operation with enclosure doors closed	0	N	N
Reading a panel meter while operating a meter switch	0	N	N
CB or fused switch operation with enclosure doors open	1	N	N
Work on energized parts, including voltage testing	2*	Y	Y
Work on control circuits with energized parts 120 V or below, exposed	0	Y	Y
Work on control circuits with energized parts >120 V exposed	2*	Y	Y
Insertion or removal (racking) of CBs from cubicles, doors open	3	N	N
Insertion or removal (racking) of CBs from cubicles, doors closed	2	N	N
Application of safety grounds, after voltage test	2*	Y	N
Removal of bolted covers (to expose bare, energized parts)	3	N	N
Opening hinged covers (to expose bare, energized parts)	2	N	N

Other 600 V Class (277 V through 600 V, nominal) Equipment — Note 3			
Lighting or small power transformers (600 V, maximum)	—	—	—
Removal of bolted covers (to expose bare, energized parts)	2*	N	N
Opening hinged covers (to expose bare, energized parts)	1	N	N
Work on energized parts, including voltage testing	2*	Y	Y
Application of safety grounds, after voltage test	2*	Y	N
Revenue meters (kW-hour, at primary voltage and current)	—	—	—
Insertion or removal	2*	Y	N
Cable trough or tray cover removal or installation	1	N	N
Miscellaneous equipment cover removal or installation	1	N	N
Work on energized parts, including voltage testing	2*	Y	Y
Application of safety grounds, after voltage test	2*	Y	N

Legend:
V-rated Gloves are gloves rated and tested for the maximum line-to-line voltage upon which work will be done.
V-rated Tools are tools rated and tested for the maximum line-to-line voltage upon which work will be done.
2* means that a double-layer switching hood and hearing protection are required for this task in addition to the other Hazard/Risk Category 2 requirements of Table 3-3.9.2 of Part II.
Y = yes (required)
N = no (not required)

Notes:
1. 25 kA short circuit current available, 0.03 second (2 cycle) fault clearing time.
2. 65 kA short circuit current available, 0.03 second (2 cycle) fault clearing time.
3. For < 10 kA short circuit current available, the Hazard/Risk Category required may be reduced by one number.
4. 65 kA short circuit current available, 0.33 second (20 cycle) fault clearing time.
5. 65 kA short circuit current available, up to 1.0 second (60 cycle) fault clearing time.
6. For < 25 kA short circuit current available, the Hazard/Risk Category required may be reduced by one number.

Table 2. Protective Clothing and Personal Protective Equipment Matrix

Protective Clothing & Equipment	Protective Systems for Hazard/Risk Category					
Hazard/Risk Category Number	-1 (Note 3)	0	1	2	3	4
Untreated Natural Fiber						
a. T-shirt (short-sleeve)	X			X	X	X
b. Shirt (long-sleeve)		X				
c. Pants (long)	X	X	X (Note 4)	X (Note 6)	X	X
FR Clothing (Note 1)						
a. Long-sleeve shirt			X	X	X (Note 9)	X
b. Pants			X (Note 4)	X (Note 6)	X (Note 9)	X
c. Coverall			(Note 5)	(Note 7)	X (Note 9)	(Note 5)
d. Jacket, parka, or rainwear			AN	AN	AN	AN
FR Protective Equipment						
a. Flash suit jacket (2-layer)						X
b. Flash suit pants (2-layer)						X
Head protection	—	—	—	—	—	—
a. Hard hat			X	X	X	X
b. FR hard hat liner					X	X
Eye protection		—	—	—	—	—
a. Safety glasses	X	X	X	AL	AL	AL
b. Safety goggles				AL	AL	AL
Face protection double-layer switching hood				AR (Note 8)	X	X
Hearing protection (ear canal inserts)				AR (Note 8)	X	X
Leather gloves (Note 2)			AN	X	X	X
Leather work shoes			AN	X	X	X

Legend:
AN = As needed
AL = Select one in group
AR = As required
X = Minimum required

Notes:
1. See Hazard Risk Category Classification (ATPV is the Arc Thermal Performance Exposure Value for a garment in cal/cm^2 .)
2. If voltage-rated gloves are required, the leather protectors worn external to the rubber gloves satisfy this requirement.
3. Class −1 is only defined if determined by Notes 3 or 6 of the Hazard Risk Category Classification
4. Regular weight (minimum 12 oz/yd^2 fabric weight), untreated, denim cotton blue jeans are acceptable in lieu of FR pants. The FR pants used for Hazard/Risk Category 1 shall have a minimum ATPV of 5.
5. Alternate is to use FR coveralls (minimum ATPV of 5) instead of FR shirt and FR pants.
6. If the FR pants have a minimum ATPV of 8, long pants of untreated natural fiber are not required beneath the FR pants.
7. Alternate is to use FR coveralls (minimum ATPV of 5) over untreated natural fiber pants and T-shirt.
8. A double-layer switching hood and hearing protection are required for the tasks designated 2* in Hazard Risk Category Classification
9. Alternate is to use two sets of FR coveralls (each with a minimum ATPV of 5) over untreated natural fiber clothing, instead of FR coveralls over FR shirt and FR pants over untreated natural fiber clothing.