Memorandum

May 2, 2014

To: Martha Michels

From: Dave Mertz, John Anderson Jr.

Subject: Risk analysis for electrical switching by non-electrical personnel

Introduction

Historically, certain personnel who are not regarded as qualified to perform energized electrical work have performed switching of electrical equipment, typically by operating disconnect switches (also known as safety or knife switches) and circuit breakers located in panelboards. These tasks were probably done without knowledge of the hazards potentially present and certainly without any training on how these risks could be mitigated. Particle Physics Division (PPD) developed a training program for these individuals to inform them of work procedures and personal protective equipment (PPE) that minimize their exposure to the energy produced in the unlikely event that an arc-flash would occur when they operated the electrical equipment. The work procedures were based on code requirements and industry best practices. The PPE requirements were based on the requirements given in NFPA 70E, *Standard for Electrical Safety in the Workplace,* for circuit breaker and switch operation under conditions that limit the amount of energy that could be released in an arc-flash event. Because there are a several isolated installations at the laboratory that have been identified as exceeding the conditions specified in the standard, and many other installations that have not yet been sufficiently characterized to determine if the standard's conditions are exceeded, this risk analysis has been prepared to assess the level of risk that is posed by continuing this activity and demonstrate the risk reduction accomplished through the procedures and PPE presented in the training materials.

Regulatory Considerations

NFPA 70, *National Electrical Code*: This standard addresses the physical installation of electrical equipment. Of particular relevance to this analysis is Article 110.26(A), *Working Space*, and Article 100.26(C), *Entrance and Egress from Working Space*.

NFPA 70E, *Standard for Electrical Safety in the Workplace*: This standard addresses the conditions under which energized electrical work is permitted, the methods for determining the extent of the hazard posed by particular equipment and installations, and the proper PPE to be used when energized electrical work is performed.

IEEE 1584, *Guide for Performing Arc-Flash Hazard Calculations*: This standard provides a computational method for calculating the degree of arc-flash hazards.

Energized Electrical Work - Brief History

The hazard posed by energized electrical equipment cannot be accurately recognized by simple observation, unlike a rotating shaft or a large suspended mass. Even the hazard posed by identical equipment can vary enormously depending on the rest of the electrical system to which they are connected. Prior to 1979, no U. S. standard existed to quantify these hazards and specify means to ameliorate these hazards. In 1976, the NFPA formed a development committee for NFPA 70E at the encouragement of the U. S. Occupational Safety and Health Administration (OSHA). The first edition of the standard was published in 1979 and has been periodically revised since then.

A culture has existed in the electrical trades that questioned the competence and other desirable qualities of tradesmen that hesitated to work on energized equipment other than that which posed an immediate and obvious deadly hazard such as overhead utility lines. This nonchalance is present in those outside of the trade as well, since the hazard is not apparent and incidents are infrequent. The good news is that consistent awareness and enforcement efforts by the electrical trades and related organizations are changing this culture.

Scope of Proposed Activity

The work covered by this proposed training is analogous to operating a wall switch that controls lighting, except that the devices used may operate at a higher voltage, control greater current, or both. Several limitations have been placed on this activity by the training:

Medium and high voltage equipment is excluded.

Only branch (load) circuits may be switched. Feeder circuits that serve other electrical distribution equipment are excluded.

All covers must be fastened in place as the manufacturer intended.

Only equipment that is in good condition may be operated.

The working space and clear entrance and egress from the equipment must be cleared.

The worker will locate his or her self away from the direction in which arc-flash energy could be released.

The worker will correctly use specified PPE.

Analysis of Hazards and Risk

To evaluate the hazards and risks from applying the proposed work procedures and PPE usage, one must start with the assumption that workers are given no instruction or training, and operate disconnect switches and circuit breakers as they would ordinary wall switches. Next we need to define the maximum acceptable risk.

Consistent with the draft Implementation Guide for DOE O 420.2C, Safety of Accelerator Facilities, the panel used ANSI/ASSE Z590.3-2011, Prevention through Design Guidelines for Addressing Occupational Hazards and Risks in Design and Redesign Processes to qualitatively assess the hazards and risks from this proposal. The standard uses qualitative terms to assess the probability of an occurrence and the severity of the consequences from an event to assess the risk.

The severity of an incident or exposure is expressed in terms such as Catastrophic, Critical, Marginal, Negligible, and Insignificant.

The following are typical definitions used for severity.

Incident or Exposure Severity Descriptions

Catastrophic:	One or more fatalities, total system loss, chemical release with lasting environmental or public health impact.
Critical:	Disabling injury or illness, major property damage and business downtime, chemical release with temporary environmental or public health impact.
Marginal:	Medical treatment or restricted work, minor subsystem loss or damage, chemical release triggering external reporting requirements.
Negligible:	First aid or minor medical treatment only, non-serious equipment or facility damage, chemical release requiring routine cleanup without reporting.
Insignificant:	Inconsequential with respect to injuries or illnesses, system loss or downtime, or environmental chemical release.

The probability of an incident or exposure is expressed in terms such as Frequent, Likely, Occasional, Seldom, and Unlikely.

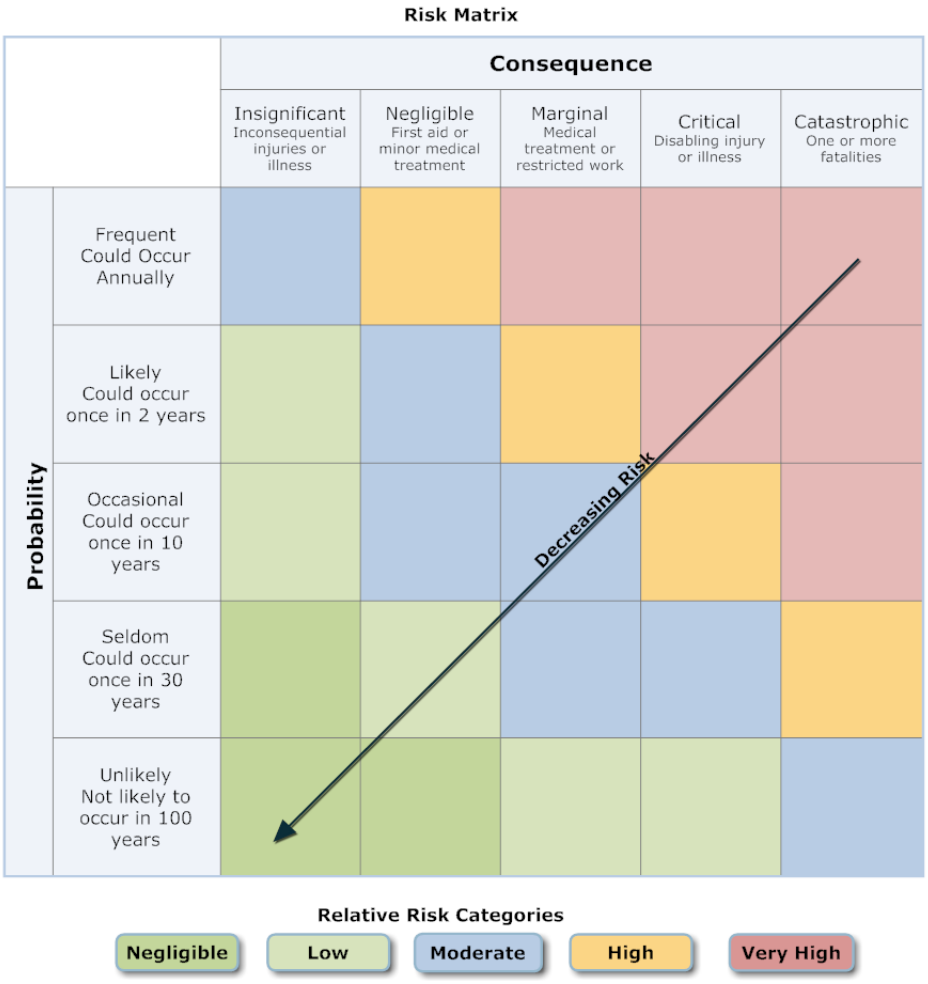
The following are typical definitions used for probability

Incident or Exposure Probability Descriptions

Frequent:	Likely to occur repeatedly. Could occur annually.
Likely:	Probably will occur several times. Could occur once in two years.
Occasional:	Could occur intermittently. Could occur once in ten years.
Seldom:	Could occur, but hardly ever. Could occur once in thirty years.

Unlikely: Improbable, may assume incident or exposure will not occur. Occurring not more than once in one hundred years.

The risk from an activity is the product of the consequence and probability which can be viewed on the following example risk matrix. The risk colors in the matrix are used to provide qualitative indicators of the relative risk using a word descriptive grading and scoring system. They only have value in showing the relative risk in the matrix in a qualitative way. For example, an activity that has an *Insignificant* consequence and a probability that it is *Unlikely* to occur would be a *Negligible* risk activity generally not requiring any controls to mitigate the activity. When an activity has a *Catastrophic* consequence and a probability that it will *Frequently* occur would be a *Very High* risk activity with controls established to prevent its occurrence.



Risk Scoring and Action Categories

The risks and action levels are categorized in the following table.

Category	**Action**
Negligible Risk	No Action Required
Low Risk	Remedial action discretionary
Moderate Risk	Remedial Action to be taken at the appropriate time
High Risk	Unacceptable – Remedial action to be given a high priority
Very High Risk	Unacceptable – Operation not permissible. Immediate action necessary

The consequence and probability descriptions along with the risk matrix provides a way to qualitatively analyze the risks and risk reductions from using work procedures and PPE to limit the consequence of an arc-flash event. Theory, experiments, and field incidents have all proven that low-voltage arc-flash events can cause fatalities. This gives little option but to rate the potential consequence as catastrophic.

To use probability criteria for assessing the likelihood of occurrence, we need to determine how often an accident event might occur. The laboratory has a large quantity and wide variety of electrical distribution and switching equipment. Based on ORPS records and conversations with veteran Fermilab personnel, there is no documentation or memory of an arc-flash even that was initiated by the operation of a disconnect switch or circuit breaker. Seven arc-flash events were documented in the ORPS database since 2002, resulting from open-panel manipulative work, concrete coring, and medium voltage equipment operation. None of these events resulted in any injury.

When assessing frequencies of occurrence, identifying near misses can reveal additional potential for an incident to occur. In an arc-flash incident of sufficient energy to cause injury, the outages and damaged electrical equipment caused by incident make it difficult to overlook its occurrence. We can conclude there has not been a body of arc-flash events that have been missed. This does not mean that there are no incidents of electrical malfunctions, but that the design of the equipment by and large prevents equipment failures from producing arc-flash events, and that our procedures for protecting personnel from these hazards work as intended.

Based on this review of site incidents and a review of the (not very) available literature and statistics on the occurrence of arc-flash incidents during closed-cover switching operations on equipment under 600 volts, a case could be made for probability of “unlikely,” and certainly not more often than “seldom.”

Quantification of the Hazard

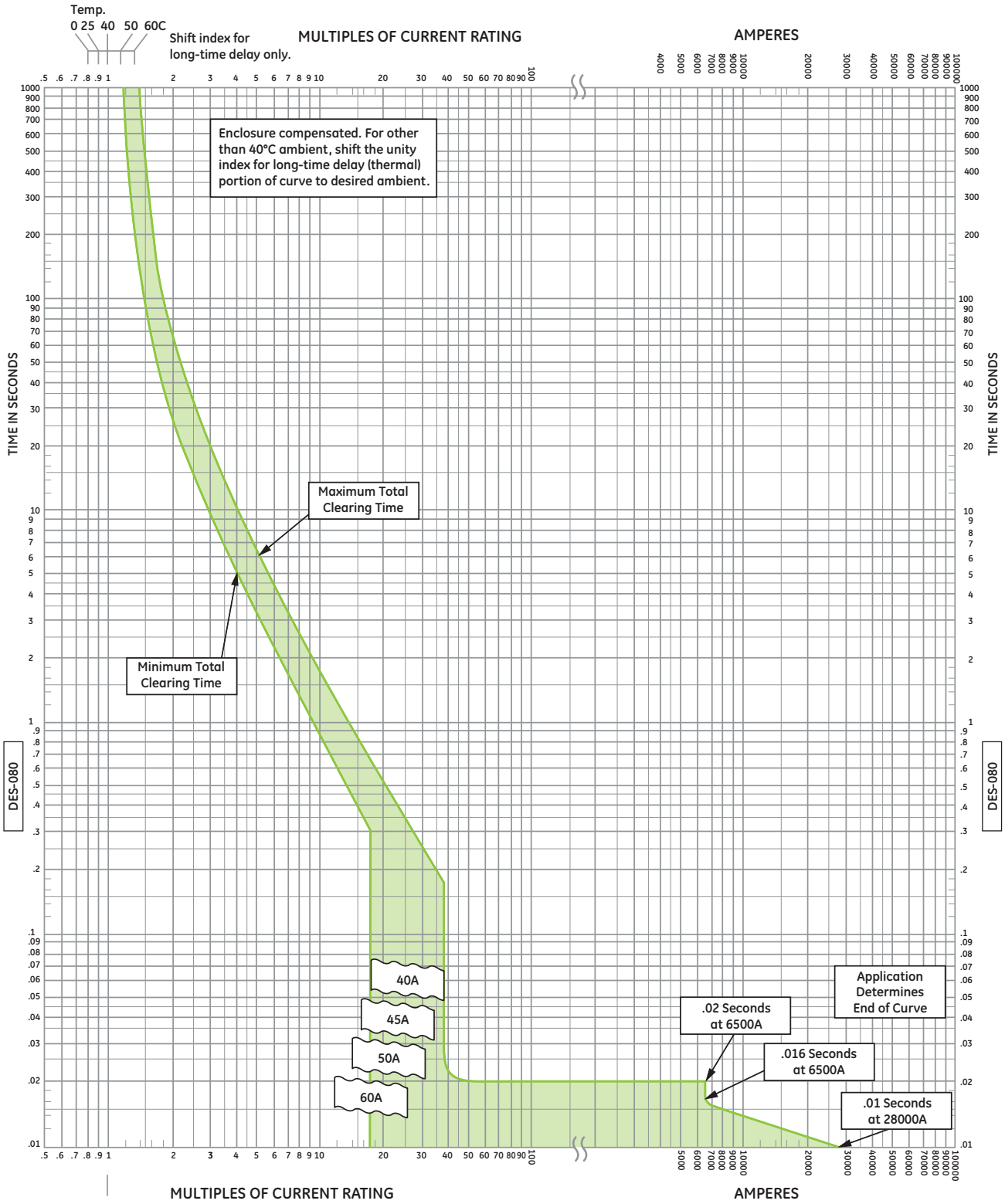
The standard used to specify required PPE for energized electrical work is NFPA 70E, *Standard for Electrical Safety in the Workplace*. The PPE specified in the proposed training is drawn from this standard, in particular Table 130.7(C)(15)(a). The use of this Table is contingent on the equipment having no more than 25,000 amperes of fault current and a clearing time not exceeding 0.03 seconds. Portions of the lab's electrical system have been documented and analyzed to determine the actual fault current and clearing time values, and the vast majority of the equipment analyzed fall within the Table's restrictions. There are a few that do not, and these fail to meet the clearing time requirement, not the fault current requirement. This is typical of commercial and industrial installations. The remainder of the laboratory's electrical system has not yet received both the documentation and analysis necessary to know if any particular piece of equipment meets the table's restrictions. Based on the similarity of the unanalyzed portions of the laboratory's electrical system to the portion that has been analyzed and to other commercial and industrial facilities, it is reasonable to expect that electrical equipment that do not meet the Table's restrictions are very rare, but may not be completely absent.

Limitations of Existing Research

The research that has been done to field evaluate the theoretical predictions of arc-flash hazard modeling has been primarily based on after-the-fact inspections of incidents. Some very basic hazard quantification testing has been done, but nothing that closely simulates the situations this training addresses. A limited amount of laboratory evaluation has also been performed by equipment manufacturers, but it has been aimed at quantifying the improved protection offered by optional arc-flash mitigation features. This arc-flash mitigation work has been focused on higher voltage and amperage equipment than what the personnel who receive this training will be authorized to operate, so it is of little relevance to this analysis.

One of the conditions that has not received research attention is the degree of hazard posed by (relatively) low-current arcs with long durations such that they do not meet the restriction in Table 130.7(C)(15)(a). Figure 1 is a time-current chart (TCC) for a typical thermal-magnetic molded-case circuit breaker of the type that would either be operated by or protect the disconnect switch operated by personnel who would receive this training. The band shown on this TCC indicates, for a given amperage on the X-axis, the circuit breaker will open in the range of time on the Y-axis where the vertical amperage line intersect the sides of the band on the chart. The width of that band is due to manufacturing variations. Note that the X-axis is normalized so the rated amperage of the circuit breaker is shown as "1."

The band consists of two regions. The first is the "foot" of the curve, called the "magnetic" or "instantaneous" region. This illustrates the operation of the magnetic mechanism is the circuit breaker that initiates clearing a high-current fault as soon as it occurs. Faults in this magnetic region clear in hundredths of a second. The second region is the "leg" of the curve, and this is called the "thermal" or "overload" part of the curve. In this region the



GE Consumer & Industrial - Electrical Distribution

Current Ratings
40, 45, 50, and 60 Amperes

Voltage Ratings (Max.)
1-pole – 277 Vac (125 Vdc)
2- and 3-pole – 480 Vac (250 Vdc)

Frequency Ratings
60 Hertz

Molded Case Circuit Breaker

Type TEYD, TEYH, TEYL, 40-60 Amperes
Enclosure Compensated
Long-time Delay and Instantaneous
Time-current Curves

Curves show enclosure-compensated circuit breaker in open air, 40°C ambient, wired with conductors of corresponding rating, no prior load. For all other ambients, use rating shift index at top of sheet.

DES-080

Adjustments
Long-time delay thermal trip: not adjustable.
Instantaneous magnetic trip: not adjustable.

10.12

FIGURE 1

circuit breaker simulates the heating that would occur on the wiring and opens the circuit before the insulation on the wires is damaged. The circuit breaker can take anywhere from several tenths of a second to several minutes to trip under an overload condition.

There are electrical installations, including certain locations at the laboratory, where higher-impedance transformers and long circuit lengths, restrict the fault current to values below the magnetic region, and it could take several seconds for circuit breaker to open. Though the fault is of a low magnitude, the delayed tripping allows for the delivery of a significant amount of energy. At no place do the arc-flash regulations and guides specify a time at which the energy calculation may be cut off other than when the circuit breaker operates, at which the energy released can be truncated.

Yet many organizations choose to use what is known as the “two second rule” to acknowledge that after a certain time, any persons at risk of an arc-flash exposure will have moved outside of the range of injurious arc-flash energy, whether under their own power or not. Limiting arc-flash calculations to a certain time duration reduces the total energy counted and so can require less cumbersome PPE for the rare equipment with the potential for lower-magnitude, long-clearing faults. Application of a 2-second time limit would reduce the PPE required for the known non-conforming equipment at the lab to the maximum value required by the Table for any work on conforming equipment.

Arc-flash modeling makes several assumptions about conditions when an incident occurs. Among these assumptions are that the enclosure cover is removed. This presents a worse scenario than a closed cover for the energy exposure (and it’s much easier to mathematically simulate). Testing to quantify the benefit of a closed cover has only begun within the last year. The tests that were performed universally used fault currents near the rated upper limit of the enclosure, and demonstrated that the covers did give a measurable reduction, but not sufficient to reduce the PPE requirements. Much of the exposure came through distortion of the cover during the near-instantaneous energy release. It is logical that lower-intensity, longer duration events would not distort the cover as much as these tests did, resulting lower energy exposures. Anecdotal reports have confirmed this, but it has not yet been experimentally quantified.

Hazard and Risk Mitigation

As noted before, arc-flash modeling makes several assumptions about the conditions that exist when an incident occurs. Not surprisingly, most of these assumptions place individuals at maximum risk for exposure to the arc-flash energy. In addition to the removed panel cover, calculations for these voltage levels locate the person 18” inches away and directly in front of the enclosure, which would be a typical for a person doing testing or manipulative work. The work procedures in the training instruct the person to stand to one side away from the potential energy release and look away from the panel or switch to further protect the sensitive facial tissues.

The trainees are only permitted to operate switches or circuit breakers located in enclosures that are in good condition with covers retained as intended by the manufacturer. This

provides the greatest likelihood that the enclosure will protect the trainee from the arc-flash energy, even if this reduction has yet to be experimentally quantified.

The trainees are instructed to ensure there is clear working space and an open egress path as required by NFPA 70 Article 110.26. This prevents them from assuming awkward positions or being trapped in a limited area that would prevent them from self-evacuating if an arc-flash was to occur.

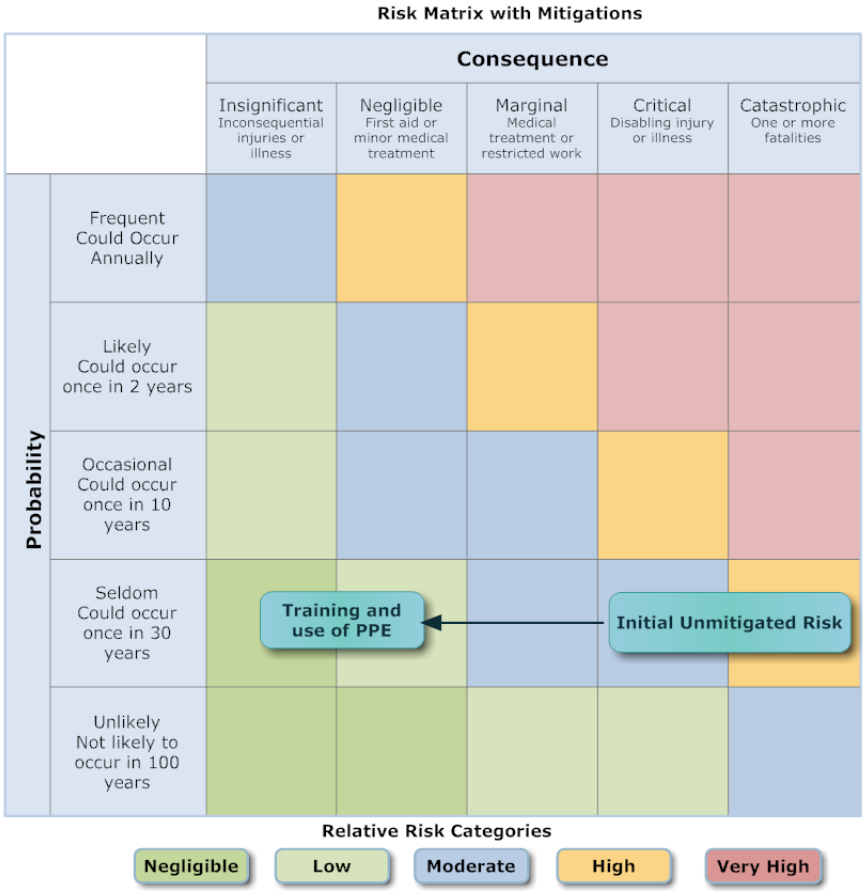
The training includes proper selection of PPE to reduce the exposure of trainees to arc-flash energy.

Providing this training gives the trainees the knowledge of how to avoid unnecessary exposure to possible arc-flash energy. In nearly all cases this will, according to the standards, be sufficient to protect them against any injury worse than a first-degree burn. In the rare situation that the calculations indicate that the protection required by the standard is not sufficient, the additional steps taken to ensure protective covers are in place and to avoid the direct path of the arc-flash will further ameliorate the potential for injury.

This training course is focused on specific procedures and PPE requirements for specific and limited tasks. This is certainly an improvement over the lack of training that was previously the case, and by its limited scope and focus will improve retention over requiring the full 4-hour NFPA 70E training that will bury the limited instruction they require within an avalanche of information that will be of little or no use to them.

Risk Reduction

The following risk matrix maps the effect of controls that the training requirements put in place. Beginning with an arc-flash event that seldom occurs but could have catastrophic consequences (High to Very High Risk), the requirements to avoid the direct path of the arc flash and avert the face from the potential arc-flash source, ensure that the panel enclosure is in good physical condition and properly fastened shut, and to wear basic arc-flash PPE will reduce the hazard of these tasks to a negligible Low Risk classification. Because no changes are made to the physical equipment, the probability of the hazard occurring is unchanged.



Conclusion

This report provides justification to provide limited, focused training to those performing switch and circuit breaker operations. The work procedures and PPE required significantly reduce the potential exposure to the hazards versus the assumptions made by the standards used to determine the hazards. Providing training regarding the hazards present and the methods to ameliorate them is an improvement over the previous absence of training. By furnishing a short course focused on the specific hazards and means of mitigation for the specific tasks these individuals perform, retention of this information will be improved over furnishing these individuals with the full NFPA 70E course in which the information they need is contained within a far larger set of information, most of which will be extraneous to them.

We request your consideration and approval of this report. If you express your support for it, the Operation of Switches and Circuit Breakers training course will be made available lab-wide.

Cc: Electrical Safety Subcommittee, ESH&Q Industrial Health Group