CHAPTER 1

ELECTRICAL SAFETY

GOALS

- To understand the basic requirements of OSHA 1910.269 and Subpart S
- To apply recommendations of NFPA 70 (National Electrical Code®) and NFPA 70E (Electrical Safety in the Workplace) for compliance with OSHA 1910 Subpart S
- To apply recommendations of IEEE C2 (National Electrical Safety Code) for compliance with OSHA 1910.269
- To be able to determine minimum approach distance (MAD), limited approach boundary, restricted approach boundary, and arc flash boundary for installation
- To be able to determine minimum safety clearance for electric supply station fences
- To be able to determine the minimum illumination requirements for electric supply station locations
- To be able to determine the proper electrical PPE (personal protective equipment) required for various tasks
- To be able to determine the correct classification for areas where hazardous materials may be present

IF ONE were to try to reduce the function of the electrical engineer in the electric power generation industry to one sentence, it would be "*to ensure the design, implementation, and operation of a SAFE and RELIABLE electrical system.*" Electrical safety is of primary importance in the electric utility generation industry. The generation industry is unique from other industrial environments. The available short-circuit fault currents can be very large since the generation source is close and can supply a large amount of fault current. The service voltages at various pieces of equipment can be greater in magnitude for the larger electrical machines utilized in the generation station. Combustible materials may be handled, stored, and utilized in power generation facilities. The above conditions require the power plant electrical engineer

Energy Production Systems Engineering: An Introduction for Electrical Engineers to Electrical Power Generation Facilities, Systems, and Equipment, First Edition. Thomas H. Blair.

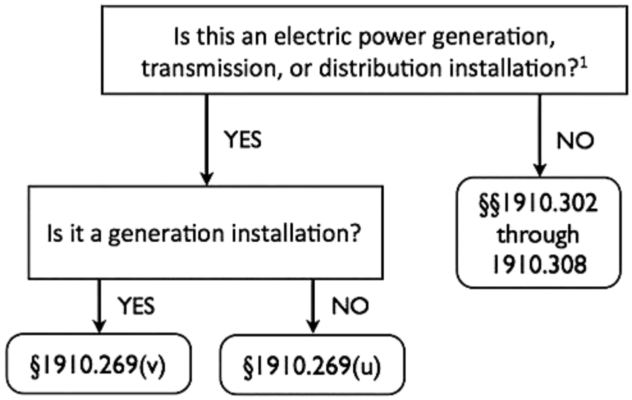

Figure 1.1 Appendix A-1 – Application of 1910.269 and 1910 Subpart S to Electrical Installations. *Source*: Reproduced with permission of U.S. Department of Labor.

to be very familiar with governmental regulations and industry standards regarding safety requirements to ensure the safe operation of the generation facility.

OSHA (Occupational Health and Safety Administration) (osha.gov) issues regulations that cover occupational health and safety. These regulations have the same effect as law. For general industry, which includes utilities, the applicable regulation is OSHA CFR 1910 – General Industry Standards. For general industry, electrical safety is covered under Subpart S. However, under OSHA CFR 1910, there is a separate section for special industries under Subpart R and the electric utility industry is covered under OSHA 1910.269 of Subpart R. This section covers the operation and maintenance of electric power generation systems and equipment and applies to installations utilized for the generation of electrical energy that are accessible only to qualified employees. One might think that all of the requirements for a generation facility fall under OSHA CFR 1910.269 and not OSHA CFR 1910 Subpart S since OSHA CFR 1910.269 regulations were written for electric generation, transmission, and distribution systems, but that is not always the case. So how does a plant engineer know when to apply OSHA 1910 Subpart S (general industry) or OSHA 1910 Subpart R 269 or possibly both regulations? OSHA provides guidance with that question in Appendix A of 1910.269.

To understand how Appendix A addresses this, we need to understand that OSHA segregates its safety requirements into two general categories: electrical safe installation methods and electrical safe work practices.

1910.269 Appendix A-1 as shown in Figure 1.1 answers the question of which regulation (1910.269 or 1910 Subpart S) applies to electrical installation requirements and 1910.269 Appendix A-2 as shown in Figure 1.2 answers the question of which regulation (1910.269 or 1910 Subpart S) applies to electrical safe work practices.

For regulations regarding the safety of the electrical installation, if the facility is directly associated with a generation, transmission, or distribution system, then OSHA CFR 1910.269 is the regulation that describes safe installation requirements. If the facility is not directly associated with generation, transmission, and distribution,

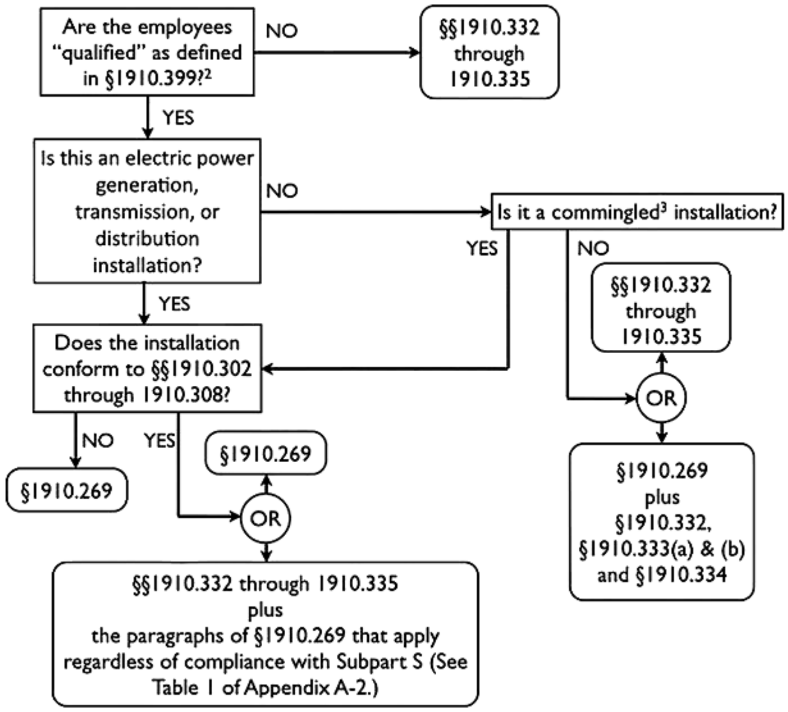

Figure 1.2 Appendix A-2 – Application of 1910.269 and 1910 Subpart S to Electrical Safety-Related Work Practices. *Source*: Reproduced with permission of U.S. Department of Labor.

then 1910 Subpart S applies. For example, if we were to install a motor control center (MCC) in the turbine building of an electric utility generation station, then the safe installation regulations would be defined by 1910.269. However, if we were to install an MCC in a warehouse that is not located on the generation station facility, then the safe installation regulations would be defined by 1910 Subpart S.

The choice of which OSHA standard to use for electrical safe work practices depends both on the location of the work and the qualification of the personnel performing the electrical work. First, we must answer the question, what defines a "qualified person." OSHA defines a *qualified person* as one who has "received training in and has demonstrated skills and knowledge in the construction and operation of electric equipment and installations and the hazards involved" (OSHA 1910.399).

For electrical safe work practice regulations, if the personnel performing the task are not qualified, then the safe work practices of Subpart S are the regulations that govern the work regardless of whether the installation where the work is being performed is on a generation facility or not. For example, if we were to install an air compressor in a generation facility and the equipment supplier is sending a field engineer to assist with startup of the compressor and the field engineer is not trained on the electrical safe work practices of OSHA 1910.269, then the safe work practices for this task must comply with OSHA Subpart S, even though this task is being performed at a generation facility.

However, if the personnel performing the task are qualified AND if the installation is a generation facility, then the safe work practices of 1910.269 apply to the task. So for normal maintenance done at the generation station where the task is performed by station personnel that are trained according to OSHA 1910.269, the tasks are covered under OSHA 1910.269. For commingled installations, the reader is directed to OSHA 1910.269, Appendix A for guidance.

As the reader can see, even though OSHA 1910.269 is written for generation, transmission, and distribution systems, there are instances where OSHA 1910 subpart S applies, so the electric utility engineer must know and understand the installation requirements and safe work practices of both OSHA 1910 Subpart S (general industry) and OSHA 1910.269 (electric utilities).

So where does the electric utility engineer obtain guidance on how to comply with all of these regulations? For the safe installation requirements for general industry described by OSHA 1910 Subpart S (sections 302 to 308), NFPA 70® (National Electric Code® or NEC®) provides guidance on how to comply with these federal regulations. (NFPA 70®, National Electrical Code®, and NEC® are registered trademarks of the National Fire Protection Association, Quincy, MA). For the safe installation requirements for the electric utility industry of OSHA 1910.269, IEEE C2 (National Electrical Safety Code or NESC) provides guidance on how to comply with federal regulations at generation station installations. Specifically, IEEE C2 – Part 1 describes electric supply station installation requirements, IEEE C2 – Part 2 describes overhead line installation requirements, IEEE C2 – Part 3 describes underground line installation requirements.

For the safe work practice requirements for general industry of OSHA 1910 Subpart S (sections 332 to 335), NFPA 70E (Electrical Safety in the Workplace) provides guidance on how to comply with federal regulations. For the safe work practice requirements for the electric utility industry of OSHA 1910.269, IEEE C2 – Part 4 – (NESC) provides guidance on how to comply with federal regulations.

While these codes are not law or regulation, they are referenced by OSHA federal regulation as methods to ensure compliance with the law. Additionally, OSHA regulation updates take many years to occur due to the process of public notification and comment before changing official regulations. However, NEC® is updated every 3 years, NFPA 70E is updated every 4 years, and NESC is updated every 5 years. Therefore, these codes have the most up-to-date information regarding electrical safety. The electric generation utility engineer should have a current copy available of all three of these standards and be familiar with the information contained within. In Chapter 1, we describe just some of the installation and safe work practice information contained in these codes. The reader is reminded to always check the latest version of the codes for updates.

One last note of caution, the OSHA standards and associated codes are NOT design guides, but MINIMUM requirements. When applying these codes, remember that these are the MINIMUM standards to ensure safety; but good engineering practice may suggest additional safety measures in some instances.

INSTALLATION SAFETY REQUIREMENTS—GENERAL INDUSTRY (NEC®)

Access to Working Space <600 V

To ensure the safety of personnel when accessing exposed electrical parts of equipment, minimum equipment clearances are given in codes and standards depending on the nominal voltage of the circuit in question and the equipment. If the structures surrounding the area are neither energized nor grounded (if structures are insulated), then the second column in Table 1.1 applies. If the structure surrounding the area is grounded, then the third column in Table 1.1 applies (note that conductive or partially conductive materials such as concrete are considered grounded). If the structure surrounding the area is energized, then the fourth column in Table 1.1 applies. Additionally, the working space must be of sufficient width, depth, and height to permit all equipment doors to open 90 degrees. The width of the working space must be at least the width of the equipment and cannot be less than 30 in.

Remember that these are minimum requirements. There may be instances where the working space needs to be even larger than the values required by codes. One example where this commonly occurs is in front of switchgear where the breakers can be racked out and removed (this is described in more detail in Chapter 19: Switchgear). The space required for the racking device (including clearance to other energized equipment in the area) commonly is larger than the minimum requirements of code. The design engineer should evaluate both the equipment to be installed and the typical types of maintenance that will be performed and ensure that the working space provided is adequate for personnel safety.

In regard to access to rooms containing electrical equipment, if the service provided is less than 1200 A, then there must be at least one entrance consisting of a minimum of 24-in.-wide by 6-ft-high door provided with panic hardware that allows for egress from the working space by pushing on door from the inside of the building. Where the electrical equipment is wider than 6 ft, there must be two doors.

If the service provided is greater than 1200 A, then a minimum of two, 24-in.-wide by 6-ft-high doors must be provided with panic hardware that allows for egress from either side of working space by pushing on door. This again is an area where

TABLE 1.1 Minimum Aisle Working Space for Nominal Voltage Less than 600 V

Nominal Voltage to Ground (V)	Live to Not Ground or Not Live	Live to Ground	Live to Live
0–150	900 mm 3 ft	900 mm 3 ft	900 mm 3 ft
151–600	900 mm 3 ft	1.1 m 3.5 ft	1.2 m 4 ft

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these are minimum requirements. If, during the process of performing maintenance such as racking out equipment, one means of egress may become blocked, the design engineer would be justified in adding additional means of egress for personnel.

Access to Working Space >600 V

In rooms and enclosures where the voltage exceeds 600 V, NEC® requires rooms to be locked and signage to be posted that reads,

DANGER – HIGH VOLTAGE – KEEP OUT

For equipment that nominally operates in excess of 600 V, Table 1.2 describes the minimum working space requirements. The same conditions for surrounding equipment that applied to Table 1.1 apply to Table 1.2. If the structures surrounding the area is neither energized nor grounded (if structures are insulated) then the second column in Table 1.2 applies. If the structure surrounding the area is grounded, then the third column in Table 1.2 applies. If the structure surrounding the area is energized, then the fourth column in Table 1.2 applies.

Example 1.1 You are designing an MCC that is powered from a 480 Vac phase-to-phase, 277 Vac phase-to-ground source. You will place the MCC in an electrical equipment room where the wall across the aisle from the 480 V circuits is grounded. What is the minimum aisle working space for this application?

Solution: Referring to Table 1.1, we find the minimum aisle working space to be 3.5 ft.

For exposed energized conductors located outdoors, NEC® requires that the conductors be enclosed in a fence that is 7 ft minimum in height. Table 1.3 describes the minimum distance from the fence to the live part being protected.

NEC® defines the minimum allowable branch circuit conductor size for a given branch circuit breaker. Following matrix is a summary of branch circuit minimum conductor sizes based on branch circuit protection.

Breaker	15 A	20 A	30 A	40 A	50 A
Conductor	14 AWG	12 AWG	10 AWG	8 AWG	6 AWG

TABLE 1.2 Minimum Aisle Working Space for Nominal Voltage >600 V Around Electrical Equipment

Voltage ph-gnd	Live vs. Insulated	Live vs. Gnd	Live vs. Live
601 V to 2,500 V	900 mm (3 ft)	1.2 m (4 ft)	1.5 m (5 ft)
2,501 V to 9,000 V	1.2 m (4 ft)	1.5 m (5 ft)	1.8 m (6 ft)
9,001 V to 25 kV	1.5 m (5 ft)	1.8 m (6 ft)	2.8 m (9 ft)
25,001 V to 75 kV	1.8 m (6 ft)	2.5 m (8 ft)	3.0 m (10 ft)
Above 75 kV	2.5 m (8 ft)	3 m (10 ft)	3.7 m (12 ft)

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TABLE 1.3 Minimum Distance from Fence to Live Parts

	Minimum Distance from Fence to Live Parts	
Nominal Voltage	m	ft
601–13,799 V	3.05	10
13,800–230,000 V	4.57	15
Over 230,000 V	5.49	18

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Just to reinforce the notion that codes are not design standards, the size of the conductor recommended by NEC® is not the required conductor size, but the minimum allowable conductor size. For long runs where voltage drop might be an issue, the design engineer might choose to oversize the branch circuit conductor which is acceptable. Codes such as NEC® and NESC are not design guides, but only provide the minimum safety requirements for installation.

Grounding and bonding is so important that it has its own chapter and is described in Chapter 21. But for safety, it is worth mentioning here that NEC® requires the electrical distribution system to be grounded and bonded and requires the electrical distribution system to have one main bonding jumper between the main supply neutral bar and ground bar. The functions of the grounding conductor (also known as neutral conductor) and bonding conductor (sometimes referred to as the grounded conductor) are distinctly different. Downstream equipment enclosures are bonded back to the main supply *ground* bar via the *grounded* conductor and downstream equipment neutral terminations are connected back to the main supply *neutral* bar via the *grounding* conductor. The purpose of the *grounding* conductor is to provide a path for current to return to the source and, if there is a phase-to-neutral fault, this current will clear the upstream breaker to remove the fault from the energized electrical system. The purpose of the *grounded* conductor is not to provide a path for fault current, but to maintain electrical continuity between system ground and equipment enclosures in the field. This is done to minimize touch potentials during faults to protect personnel.

INSTALLATION SAFETY REQUIREMENTS—SPECIAL INDUSTRY – UTILITY (NESC)

Access to Exposed Energized Conductors Outdoor

In some areas of a generation facility, there may be exposed overhead conductors. A typical application is where the plant interfaces with the transmission and distribution system. There are minimum distances that need to be maintained from the general public to these exposed circuit conductors. In order to keep non-qualified personnel from accessing the energized circuits, NESC provides guidance on minimum fence

TABLE 1.4 Values of Minimum Distance from Fence to Outdoor Exposed Energized Conductor for Use with NESC Figure 110-1

Nominal Voltage Between Phases (V)	Typical BIL	Dimension "R" m	ft
151–7,200	95	3	10
13,800	110	3.1	10.1
23,000	150	3.1	10.3
34,500	200	3.2	10.6
46,000	250	3.3	10.9
69,000	350	3.5	11.6
115,000	550	4	13
138,000	650	4.2	13.7
161,000	750	4.4	14.3
230,000	825	4.5	14.9
230,000	900	4.7	15.4

Source: Reproduced with permission of IEEE.

space requirements between energized conductors and the fence. This is very similar to the requirements of NEC® mentioned in Table 1.3.

Table 1.4, along with Figure 1.3, shows the minimum radius from a point on the fence 5 ft from grade to the exposed energized conductor to ensure non-qualified people are not exposed to the hazard presented by exposed energized conductors. Note, the fence height must be 7 ft minimum and the fence must be grounded to

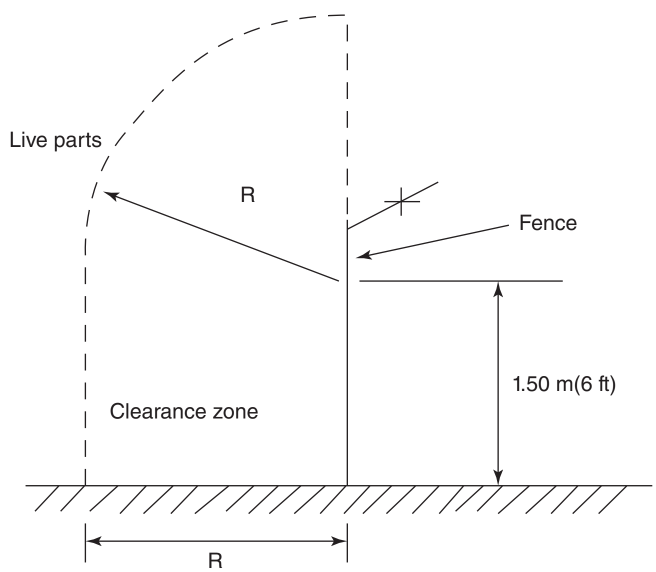

Figure 1.3 Safety clearance to electric supply station fences. *Source*: Reproduced with permission of IEEE.

TABLE 1.5 Minimum Overhead Clearance from Ground to Outdoor Exposed Energized Conductor (for V < 750 Vac)

- 3.6 m (12 ft) – sidewalks and areas accessible to pedestrians only
- 4.9 m (16 ft) – residential driveways, parking lots, and alleys
- 4.9 m (16 ft) – roads, streets, and areas exposed to truck traffic
- 7.3 m (24 ft) – track rails of rail roads

Source: Reproduced with permission of IEEE.

the ground grid to limit touch potential (touch potential is explained in Chapter 21: Ground System).

NESC also provides guidance for exposed overhead lines and minimum clearance from ground depending on the type of traffic that is expected below the exposed lines. This information is found in NESC Part 2, section 232, and summarized in Table 232-1. For example, for exposed conductors energized at less than 750 Vac, the following minimum clearances apply. For areas where only pedestrian traffic is expected, 3.6 m (12 ft) is the minimum clearance from ground to the overhead lines. For areas that transverse residential driveways, parking lots, and alleys, 4.9 m (16 ft) is the minimum clearance from ground to overhead lines. For areas where exposed conductors transverse roads, streets, and areas exposed to truck traffic, 4.9 m (16 ft) is the minimum clearance from ground to overhead lines. For areas where exposed conductors transverse track rails of rail roads, 7.3 m (24 ft) is the minimum clearance from ground to overhead lines. All of these distances are to be maintained during periods of maximum line sag. This data is summarized in Table 1.5.

Example 1.2 You are designing an exposed overhead distribution line that is crossing a sidewalk that will be accessible to pedestrian traffic only. What is the minimum from ground to the overhead line for this application?

Solution: Minimum clearance from ground to overhead line for this application per Table 1.5 is 12 ft.

NESC requires a minimum level of illumination depending on the location or the work place in the generation facility and NESC Table 111-1 provides this guidance. This is to ensure that the area is adequately illuminated for the typical tasks performed in these areas to be performed safely. Table 1.6 is a partial listing of locations in a typical generation facility and the minimum required illumination levels.

In addition to normal lighting requirements listed in Table 1.6, NESC requires emergency lighting to be provided that is energized from an independent source (typically a battery) at locations of egress to provide for safe exit during emergencies such as fire where normal lighting is de-energized. The minimum illumination level at these exits is 11 lux (1 foot-candle) and the independent source must keep the emergency light energized for at least 90 minutes.

Just like NEC®, the NESC requires a minimum amount of working space around electrical equipment. A minimum of 7 ft of head room is required with a

TABLE 1.6 Illumination Levels Required in an Electric Utility Power Generation Station

Location	Lux	Foot-Candles
Generating Station (Interior)		
Highly critical areas occupied most of the time	270	25
Areas occupied most of the time	160	15
Critical areas occupied infrequently	110	10
Areas occupied infrequently	55	5
Generating Station (Exterior)		
Building pedestrian main entrance	110	10
Critical areas occupied infrequently	55	5
Areas occupied occasionally by pedestrians	22	2
Areas occupied occasionally by vehicles	11	1
Areas occupied infrequently	5.5	0.5
Remote areas	2.2	0.2
Substation		
Control building interior	55	5
General exterior horizontal end equipment vertical	22	2
Remote areas	2.2	0.2

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minimum working depth in front of equipment of 3 ft. For voltages <600 Vac, the values in NESC are the same as the values in NEC® as shown in Table 125-1 of NESC as described in Table 1.7. For voltages >600 V, the values in NESC listed in Table 124.1 of NESC as described in Table 1.8.

NESC has requirements for the safety of rotating equipment, safety of battery systems, safety of transformers, conductors, circuit breakers, fuses, and switchgear. These safety requirements are discussed in the respective sections of this book to reinforce the importance of safety in the design and operation of this equipment.

Now that we have discussed installation safety requirements, we will discuss electrical safe work practice requirements.

TABLE 1.7 Working Space <600 V

	Clear Distance					
	Condition 1		Condition 2		Condition 3	
Voltage to Ground (V)	mm	ft	mm	ft	mm	ft
0–150	900	3	900	3	900	3
151–600	900	3	1070	3 − 1/2	1200	4

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Condition 1: Exposed energized parts on one side and no energized or grounded parts on the other side of the working space.

Condition 2: Exposed energized parts on one side and grounded parts on the other side of the working space.

Condition 3: Exposed energized parts on both sides of the working space.

TABLE 1.8 Working Space >600 V

NESC Table 124-1 – Working space >600 V

Column 1	Column C	Column 2		Column 3		Column 4	
Max Design Voltage Between Phases	Basic Impulse Insulation Level (BIL)	Vertical Clearance of Unguarded Parts		Horizontal Clearance of Unguarded Parts		Clearance Guard to Live Parts	
kV	kV	ft	in	ft	in	ft	in
0.3	–	Not specified		Not specified		Not specified	
0.6	–	8	8	3	4	0	2
2.4	–	8	9	3	4	0	3
7.2	95	8	10	3	4	0	4
15	95	8	10	3	4	0	4
15	110	9	0	3	6	0	6
25	125	9	1	3	7	0	7
25	150	9	3	3	9	0	9
35	200	9	6	4	0	1	0
48	250	9	10	4	4	1	4
72.5	250	9	10	4	4	1	4
72.5	350	10	5	4	11	1	11
121	350	10	5	4	11	1	11
121	550	11	7	6	1	3	1
145	350	10	5	4	11	1	11
145	550	11	7	6	1	3	1
145	650	12	2	6	8	3	8
169	550	11	7	6	1	3	1
169	650	12	2	6	8	3	8
169	750	12	10	7	4	4	4
242	550	11	7	6	1	3	1
242	650	12	2	6	8	3	8
242	750	12	10	7	4	4	4
242	900	13	9	8	3	5	3
242	1050	14	10	9	4	6	4

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SAFE WORK PRACTICE REQUIREMENTS

So what are the potential hazards in a power plant environment in regard to safe work practices? Some of the possibilities are electrical shock, arc flash, arc blast, fall, projectiles, and fire ignition.

Electrical shock occurs when a part of the body comes in contact with an energized circuit. To avoid this hazard, the employee must know the various electrical energy sources, be able to identify the voltage level associated with the hazard, determine what actions are necessary to reduce and/or eliminate the hazard, and be allowed to take those actions to avoid the hazard. The preferred method for prevention of electrical shocks is to ensure that the circuit is de-energized by placing it in an electrically safe work condition prior to performing work on that circuit. If it is determined that the circuit cannot be de-energized, then NFPA 70E and NESC Part 4 provide guidance of procedures and equipment to be utilized when *working on* a system energized. This is known as energized electrical work.

In one recent survey of electrical workers, 97% of workers had experienced a shock at work sometime in the past and 58% were exposed to energized circuits every day. One might think that a majority of the incidents involve younger, less experienced workers. However, one survey shows the following distribution of electrocutions by age.

- <20 = 10%
- 20–24 = 18%
- 25–34 = 34%
- 35–44 = 22%
- 45–54 = 10%
- >55 = 6%

As can be seen from the above data, the most likely age range is the 25–34 year range. Therefore, the concept that experience makes one less likely to be involved with an electrical contact incident is incorrect. In fact, there are more than 30,000 electrical contact events that happen every year in the United States. A majority of these occur on system voltages less than 600 V. One may think that higher voltages may present higher hazards, but from a frequency of incident viewpoint, this is not the case. The hazard exists on any energized circuit.

Identifying circuit parts that are “exposed live parts” may not be as straight forward as one would think. An energized uncovered bus bar in a piece of electrical equipment is an “exposed live part” for certain. However, how about the covered bus shown in the photo in Figure 1.4?

The cable jacket that provides the covering on the cable has a dielectric rating for the voltage involved and is therefore considered insulated. However, the covering on the bus does not have a dielectric rating and is not considered insulated and therefore should be treated as an energized circuit until it is placed in an electrically safe working condition.

In order to avoid electrical shock hazards, a shock hazard analysis should always be performed whenever work is to be performed on or near energized electrical equipment. A shock hazard analysis is a procedure where the voltage level of the circuit is determined; all potential sources supplying the circuit are determined and then all sources are isolated by putting the circuit in an electrically safe working condition. The shock hazard analysis should also determine the necessary PPE required to safely test the circuit for the absence of voltage during the process of placing the circuit in an electrically safe work condition.

Table 1.9 describes the effect that current passing through a body has on the body. The higher value is for larger framed bodies and the lower value is for smaller framed bodies.

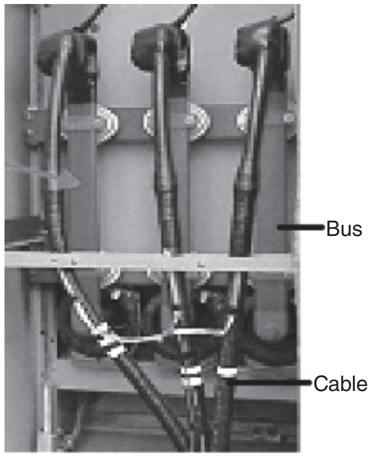

Figure 1.4 Photo of load termination compartment in typical medium voltage switchgear.

To place a circuit in an electrically safe work condition, the employee must perform the following minimum steps.

- Determine all possible sources (include stored or induced energy)
- Interrupt the load, if the isolation device is not rated to interrupt load
- Isolate the conductor or circuit part from the energized electrical system
- Visually verify the isolation
- Lock and/or tag the isolation device(s)
- Test the circuit to ensure the absence of voltage
- If the potential for induced voltages exist, ground the circuit

Control circuits are never to be used as a means of lockout. Only equipment designed for the purpose of lockout should be used as isolation boundaries. For

TABLE 1.9 Effects on the Human Body from Contact with Energized Circuits

	AC Current (A)	
Effect of Current	High	Low
Perception threshold (tingling)	0.001	0.0007
Slight shock – not painful (no loss of ctrl)	0.0018	0.0012
Shock – painful (no loss of ctrl)	0.009	0.006
Shock – severe (muscle ctrl loss, breathing difficulty)	0.023	0.015
Possible ventricular fibrillation (3 sec shock, “let go” threshold)	0.1	0.1
Possible ventricular fibrillation (1 sec shock)	0.2	0.2
Heart muscle activity ceases	0.5	0.5
Tissue and organs burn	1.5	1.5

Source: Reproduced with permission of National Institute for Occupational Safety and Health (NIOSH).

example, a pull cord on a conveyor belt is interlocked with a contactor to de-energize the contactor when the pull cord is activated. While the pull cord is an important safety interlock, it should never be used as a means for isolation for lockout. The reason for this is that the device that isolates power (the contactor) is not locked and could be mechanically pulled in to energize the circuit, thereby bypassing the locking device and the protection of the lock.

Until all of the these steps are completed (this includes testing the circuit and grounding the circuit if required), the circuit must be considered energized and working on the circuit must be considered as energized electrical work. You may realize at this point that the task of testing the circuit to ensure the absence of voltage alone is considered energized electrical work and requires the proper personnel protective equipment (PPE) and safe work practices, since the process of testing a circuit to ensure the absence of voltage may require contact with the circuit before all steps are completed. Electrical safe work practices should be utilized when verifying the absence of voltage. Additionally, when verifying absence of voltage, the meter being utilized should be tested on a known source to verify it is functioning first, then tested on the circuit that is to be put in the electrically safe working condition, and then tested again on a known source to verify if it is still functioning. This is also known as the "test the tester, test the circuit, test the tester" method. This is done to ensure the integrity of the meter used and the validity of the absence of voltage reading. Also ensure that the voltage meter being used is rated for the anticipated voltage level of the system. There have been cases where a worker obtained the incorrect meter and tested a circuit that the meter was not rated for with catastrophic results.

There are two basic methods of lockout/tagout defined by OSHA. The first method known as the simple lockout method which involves only one set of circuit conductors or circuit parts. Each worker is responsible for their own isolation and lock. Under the simple lockout method, a written procedure is not required for each lock. Alternately (and more typical in a power plant environment), the second lockout method is known as the complex lockout/tagout procedure and it involves the use of a lockout procedure. This system is required to be documented. Instead of the individual performing the work being responsible for the isolation, there are three people minimum involved in the isolation procedure. The first is the qualified person in charge of the lockout. The second is the operator that performs the isolation, installs the lock, and verifies that the circuit is de-energized. The third person is the one who is working on the circuit and they are known as the affected person. This system allows for a method to communicate the change of a lockout status to all affected persons.

When it is determined that work has to be performed on equipment that is not put in an electrically safe working condition, then an Electrical Safe Work Permit (ESWP) should be filled out for the task at hand. This is a very useful document, as it guides the affected employee to analyze the circuit and determine the shock and arc flash protection boundaries and the required PPE to work safely. It also forces the persons asking the affected employee to work a system energized to justify why the system cannot be placed in an electrically safe work condition. Specifically, the ESWP has the following items covered and should be filled out and any safety concerns resolved before any energized work is commenced.

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- A description of the circuit
- Justification or need to work energized
- A description of the safe work practices
- Results of the shock hazard analysis
- Determination of shock protection boundaries
- Results of the flash hazard analysis
- The *flash protection boundary*
- The necessary personal protective equipment (PPE)
- Means employed to restrict access
- Evidence of job briefing
- Energized work approval

When working on energized circuits, select the proper equipment and PPE required for the voltage level of the system. Do not use a 600 V-rated volt meter to test a 5000 V circuit just because you “know” it is de-energized. If during the test you find that the equipment is not de-energized, severe injury or death can arise for the misuse of the wrong class of meter. Also, the PPE selected should be rated for the voltage level encountered. Details on the correct PPE to select for various types of hazards can be found from the Occupational Safety and Health Administration informational booklet OSHA 3151-12R 2003.

ELECTRICAL PPE

Electrical PPE can be broken down into two basic categories that are defined by the type of hazard that the PPE is intended to protect against. The first category is *shock protection* PPE. The purpose of shock protection PPE is to provide an electrically insulating barrier between the employee and the energized part. Any part of the employee’s body must be protected from the hazard of electrical shock by the use of electrical PPE when reaching into the *restricted approach boundary* during electrical energized work. Shock protection PPE includes non-conducting hard hats, non-conducting safety glasses, voltage-rated insulating gloves with leather protectors, and insulating sleeves for higher voltages. In addition to these items, types of supplemental shock protection that may be used are dielectric safety shoes, insulated blankets, and insulating floor mats. Figure 1.5 shows the typical type of personal shock protection PPE utilized in the generation station.

The second category of electrical PPE is *arc flash protection* PPE. The purpose of arc flash protection PPE is to provide a thermally insulating barrier between the employee and the energized part to reduce the thermal energy exposure of the employee’s skin in the event of an electrical arcing event. Any part of the employee’s body must be protected from the hazard of an electrical arc flash by the use of arc flash PPE when reaching into the arc flash boundary during electrical energized work or when the employee is interacting with the electrical equipment in a fashion that

Figure 1.5 Photo of typical shock protection PPE. *Source*: Reproduced with permission of OSHA.

could result in an electrical arc flash. The material that forms this thermal barrier is treated to inhibit the material from igniting when exposed to elevated temperatures up to the energy values that the material is rated for. The energy value that the material has been tested to is known as the *arc rating* (AR) or *arc thermal performance value* (ATPV). ATPV is defined as the arc incident energy required to cause the onset of second-degree burn under the material that is being tested. Arc-rated PPE should not be confused with *flame-resistant* (FR) PPE. FR PPE is treated such that it does not support combustion once the ignition source is removed, but FR PPE is not tested for its response to electrical arcs like AR-rated PPE is. When selecting PPE for protection against the hazards of electrical arcs, ensure that the PPE has an AR rating. Figure 1.6 shows the type of personal arc flash protection PPE utilized in the generation station.

Arc flash protection PPE includes arc-rated (AR) shirt and pants or a full AR-rated coverall suit, AR-rated face shield and balaclava or AR-rated hood, and AR-rated gloves. For tasks that involve both electrical hazards and arc flash hazards, electrically rated gloves with leather protectors can be used instead of AR-rated gloves as the leather protectors provide thermal protection and the electrically rated glove provides the electrical protection.

Just as we stressed previously that the equipment utilized should be rated for the voltage exposure of the task, the shock protection PPE that is utilized must be rated for the voltage exposure of the task. For example, insulating gloves have various ratings or classes depending on their test voltage value and maximum allowable working voltage level. See Table 1.10 for information on proper glove selection based on the system working voltage.

Example 1.3 You have been tasked to test a circuit for potential where the circuit is rated for 4160 V. What is the minimum glove class acceptable for this task?

Figure 1.6 Photo of typical arc flash protection PPE. *Source*: Reproduced with permission of OSHA.

Solution: From Table 1.10, the minimum acceptable class of glove is Class 1 which is rated for use up to 7500 Vac. (Note that while Class 0 glove is tested at 5000 V, it is only allowed to be used on voltages up to 1000 V.)

Any object that enters the restricted approach boundary of an exposed energized conductor must provide protection for the employee using the object. We have discussed electrical shock protection PPE, but if an employee uses a tool inside the restricted approach boundary, that tool must also provide insulation between the

TABLE 1.10 Marking of Rubber-Insulated Glove Classes

Definition of Lineman Insulated Glove Classes		
Class Number	Test Voltage	AC Maximum Use Voltage
00	2,500 Vac	500 Vac
0	5,000 Vac	1,000 Vac
1	10,000 Vac	7,500 Vac
2	20,000 Vac	17,000 Vac
3	30,000 Vac	26,500 Vac
4	40,000 Vac	36,000 Vac

Source: Reproduced with permission of OSHA.

Figure 1.7 Typical insulated tools. *Source*: Reproduced with permission of OSHA.

exposed energized conductor and the employee. Insulated tools are rated to withstand at least 1000 V. Note that a metal screwdriver wrapped in electrician's tape does not constitute an insulated tool. Insulated tools have their dielectric strength tested just like shock protection PPE. When performing energized work, only use rated and tested insulated tools. Most types of tools utilized in electrical work are available in insulated versions as shown in Figure 1.7.

In addition to the hazard from electrical shock, there also exists a hazard from an arcing fault from the heat, pressure wave, sound wave, and projectiles that arise from such a blast. When an arcing fault occurs, the temperature of the arc can exceed 35,000°F, which is about four times hotter than the temperature of the sun, and create plasma. Plasma is an ionized gas consisting of positive ions and free electrons. Arcing faults can and do kill at distances exceeding 10 ft depending on the conditions at the time of the event.

To discuss the arc flash hazard, we have to understand some definitions. The hazard associated with heat is defined by the incident energy exposure level which is expressed in calories per square centimeter (cal/cm^2). To put some understanding of the numbers, 1 cal/cm^2 is equivalent to the exposure on the tip of a finger by a cigarette lighter for approximately one second. Also, when looking at damage to the skin that is exposed to heat energy from an arcing event, an exposure energy of only 1.2 cal/cm^2 may cause a second-degree burn on the human skin.

In addition to the hazard presented by the heat of an arcing fault, there are hazards associated with the blast as well. When copper is exposed to an arcing event and expands, it can expand to 67,000 times its solid volume. This rapid expansion creates a pressure wave and sound wave. This pressure wave can create a fall hazard.

Also the pressure wave can cause internal organ damage such as collapsed lungs. The sound wave can cause the sound levels to exceed 160 dB, rupturing ear drums. Associated with the pressure wave is the shrapnel that is in the gas cloud that can leave the source of the arcing fault at speeds exceeding 700 miles/hr which is fast enough to allow shrapnel to completely penetrate the human body.

Below are some definitions specific to arc fault.

- **ATPV**: Maximum incident energy of a PPE system prior to break open.
- **Arc rating**: The value attributed to materials that describe their ability to withstand exposure to an electrical arc discharge. The arc rating is expressed in cal/cm^2 and is derived from the determined value of the ATPV or energy of break-open threshold (EBT) (should a material system exhibit a break-open response below the ATPV value). Arc rating is reported as either ATPV or EBT, whichever is the lower value.
- **Flash hazard:** Condition caused by the release of energy caused by an electric arc.
- **Flashes protection boundary:** Distance from live parts where second-degree burns would result if an arc flash occurred. By definition, this is the distance at which the incident energy level is at 1.2 cal/cm^2.
- **Limited approach boundary:** Distance from live parts where shock hazard exists.
- **Restricted approach boundary:** Distance beyond which only qualified persons may enter because it requires shock protection equipment or techniques.
- **Exposed live part:** Not suitably guarded, isolated, or insulated.
- **Working near (live parts):** Any activity inside a limited approach boundary.
- **Working on (live parts)**: Any activity inside a restricted approach boundary including coming in contact with live parts with body or equipment regardless of PPE.

The arc flash boundary is the distance from the source of an arc where the incident energy level will be 1.2 cal/cm^2, which is enough thermal energy to cause a second-degree burn.

OSHA updated CFR 1910.269 in 2014 (the previous revision was in 1994) and added the following regulation requiring employers to protect their employees from the hazards of arc flash.

1910.269 (I) (8): Protection from flames and electric arcs

(i) The employer shall assess the workplace to identify employees exposed to hazards from flames or from electric arcs.

(ii) For each employee exposed to hazards from electric arcs, the employer shall make a reasonable estimate of the incident heat energy to which the employee would be exposed.

As mentioned previously, an employee must utilize shock protection PPE whenever they are in the restricted approach boundary (for tasks that conform to

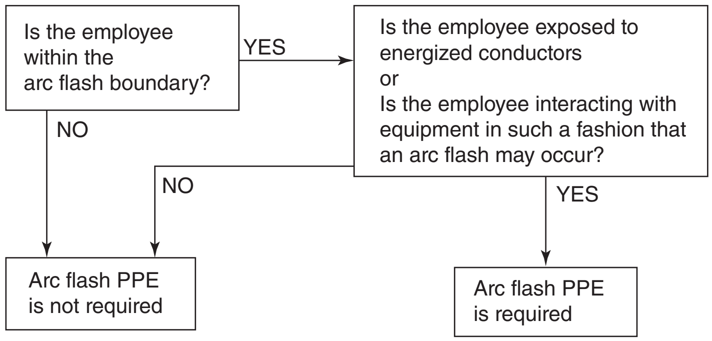

Figure 1.8 Decision matrix if a task requires arc flash PPE.

Subpart S) or whenever they are in the minimum approach distance (for tasks that conform to Part 269). How about arc flash PPE? An employee must utilize arc flash-rated PPE whenever they are exposed to a potential arc flash. So when is that? Whenever the employee is within the arc flash boundary and if the employee is exposed to energized conductors OR if the employee is interacting with the equipment in such a fashion as they could be exposed to an arc flash, then the employee must utilize arc-rated PPE. The flow chart in Figure 1.8 depicts this explanation.

OSHA allows for the use of tables such as those found in NESC or by analysis. Appendix E of OSHA 1910.269, as is shown in Table 1.11, lists which methods of incident energy calculation are applicable for various voltage levels whether the exposure is in open air or in an enclosure.

For voltages less than 15 kV, OSHA recommends the use of NFPA 70E tables or IEEE 1584 equations as methods to determine the incident energy levels. For voltages in excess of 15 kV, OSHA does not recommend the use of NFPA 70E or IEEE1584, but rather recommends ARCPRO for analysis or NESC tables can alternately be utilized. IEEE 1584 and ARCPRO analysis methods tend to be calculation-intensive.

TABLE 1.11 Allowable Methods for Selection of Arc Flash Boundary and PPE

Incident Energy Calculation Method	600 V and Less			601 V to 15 kV			More than 15 kV		
	1P	3PA	3PB	1P	3PA	3PB	1P	3PA	3PB
NFPA 70E-2012 Annex D (Lee equation)	Y-C	Y	N	Y-C	Y-C	N	N	N	N
Doughty, Neal, and Floyd	Y-C	Y	Y	N	N	N	N	N	N
IEEE Std 1584b-2011	Y	Y	Y	Y	Y	Y	N	N	N
ARCPRO	Y	N	N	Y	N	N	Y	Y	Y

Source: Reproduced with permission of OSHA.
1P: Single-phase arc in open air.
3PA: Three-phase arc in open air.
3PB: Three-phase arc in an enclosure (box).
Y: Acceptable – produces a reasonable estimate of incident heat energy from this type of electric arc.
N: Not acceptable – does not produce a reasonable estimate of incident heat energy from this type of electric arc.
Y-C: Produces a reasonable, but conservative, estimate of incident heat energy from this type of electric arc.

ARCPRO and IEEE 1584 analysis software takes into account many variables such as the voltage level of the system, the gap between buses, the clearing time of the device, and other parameters that affect the value of the incident energy level. Due to the complexity of these calculations, the details of these calculations are beyond the scope of this introductory material. Normally, a computer-based software is utilized to obtain results (Note: IEEE provides spreadsheet along with IEEE 1584 to assist in calculations of incident energy levels). Below we will explain the use of the table method in NFPA 70E that OSHA allows for systems less than 15 kV and we will explain the use of the table method in NESC that OSHA allows for systems over 15 kV.

ARC FLASH ANALYSIS UTILIZING NFPA 70E TABLES

The arc flash PPE category and arc flash boundary can be determined using NFPA 70E Table 130.7(C)(15)(A)(b) – Arc-Flash Hazard PPE Categories for Alternating Current (ac) Systems or Table 130.7(C)(15)(B) – Arc-Flash Hazard PPE Categories for Direct Current (DC) Systems.

These tables break the task down to three questions: What is the type of equipment that the task involves? What is the maximum short-circuit current available? And what is the maximum fault clearing time? With those three pieces of information, the tables can be used to determine the arc flash PPE category (based on a working distance given in the table) and the arc flash boundary. Remember that if the task is being done outside the arc flash boundary, then arc flash PPE is not required because the incident energy level is less than 1.2 cal/cm^2. The student can access NFPA 70E® online at http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=70E. In NFPA 70E, Table 130.7(C)(15)(A)(b) (Arc-Flash Hazard PPE Categories for Alternating Current (AC) Systems) provides guidance to the arc flash PPE category and arc flash boundary for AC systems for various types of equipment. Note that the short-circuit current available, the maximum clearing time, and the working distance are all important parameters to the table. To utilize the tables, the actual short-circuit current must be equal to or less than the value given in the table, the actual clearing time must be equal to or less than the value given in the table, and the working distance must be equal to or greater than the value given in the table. Similarly, for DC systems, Table 130.7(C)(15)(B) (Arc-Flash Hazard PPE Categories for Direct Current (DC) Systems) provides guidance to the arc flash PPE category and arc flash boundary for DC systems for various types of equipment. Just as for the AC table, the short-circuit current and clearing time of the actual application must be equal to or less than the value in the table and the working distance must be equal to or greater than the value in the table.

Example 1.4 You have been given a task of pulling a molded case circuit breaker from a 120/240 Vac panel. The fault current at the panel is 10 kA and the panel is protected by a current limiting fuse, so the clearing time is 1 cycle. What is the arc flash boundary and what is the arc flash PPE required to perform the above task?

Solution: To solve, the student will need to view the current NFPA 70E standard at: http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=70E.

From Table 130.7(C)(15)(A)(b) first row, which lists the requirements for panels with voltages at 240 Vac and below and short-circuit currents of 25 kA and clearing time less than 2 cycles, we find that the arc flash PPE required is Category 1 at a distance of 18 in. and the arc flash boundary is 19 in.

So what is arc flash PPE Category 1? NFPA 70E breaks down arc flash categories into four levels based on a range of energy exposure possible. Arc flash PPE Category 1 must protect again an incident energy level of at least 4 cal/cm^2. Arc flash PPE Category 2 must protect again an incident energy level of at least 8 cal/cm^2. Arc flash PPE Category 3 must protect again an incident energy level of at least 25 cal/cm^2. Arc flash PPE Category 4 must protect again an incident energy level of at least 40 cal/cm^2. Notice that there is no category above 40 cal/cm^2. This is because at energy levels that high, heat is not the only hazard to personnel but also hot gases, projectiles, pressure wave, and UV radiation. Due to the magnitude of these other hazards, there is no level of PPE that can protect a person at energy levels in excess of 40 cal/cm^2.

Example 1.5 A task has been assigned to remove a molded case circuit breaker from a 120 Vac panel where there is a maximum bolted fault value of 8 kA and the clearing time is 5 cycles; can you use the tables in NFPA 70E for the determination of the correct arc flash PPE for this task? If you can, what is the arc flash PPE level required for this task?

Solution: To solve, the student will need to view the current NFPA 70E standard at: http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=70E.

You could not use the table to determine the PPE, but have to perform a full arc flash analysis. This is because the table lists only one row for 240 Vac panels and it has the limits of a maximum fault current of up to 25 kA and maximum clearing time of up to 2 cycles. Since clearing time of this application is actually 5 cycles, the tables cannot be used and an analysis must be performed.

Example 1.6 You have been given a task of pulling a molded case circuit breaker from a 125 Vdc panel. The fault current at the panel is 10 kA and the panel is protected by a current limiting fuse, so the clearing time is 1 cycle. What is the arc flash boundary and what is the arc flash PPE required to perform the above task?

Solution: To solve, the student will need to view the current NFPA 70E standard at: http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=70E.

From Table 130.7(C)(15)(B) third row, which lists the requirements for panels with voltages between 100 Vdc and 250 Vdc and short-circuit currents between 7 kA and 15 kA and clearing time less than 2 seconds, we find that the arc flash PPE required is Category 3 at a distance of 18 in. and the arc flash boundary is 6 ft.

The hazard of arc flash can be minimized by proper equipment design and proper operational procedures. PPE should be a last resort to meeting the requirements of arc flash protection. The incident energy of the arc flash hazard is primarily a function of current and time. By specifying low current let through fuses, equipment on the downstream side of fuses can have reduced incident energy levels. Current limiting fuses can provide a dramatic reduction of incident energy levels if the value for arcing current is within the current limiting range of the fuse. When the fuse is applied such that the arcing current is within the current limiting range of the fuse, the fuse will clear this fault current in less than one cycle. One drawback of using the current-limiting fuse is the difficulty in trying to coordinate downstream protection devices with the fuse. Therefore, current-limiting fuses are used only when they are the last circuit-protective device on the radial feeder.

Relay settings are another method of providing faster trip times for electrical equipment. The challenge for the protection engineer is to provide long enough trip settings to allow for both normal system operations such as motor locked rotor currents when starting and to allow for coordination of the protective system such that, when a fault occurs, the relays operate fast enough to provide minimum amount of incident energy levels at the equipment where the fault occurs and still allow for acceptable coordination.

The above discussion addressed arc flash as defined by NFPA 70E which is the standard OSHA recommends for voltages of 15 kV and below. For voltages in excess of 15 kV, OSHA recommends use of NESC. NESC arc flash tables were substantially updated in the 2012 version. Table 410-1, as shown in Table 1.12, addresses arc flash PPE requirements for various types of equipment for voltages of 50 Vac to 1000 Vac. Table 410-2, a portion of which is shown in Table 1.13, addresses arc flash PPE requirements for voltages from 1.1 kV to 46 kV based on the system voltage level, maximum fault current level, and maximum fault clearing time. Table 410-3 addresses arc flash PPE requirements for voltages in excess of 46 kV based on the system voltage level, maximum fault current level, and maximum fault clearing time.

TABLE 1.12 Clothing Systems for Voltages <1 kV

	Nominal Voltage Range and cal/cm^2		
Equipment Type	50–250 V	251–600 V	601–1000 V
Self-contained meters/cabinets	4	20	30
Pad-mounted transformers	4	4	6
CT meters and control wiring	4	4	6
Metal-clad switchgear/MCCs	8	40	60
Pedestals/pull boxes/hand holes	4	8	12
Open air (includes lines)	4	4	6
Network protectors	4	>60	>60
Panel boards – single-phase (all)/three-phase (<100 A)	4	8	12
Panel boards – three-phase (>100 A)	4	>60	>60

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TABLE 1.13 Clothing Systems for Voltages >1 kV

		4-Cal System	8 Cal-System	12-Cal System
Phase-to-Phase Voltage (kV)	Fault Current (kA)	Max Clearing Time (cycles)	Max Clearing Time (cycles)	Max Clearing Time (cycles)
1 to 15	5	46.5	93	139.5
	10	18	36.1	54.1
	15	10	20.1	30.1
	20	6.5	13	19.5
15.1 to 25	5	27.6	55.2	82.8
	10	11.4	22.7	34.1
	15	6.6	13.2	19.8
	20	4.4	8.8	13.2
25.1 to 36	5	20.9	41.7	62.6
	10	8.8	17.6	26.5
	15	5.2	10.4	15.7
	20	3.5	7.1	10.6

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Example 1.7 You have been given the task of performing a phase check between two circuits energized at 22 kV. The maximum fault current level is 10 kA and the maximum clearing time is 5 cycles. What is the minimum arc flash PPE required for this task?

Solution: From NESC Table 410-2 (Table 1.16 in text book) we can see that for 22 kV, a fault current level of 10 kA, and a 5 cycle clearing time, a 4 calorie suit will provide adequate protection.

Approach Boundaries

The minimum distance that a person is permitted to get to an exposed energized conductor is defined by the approach boundary. This boundary is for shock protection, not arc flash protection. As such, this only applies when energized conductors are exposed. Keep in mind that the arc flash boundary may lie within the approach boundaries or may be outside of the approach boundaries. The definitions of the approach boundaries are listed below.

- **Limited approach boundary:** Distance from live parts where shock hazard exists. Persons must either be qualified or be escorted by a qualified person to enter the limited approach boundary. Note, there is a value for a fixed conductor and another value for a movable conductor. Unqualified persons are not permitted to cross the restricted approach boundary even when escorted by a qualified person.

- Restricted approach boundary: A distance beyond which only qualified persons may enter because it requires shock protection equipment or techniques. It is considered the same as making contact with the energized conductor. Inside the restricted approach boundary, the employee must utilize shock protection PPE, insulated tools, and safe energized electrical work practices.

Prior to the 2015 version of NFPA 70E®, there was also a "prohibited approach boundary," but this term was removed as of the 2015 version of NFPA 70E®. The values for boundary distances are given in NFPA 70E, Table 130.4 (D) (a) for AC systems and Table 130.4 (D) (b) for DC systems. The student is encouraged to view the current NFPA 70E standard at: http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=70E.

HAZARDOUS/CLASSIFIED AREAS

In environments where ignitable and/or combustible materials are stored, handled, or utilized, where the materials may be in sufficient quantities to introduce a fire or explosion hazard, the area must be classified as to the type of hazard. Equipment utilized in a classified area must be rated for service in this area. The equipment must be labeled for the area classification, the gas classification group, and the operating temperature of the equipment. For Class I equipment, the operating temperature of the equipment must be less than the autoignition temperature of the material presenting the hazard for that area. Additionally, threaded metallic conduit that presents a conductive path must be wrench tight. Equipment with conductive panels and surfaces must have panels and surfaces solidly secured such that a good path for conduction of fault current is present. Flexible metallic conduit must utilize a grounding bushing on each side of the metallic conduit and have a *bonding jumper* in parallel with the flexible metallic conduit to provide this path for the conduction of fault currents. The goal is to ensure that, should fault current flow in the metallic materials, there are no high impedance connections between metallic parts that can present and arc/spark hazard in the hazardous environment providing an ignition source. NEC® also requires that any equipment utilized in a classified area be selected under the supervision of a registered professional engineer. The process of calculations and the results of the calculations for area classification are required to be documented.

The NESC refers the user back to the NEC® articles 500 to 517 for classification of hazardous areas but NESC provides additional requirements in section 127. For example, NESC127G prohibits gaseous hydrogen storage from being located beneath electric power lines. The National Electrical Code® provides for two types of area classification, the "Class" system and the "Zone" system. To date, a majority of electric utility locations in the United States that require compliance with NEC® utilize the "Class" system.

Because of this, the "Class" system will be introduced first and the "Zone" system second. However, either system, when properly administered, will satisfy the requirements of NEC®, NFPA standards, and OSHA requirements.

CLASSIFIED AREA – "CLASS" SYSTEM

In the "Class" system, there are three classes of materials. The "class" of the system is based on the material that poses the hazard to the area. Under the "class" designation, there is a sub-designation of division. The division of the system is based on whether the material is found in the area under normal operation in quantities and form sufficient to pose a hazard, or whether the material would only be present in an abnormal condition. Additionally, a Division 1 area cannot be adjacent to an unclassified area. There must be a Division 2 area between the unclassified area and the Division 1. The NEC®-defined values for the "Class" system of area classification are listed below.

- Class I location where flammable gases or vapors may be present in air to an explosive level
  - Division 1 – Flammable gases or vapors exist under normal operations or frequently or faulty equipment operation may cause simultaneous failure of electrical equipment
  - Division 2 – Flammable gases or vapors are used, but not normally in explosive concentrations or concentration prevented by positive mechanical ventilation or is adjacent to Class I, Division 1
- Class II location where combustible dust may be present
  - Division 1 – Combustible dusts exist under normal operations or faulty equipment operation may cause simultaneous failure of electrical equipment or where combustible dusts are electrically conductive
  - Division 2 – Combustible dusts not normally in explosive concentrations or concentration may prevent cooling of electrical equipment
- Class III location where easily ignitable fibers may be present
  - Division 1 – Where fibers are produced, handled, or used
  - Division 2 – Areas where stored or handled other than manufacturing process

Example 1.8 The filling station for the hydrogen storage tanks for a power generation facility has been deemed as a location where, under normal operations of filling the storage tank with hydrogen (a flammable gas), the area will frequently contain an explosive mixture of hydrogen when the relief value lifts. What are the correct class and division for this hazardous area classification?

Solution: This would be Class I (flammable gas or vapor), Division 1 (Flammable gases or vapors exist under normal operations or frequently).

For the "Class" system of area classification, the appropriate standards to provide guidance on the classification of the locations are NEC® – National Electrical Code®, NFPA 497 – Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Area, and NFPA 499 – Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Area.

NFPA 497 provides guidance to the classification of flammable liquids, gases, and vapors. Below are some definitions that are useful to understand the application of classified systems.

The autoignition temperature (AIT) of a material is the minimum temperature required to initiate or cause self-sustained combustion of the material independently of the external heating device.

The flash point of a material is the minimum temperature at which a liquid gives off vapor in sufficient quantity to form an ignitable mixture.

A combustible liquid is any liquid that has a flash point at or above 100°F, (37.8°C). Combustible liquid classifications are broken down into three levels:

- Class II liquid – Any liquid that has a flash point at or above 100°F (37.8°C) and below 140°F (60°C)
- Class IIIA liquid – Any liquid that has a flash point at or above 140°F (60°C) and below 200°F (93°C)
- Class IIIB liquid – Any liquid that has a flash point at or above 200°F (93°C)

Combustible liquids will form an ignitable mixture only when heated above its flash point. Flammable liquids will evaporate at a rate that depends on its volatility. The lower the flash point of a material, the greater the volatility, and the faster the evaporation.

A flammable liquid is any liquid with a flash point below 100°F, (37.8°C). Their classification is broken down into four levels:

- Class I liquid – Any liquid that has a flash point below 100°F (37.8°C).
- Class IA liquid – Any liquid that has a flash point below 73°F (22.8°C) and a boiling point below 100°F (37.8°C).
- Class IB liquid – Any liquid that has a flash point below 73°F (22.8°C) and a boiling point at or above 100°F (37.8°C).
- Class IC liquid – Any liquid that has a flash point at or above 73°F (22.8°C), but below 100°F (37.8°C).

The maximum experimental safe gap (MESG) is the maximum clearance between two parallel metal surfaces that has been found to prevent an explosion from being propagated from one chamber to another chamber normalized to methane. The minimum igniting current ratio (MIC ratio) is the ratio of the minimum current required from an inductive spark discharge to ignite the most easily ignitable mixture of a gas or vapor, divided by the minimum current required from an inductive spark discharge to ignite methane under the same conditions. A lower MIC ratio means less current is required to instigate ignition.

Combustible materials in Class I (liquids and vapors) are divided into four groups depending on their MESG or their MIC ratio. These groups are as follows:

- Group A – Acetylene.
- Group B – Flammable gas or vapor that has either an MESG less than or equal to 0.45 mm or an MIC ratio of 0.40 or less. A typical Class I, Group B material is hydrogen.

- Group C – Flammable gas or vapor that has either an MESG greater than 0.45 mm and less than or equal to 0.75 mm or an MIC ratio greater than 0.40 and less than 0.80. A typical Class I, Group C material is ethylene.
- Group D – Flammable gas or vapor that has either an MESG greater than 0.75 mm or an MIC ratio greater than 0.80. A typical Class I, Group D material is Propane.

The minimum ignition energy (MIE) is the minimum energy required from a capacitive spark discharge to ignite the most easily ignitable mixture of gas or vapor.

Air density is an important property as it determines if gases will settle to the ground level, collect and displace air, or if the gases will tend to raise and disperse. Vapor density values less than 1.0 means the gas is lighter than air and will tend to dissipate rapidly in the atmosphere. Vapor density values greater than 1.0 means the gas is heavier than air and will tend to fall to grade elevation and collect in low-lying areas displacing air until they are force-ventilated away from the area.

NFPA 497, as shown in Table 1.14, provides tables with physical properties of flammable liquids, gases, and vapors to help with the classification process. Typical information is shown in Table 1.14 for several gases.

Example 1.9 The filling station for the hydrogen storage tanks has been deemed a classified area. What group letter is this gas?

Solution: This is a Group B gas (see definition of combustible material groups).

TABLE 1.14 NFPA 497 Table 4.4.2 – Selected Chemical Properties

Chemical	CAS No.	Class I Division Group	Flash Point (°C)	AIT (°C)	% LFL	% UFL	Vapor Density (Air = 1)
Hydrogen	1333-74-0	Bd		520	4.0	75.0	0.1
Hydrogen cyanide	74-90-8	Cd	−18	538	5.6	40.0	0.9
Hydrogen selenide	7783-07-5	C					
Hydrogen sulfide	7783-06-4	Cd	−18	260	4.0	44.0	1.2
Isoamyl acetate	123-92-2	D	25	360	1.0	7.5	4.5
Isoamyl alcohol	123-51-3	D	43	350	1.2	9.0	3.0
Isobutane	75-28-5	Dg		460	1.8	8.4	2.0
Isobutyl acetate	110-19-0	Dd	18	421	2.4	10.5	4.0
Isobutyl acrylate	106-63-8	D		427			4.4
Isobutyl alcohol	78-83-1	Dd	−40	416	1.2	10.9	2.5

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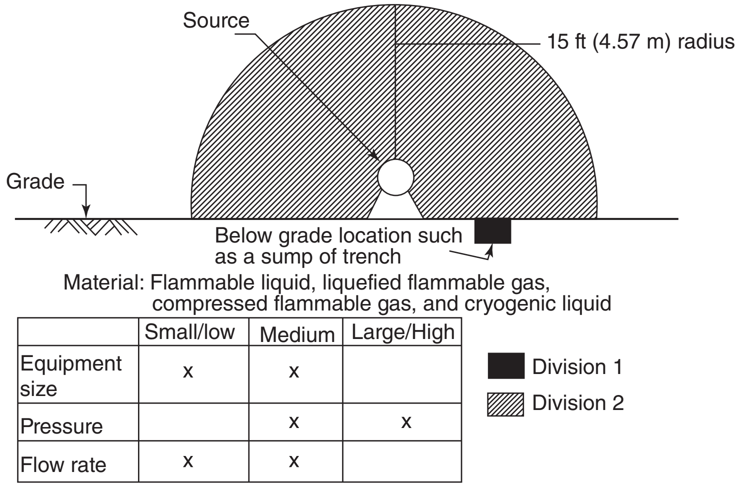

	Small/low	Medium	Large/High
Equipment size	x	x	
Pressure		x	x
Flow rate	x	x	

Figure 1.9 NFPA 497 Table 5.9.2 (a) – Leakage located outdoors, at grade. The material being handled could be a flammable liquid, a liquefied or compressed flammable gas, or a flammable cryogenic liquid. *Source*: Reproduced with permission from NFPA 497, *Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*, Copyright © 2012, National Fire Protection Association. This is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety. The student may download a free copy of the NFPA 497 standard at: http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=497.

Example 1.10 The filling station for the hydrogen storage tanks has been deemed a classified area. Will the hydrogen gas tend to displace the surrounding air and settle or will the air tend to displace the hydrogen gas and the hydrogen gas will disperse?

Solution: Hydrogen has a vapor air density of 0.1. This means that the density of hydrogen at standard atmospheric temperature and pressure is 10% of the value of air. Because of this, hydrogen would not settle to the ground level, but disperses quickly in the air.

Note that the upper flammability level in air for hydrogen is 75% and the lower flammability level in air for hydrogen is 4% from Table 1.14. This means that for concentrations below 4% hydrogen or above 75% hydrogen, the mixture of hydrogen and air is not flammable. Also, note the AIT of hydrogen is high at 520°C. Hydrogen is a Class I, Group B material.

NFPA 497 also provides guidance depending on the type of material and the physical layout of the area for dimensions for area classification. Figure 1.9 shows an example of Figure 4.9.2(a) out of the standard which applies to gases with vapor densities greater than 1 (i.e., gases tend to settle to the ground) for outdoor installations for a facility at grade. Notice for this application that the below grade location is a Division 1 location, since gases with vapor densities greater than 1 will tend to accumulate in this location.

NFPA 499 provides guidance for the classification of combustible dusts. By definition under the "Class" system, combustible dusts in sufficient quantity to present a hazard are Class II areas. Below are some definitions that are useful to understand the application of classified systems. Combustible dust is any finely divided solid material 420 microns or less in diameter that presents a fire or explosion hazard when dispersed. Class II combustible dusts are divided into three groups as follows.

- Group E – Atmospheres containing combustible metal dusts. Typical dusts in this group are aluminum, magnesium, or other metallic alloys.
- Group F – Atmospheres containing combustible carbonaceous dusts that have more than 8% total trapped volatiles or that have been sensitized by other materials so that they present an explosion hazard. Typical dusts in this group are coal, carbon black, charcoal, and coke dusts.
- Group G – Atmospheres containing combustible dusts that do not fall into the Group E or Group F designation. Typical dusts in this group are flour, grain, wood, plastic, and other similar chemicals.

Dust particles tend to settle out of the atmosphere and form a layer on equipment. This dust layer acts as a blanket and can reduce the heat removal efficiency of equipment causing equipment skin temperature of operating equipment to rise to values greater than design. This should be taken into account when specifying equipment for Class II areas. Additionally, while dusts suspended in atmosphere may present a hazard, once they drop out of the atmosphere and form layers, if left undisturbed and not in direct contact with the ignition source, they will not present a hazard. However, if a small amount of dust is in the air and provides fuel for a small explosion, the pressure wave may cause the layered material to become airborne, providing substantial amount of additional fuel causing a second and oftentimes more damaging explosion. For this reason, *good housekeeping is essential* in areas classified as Class II hazardous locations. Keeping the amount of material that has settled out on equipment to a minimum will help minimize the damage from any secondary explosions that occur due to the pressure wave displacing layered dusts.

In Class II locations, there are three common methods of ignition. The first method of ignition is having combustible dusts suspended in the atmosphere and an ignition source presents itself. The second method of ignition is when combustible dusts have formed a layer on electrical equipment, reducing the heat removal efficiency of the electrical equipment and the skin of the electrical equipment reaches the AIT of the dust. The third method is when a Group E dust (metal dust) is present either layered or suspended in air and a sufficient amount of current flows through the conductive dust to cause ignition of the dust. In determining whether a Class II area is Division 1 or Division 2, the quantity of dust, its physical and chemical properties, its dispersion properties, and the location of walls and surfaces must all be considered. If either under normal or abnormal operation of equipment, a dust cloud may form, the area should be classified as a Division 1 area. Also if a layer forms on equipment that is greater than 1/8th of an inch in thickness, then this area should be classified

TABLE 1.15 Portion of Table 4.5.2, from NFPA 499

Chemical Name	CAS No.	NEC Group	Code	Layer or Cloud Ignition Temperature (°C)
Chlorinated polyether alcohol		G		460
Chloroacetoacetanilide	101-92-8	G	M	640
Chromium (97%) electrolytic, milled	7440-47-3	E		400
Cinnamon		G		230
Citrus peel		G		270
Coal, Kentucky bituminous		F		180
Coal, Pittsburgh experimental		F		170
Coal, Wyoming		F		
Cocoa bean shell		G		370
Cocoa, natural, 19% fat		G		240

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as a Division 1 area since, in the event of a pressure wave, the layered material may become airborne and present a secondary explosion hazard.

There are also additional hazards due to dusts that do not directly associate with the explosion hazard. Group E dusts, being metallic dusts, can conduct electricity. Therefore, these dusts may provide path for shorts in electrical equipment causing failure of the electrical equipment. The resulting arc from the short may provide the ignition source for explosion. Additionally, certain ferrite-based metals are or may become magnetized by electromagnetic fields and concentrate in areas where EM field exists. Zirconium, thorium, and uranium dusts have extremely low AIT values (some as low as 20°C). This may lead to challenges when handling such dusts.

NFPA 499 provides data on various materials that can form dusts in a facility. It defines the NEC® materials group designation and provides the value of the AIT of the material. It also provides classification diagrams that show recommended dimensions for various area configurations depending on the dust properties and the surrounding area properties. Table 1.15 shows properties for several types of dust from NFPA 499 and Figure 1.10 shows a classification diagram for a Group F or Group G dust in an indoor area from NFPA 499, unrestricted area with operating equipment.

For example, from the data in Table 1.15 for Kentucky bituminous coal, NFPA defines this as a Class F dust with an AIT of 180°C. If a piece of operating equipment were located in an area that handles Kentucky Bituminous Coal and it is determined that this area is to be classified, due to concentration of the dust, the area at the equipment would be a Division 1 area. Then from Figure 1.10, the Division 1 area should extend 20 ft from the equipment. Beyond this, for an additional 10 ft, this would be classified as a Division 2 area. Beyond this, the area is unclassified assuming there are no other sources for hazardous material other than the equipment of this example.

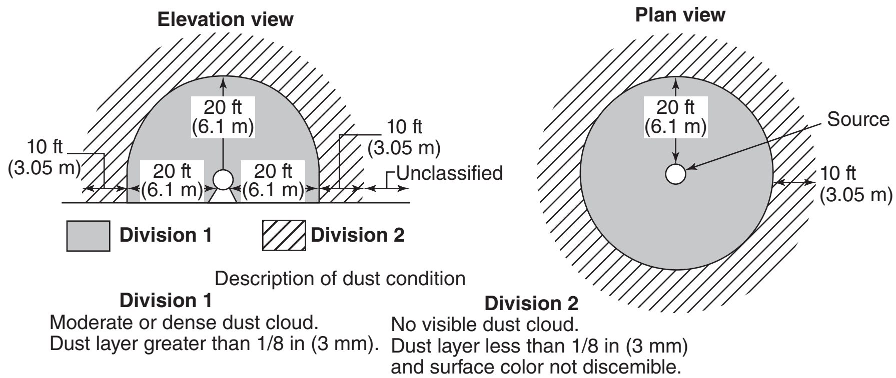

Figure 1.10 Figure 4.8(a) from NFPA 499 – Group F or Group G Dust – Indoor, Unrestricted Area; Open or Semi-Enclosed Operating Equipment. *Source*: Reproduced with permission from NFPA 499, *Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas*, Copyright © 2013, National Fire Protection Association. This is not the complete and official position of the NFPA on the referenced subject, which is represented only by the standard in its entirety. The student may download a free copy of the NFPA 499 standard at: http://www.nfpa.org/codes-and-standards/document-information-pages?mode=code&code=499.

CLASSIFIED AREA – "ZONE" SYSTEM

In the "Zone" system, the hazardous area zone is defined by three items, the type of hazard that is present in the area (defined by the "Class"), the possibility of the hazard being present in sufficient quantities to present ignitable/explosive concentrations (defined by the "Zone"), and the AIT of the hazardous material (defined by the "Group).

In the "Zone" system, the "group" defines the ignitability of the material that presents the hazard to the area. For gases and vapors, the group information provides information as to the energy required to support the combustion process for the material involved. This is denoted by the MIC or the MESG value. NFPA 497 defines three groups.

- Group IIC – Flammable gas or vapor that has either an MESG less than or equal to 0.50 mm or an MIC ratio of 0.45 or less. A typical Class I, zone, Group IIC material is acetylene or hydrogen.
- Group IIB – Flammable gas or vapor that has either an MESG greater than 0.50 mm and less than or equal to 0.90 mm or an MIC ratio greater than 0.45 and less than 0.80. A typical Class I, zone, Group IIB material is acetaldehyde or ethylene.
- Group IIA – Flammable gas or vapor that has either an MESG greater than 0.90 mm or an MIC ratio greater than 0.80. A typical Class I, zone, Group IIA material is acetone, ammonia, ethyl alcohol, gasoline, methane, or propane.

The actual "zone" is a description of the probability of the hazardous material being present in sufficient quantities to present an ignitable/explosive mixture in the environment. There are three zones for gases and vapors.

- A Zone 0 location is where a flammable atmosphere is highly likely to be present and/or may be present for long periods of time or even continuously.
- A Zone 1 location is where a flammable atmosphere is possible but not likely and is most likely not to be present for long periods of time.
- A Zone 2 location is where a flammable atmosphere is unlikely to be present except for very short periods of time. This is also used where under normal equipment operations, the flammable atmosphere is not present, but in the event of equipment malfunction, the flammable atmosphere may become present until equipment is restored.

There are also three zones for dusts and ignitable fibers.

- A Zone 20 location is an area where combustible dust or ignitable fibers and flyings are present continuously for long periods of time and in quantities sufficient to be hazardous.
- A Zone 21 location is an area where combustible dust or ignitable fibers and flyings are likely to exist occasionally under normal operation and in quantities sufficient to be hazardous.
- A Zone 22 location is an area where combustible dust or ignitable fiber and flyings are not likely to occur under normal operation in quantities sufficient to be hazardous.

As a side note, since dusts can settle on equipment and reduce the heat removal efficiency of equipment causing the equipment to run at higher temperature than normal, there may be an equipment derating applied to the AIT of the material for application of equipment.

In addition to classifying the area as to the hazardous material (group) and the likelihood of the material being present in sufficient quantities for ignitable atmosphere (zone) there is an additional classification for equipment temperature classes to ensure the equipment does not approach the AIT of the material presenting the hazard. Equipment rated for operation in classified areas has a rating "T-Class" to define the maximum operating temperature of the equipment. All equipment temperature ratings are based on a temperature rise above a certain maximum ambient temperatures. Unless otherwise listed by the equipment manufacturer, the basis for the T-Class rating is with a maximum ambient temperature of 40°C. Operation of equipment above the maximum allowable rated ambient temperature is not allowed and the equipment must have a T rating based on actual ambient conditions. This is the reason for "derate" when equipment is installed in areas with dusts that can cover equipment and lower the heat removal efficiency of the equipment leading to higher operating temperatures. Below is list of the six basic values for T-Class (there are additional T-Class ratings that some OEMs can provide).

- T_1 – 450°C
- T_2 – 300°C

- T_3 – 200°C
- T_4 – 135°C
- T_5 – 100°C
- T_6 – 85°C

Example 1.11 A classified area will contain Kentucky bituminous coal (see Table 1.15). The lighting fixtures in the room must be rated to operate at a surface temperature below the AIT of the coal. Assuming the maximum ambient temperature of the room is the same as the equipment rating of 40°C, which of the equipment T-Classes will be acceptable?

Solution: For Kentucky Bituminous Coal, the AIT is 180°C (From Table 1.15). For equipment to be utilized in an atmosphere that may contain this material, the equipment should have a T4, T5, or T6 rating. Equipment with a T1, T2, or T3 rating may result in equipment skin temperatures that exceed the AIT of the coal. If the coal is expected to cover the electrical equipment, then a derate may be applied preventing the use of the T4 rating.

BOILER CONTROL AND BURNER MANAGEMENT

Another very important subject in power plant safety is the safe operation of boiler and combustion systems and the unique hazards these systems present. NFPA 85 – Boiler and Combustion System Hazards Code provides guidance to the safe control of these systems to prevent hazards such as implosion or explosion. This standard addresses the minimum requirements for combustion systems and controls. This is a critical system for safety since, under normal operation of a boiler, we intentionally combine air, a combustible material, and an ignition source creating a hazardous atmosphere in the furnace section of the boiler. The hazardous mixture must be safety controlled to ensure that the conditions do not arise that can present an explosive or implosive event.

For most boilers, the positive transient design pressure must be at least +35 inches of water and the negative transient design pressure must be at least −35 inches of water. The positive value is to ensure that the boiler remains intact during a positive pressure excursion and does not explode. The negative value is to ensure that the boiler will remain intact during a negative pressure excursion and does not implode.

NFPA 85 covers areas such as normal startup and shut down procedures as well as procedures used in the event of a boiler trip to ensure that an explosive or implosive condition does not occur. The details for control depend on the type of system involved. Below is an introductory discussion of some of the requirements for NFPA 85. For more detailed information, the reader is advised to refer to the latest copy of NFPA 85.

At minimum, there are several interlocks required to ensure proper boiler controls. When the control system detects a loss of flame in the burner, the system must remove the fuel source to the burner and isolate the ignition source. This is because, if the fuel being supplied to the burner system is not being combusted in the furnace section, then the explosive mixture of air and fuel may remain in the boiler and in the duct system downstream. Any point that presents an ignition source (like the rotating air preheater member causing a momentary spark during rotation) could lead to an explosion of the system.

If an induced draft (ID) fan is tripped, the associated dampers to that fan should be closed unless that is the last ID fan in service. Additionally, if the ID and forced draft (FD) fans are paired, then the associated FD fan should be tripped and its associated damper closed as well. This is done to minimize the pressure transient that may occur if an ID fan tripped but the associated FD fan did not. If the last ID fan in service is tripped, then the dampers should remain full open. This is to allow for the removal of combustibles from the boiler utilizing natural ventilation and/or the ventilation of the associated FD fan. Also on the loss of all ID fans, the master fuel trip should be activated to remove fuel from the burner. Additionally, if furnace pressure exceeds (either positive or negative) pressure values provided by the boiler OEM, the master fuel trip will also be activated to safely shut the boiler down. When starting and stopping ID/FD fans, a specific sequence is required to ensure that the boiler pressure rating is not exceeded. First, an open-air path from suction to discharge of the air system must be established and verified. Since the FD fan is on the inlet side of the boiler and regulates the airflow through the boiler, and the ID fan is on the outlet side of the boiler regulating boiler pressure, the ID fan is started first so that we are able to maintain boiler pressure control. This is to ensure that the boiler does not experience a positive pressure transient during startup of the associated FD fans. Once the ID fan is started, the associated FD fan is started. Dampers are partially closed during startup to minimize load on the motors and minimize the associated time required for acceleration to speed. When shutting down an FD and ID fan train, the FD fan is stopped first, followed by the associated ID fan for the same reasons (ensure we can maintain boiler pressure with ID fan).

The above discussion presented some of the interlocks from the air side of the combustion equation. From the fuel side of the combustion equation, there are also specific responses that NFPA 85 calls out for during certain events. The primary air (PA) fan provides the transport of the fuel from the pulverizer to the combustion chamber. If the PA fan trips, the fuel valve or feeder equipment shall also be tripped that is associated with that PA fan. For a pulverized system, failure of a pulverizer shall trip the associated PA fan. Loss of coal feed to the burner must trip the associated feeder, unless the igniters are Class 1 igniters. The reason for the exception for Class 1 igniter is the amount of energy output from the igniter is sufficient to sustain a flame in the burner area until the coal feed is reestablished. In NFPA 85, igniters are broken down into the following classes.

- Class 1 igniter – An igniter that is applied to ignite the fuel input to a burner and support ignition under any burner conditions. It will provide sufficient ignition energy usually in excess of 10% of full-load burner output at its associated burner to raise any combination of burner fuel–air mixtures above the minimum ignition temperature.

- Class 2 igniter – An igniter that is applied to ignite the fuel input to a burner and support ignition only under certain prescribed light-off conditions. It may also be used to support burner operations during operating conditions. The range of ignition energy is usually between 4% and 10% of full-load burner output at its associated burner.
- Class 3 igniter – An igniter that is applied to ignite the fuel input to a burner and support ignition only under certain prescribed light-off conditions. The range of ignition energy is usually less than 4% of full-load burner output at its associated burner.
- Class 3 special igniter – A special Class 3 high energy electrical igniter that is capable of directly igniting the main fuel burner.

Example 1.12 An igniter for a burner is chosen such that the range of ignition energy is usually between 4% and 10% of full-load burner output at its associated burner. What class of igniter is this?

Solution: This is a Class 2 igniter as defined in NFPA 85.

Once the FD and ID fans are started, the dampers and burner registers are adjusted to the purge position and airflow is adjusted to the “purge airflow” position and the unit purge is started. The purpose of the unit purge is to purge the air inside the boiler sufficiently to ensure that the level of combustibles is reduced to the point where an explosive environment does not exist and the burners can be safely lit off by the igniters. Once the purge is complete, the air register or damper on the burner is adjusted to the “light-off” position, the ignitor valve is opened, and the source of ignition for the igniter will be energized. If a flame is not established within 10 seconds, the igniter valve is closed and “light off” is not reattempted until the cause for the failure to ignite is determined and corrected. After a stable igniter flame is established in the combustion zone, the air register or damper is adjusted to its “operating” position.

The above discussion is a very brief overview of one type of boiler/burner system from NFPA 85. NFPA 85 is broken into several sections and has much more detailed information pertaining to the control of each type of equipment. Table 1.16 lists the various sections of NFPA 85 and to which type of boiler they apply.

The reader is encouraged to review in detail the requirements of the standard for their specific system.

In summary, the primary function of an energy production systems engineer is to ensure both safety and reliability in the systems and procedures utilized in a generation facility. Of these two functions, safety is paramount. This includes both safe installation of equipment and the utilization of safe work practices. The typical electric utility generation station may contain several areas of concern such as electrical hazards, combustible atmospheres and materials, confined space requirements, slip, trips, and falls. As the safety of plant operations is improved, the reliability of the station will benefit also.

TABLE 1.16 NFPA 85 Section Descriptions

Section Number	Description
8501	Single-burner boiler operations
8502	Multiple-burner boiler furnaces
8503	Pulverized fuel systems
8504	Atmospheric fluidized bed boiler operation
8505	Stoker operation
8506	Heat recovery steam generators

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GLOSSARY OF TERMS

- Arc Rating – The value attributed to materials that describe their ability to withstand 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 break-open threshold (EBT) (should a material system exhibit a break-open response below the ATPV value). Arc rating is reported as either ATPV or EBT, whichever is the lower value.
- Arc Thermal Performance Value (ATPV) – Max incident energy of a PPE system prior to break-open.
- Class 1 Igniter – An igniter that is applied to ignite the fuel input to a burner and support ignition under any burner conditions. It will provide sufficient ignition energy usually in excess of 10% of full-load burner output at its associated burner to raise any combination of burner fuel/air mixtures above the minimum ignition temperature.
- Class 2 Igniter – An igniter that is applied to ignite the fuel input to a burner and support ignition only under certain prescribed light-off conditions. It may also be used to support burner operations during operating conditions. The range of ignition energy is usually between 4% and 10% of full-load burner output at its associated burner.
- Class 3 Igniter – An igniter that is applied to ignite the fuel input to a burner and support ignition only under certain prescribed light-off conditions. The range of ignition energy is usually less than 4% of full-load burner output at its associated burner.
- Class 3 Special Igniter – A special Class 3 high energy electrical igniter that is capable of directly igniting the main fuel burner.
- Class I location where flammable gases or vapors may be present in air to an explosive level

- ◦ Division 1 – Exists under normal operations or frequently or faulty equipment operation may cause simultaneous failure of electrical equipment.
- ◦ Division 2 – Liquids/gases used, but not normally in explosive concentrations or concentration prevented by positive mechanical ventilation or is adjacent to Class I, Division 1.
- Class I Liquid – Any liquid that has a flash point below 100°F (37.8°C).
- Class IA Liquid – Any liquid that has a flash point below 73°F (22.8°C) and a boiling point below 100°F (37.8°C).
- Class IB Liquid – Any liquid that has a flash point below 73°F (22.8°C) and a boiling point at or above 100°F (37.8°C).
- Class IC Liquid – Any liquid that has a flash point at or above 73°F (22.8°C), but below 100°F (37.8°C).
- Class II location where combustible dust may be present
  - ◦ Division 1 – Exists under normal operations or faulty equipment operation may cause simultaneous failure of elect equipment or where combustible dusts are eclectically conductive.
  - ◦ Division 2 – Combustible dusts not normally in explosive concentrations or concentration may prevent cooling of electrical equipment.
- Class II Liquid – Any liquid that has a flash point at or above 100°F (37.8°C) and below 140°F (60°C).
- Class IIIA Liquid – Any liquid that has a flash point at or above 140°F (60°C) and below 200°F (93°C).
- Class III location where easily ignitable fibers may be present
  - ◦ Division 1 – where fibers are produced handled, or used.
  - ◦ Division 2 – areas where stored or handled other than manufacturing process.
- Class IIIB Liquid – Any liquid that has a flash point at or above 200°F (93°C)
- Exposed Live Part – Not suitably guarded, isolated, or insulated.
- Flame-Resistant (FR) – Combustion is prevented, terminated, or inhibited with or without the removal of the ignition source.
- Flash Hazard – Condition caused by the release of energy caused by an electric arc
- Flash Protection Boundary – Distance from live parts where second-degree burns would result if an arc flash occurred. By definition, this is the distance at which the incident energy level is at 1.2 cal/cm^2.
- Group A – Acetylene.
- Group B – Flammable gas or vapor that has either an MESG less than or equal to 0.45 mm or an MIC ratio of 0.40 or less. A typical Class I, Group B material is hydrogen.
- Group C – Flammable gas or vapor that has either an MESG greater than 0.45 mm and less than or equal to 0.75 mm or an MIC ratio greater than 0.40 and less than 0.80. A typical Class I, Group C material is ethylene.

- Group D – Flammable gas or vapor that has either an MESG greater than 0.75 mm or an MIC ratio greater than 0.80. A typical Class I, Group D material is Propane.
- Group E – Atmospheres containing combustible metal dusts. Typical dusts in this group are aluminum, magnesium, or other metallic alloys.
- Group F – Atmospheres containing combustible carbonaceous dusts that have more than 8% total trapped volatiles or that have been sensitized by other materials so that they present an explosion hazard. Typical dusts in this group are coal, carbon black, charcoal, and coke dusts.
- Group G – Atmospheres containing combustible dusts that do not fall into the Group E or Group F designation. Typical dusts in this group are flour, grain, wood, plastic, and other similar chemicals.
- Limited Approach Boundary – Distance from live parts where shock hazard exists.
- Restricted Approach Boundary – Distance beyond which only qualified persons may enter because it requires shock protection equipment or techniques.
- Working Near (Live Parts) – Any activity inside a limited approach boundary.
- Working On (Live Parts) – Coming in contact with live parts with body or equipment regardless of PPE (inside restricted approach boundary).

PROBLEMS

1.1 What are the four minimum steps to establish an electrically safe work condition?

A. ____________________________

B. ____________________________

C. ____________________________

D. ____________________________

1.2 What activities below constitute energized electrical work?

A. Taking voltage readings using a contact voltage meter on a panel that has just been isolated from the source but not yet locked out

B. Racking out circuit breaker from energized bus

C. Removal of MCC buckets from energized bus

D. All the above

1.3 A task has been assigned to remove a breaker bucket from a 480 V three-phase MCC where there is a bolted fault current of 35 kA and the clearing time is 5 cycles; can you use the tables in NFPA 70E for determination of the correct arc flash PPE for this task? If you can, what is the arc flash PPE level for this task?

1.4 A task has been assigned to remove a breaker from a 125 Vdc switchboard panel where there is a bolted fault current of 2 kA and the clearing time is 5 cycles; can you use the tables in NFPA 70E for determination of the correct arc flash PPE for this task? If you can, what is the arc flash PPE level for this task?

1.5 A task has been assigned to verify the phasing of a three-phase, 22 kV circuit where the bolted fault current is 15.1 kA and the clearing time is 5 cycles. What is the arc flash PPE level that is required for this task?

1.6 Given the following activity, using table 130.4(C) of NFPA 70E what is the limited approach boundary and the restricted approach boundary in feet and inches? The activity is racking out a three-phase, 480 V line-to-line, power circuit breaker with doors open from an energized switchgear bus; therefore, the exposed bus is fixed and not movable.

Limited approach boundary ____________________________

Restricted approach boundary ____________________________

1.7 Given the following activity, using table 130.4(D) of NFPA 70E what is the limited approach boundary and the restricted approach boundary in feet and inches? The activity is to perform voltage testing of a 250 Vdc panel board circuit breaker with doors open from an energized switchgear bus; therefore, the exposed bus is fixed and not movable.

Limited approach boundary ____________________________

Restricted approach boundary ____________________________

1.8 An area where flammable gases or vapors can exist under normal operating conditions is an example of

A. Class I, Division 1 location

B. Class I, Division 2 location

C. Class II, Division 1 location

D. Class II, Division 2 location

E. Class III, Division 1 location

F. Class III, Division 2 location

1.9 Using Table 1.1 in text for a situation where there is a 480 V MCC assembly across from a concrete wall on opposite side of switchgear, what is the minimum aisle space required between the assembly and the concrete wall?

A. 3 ft

B. $3\frac{1}{2}$ ft

C. 4 ft

1.10 An energized electrical work permit is required to perform energized work. What are some of the items that should be listed in the energized electrical work permit? (Name at least 5)

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1.11 The motor controller that drives a coal pulverizer motor for a power generation facility has been deemed as a location where, under normal operations coal dust will not be present suspended in air in sufficient quantities to form an explosive concentrations and due to housekeeping controls, the layer of dust will not be sufficient to prevent cooling of the motor; however, on the failure of one of the multiple seals in the area, coal dust can become suspended in the atmosphere in quantities sufficient to form an explosive concentration should those seals fail. What are the correct class and division for this hazardous area classification?

RECOMMENDED READING

Bronze Book IEEE 739: IEEE Recommended Practice for Energy Management in Industrial and Commercial Facilities, Institute of Electrical and Electronics Engineers, 1996.

Brown Book IEEE 399: IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis, Institute of Electrical and Electronics Engineers, 1998.

Buff Book IEEE 242: IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems, Institute of Electrical and Electronics Engineers, 2001.

Department of the Army, TM 5-682, Facilities Engineering, Electrica1 Facilities Safety, November 8, 1999.

Emerald Book IEEE 1100: IEEE Recommended Practice for Powering and Grounding Electronic Equipment, Institute of Electrical and Electronics Engineers, 2006.

Gold Book IEEE 493: IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems, Institute of Electrical and Electronics Engineers, 2007.

Green Book IEEE 142: IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems, Institute of Electrical and Electronics Engineers, 2007.

IEC 61241: Electrical Apparatus for Use in the Presence of Combustible Dust, International Electro-Technical Commission, 1994.

IEC 60079:-Electrical Apparatus for Explosive Gas Atmospheres, International Electro-Technical Commission, 2011.

NFPA 101: Life Safety Code Handbook, National Fire Protection Association, 2012.

NFPA 20: Centrifugal Fire Pumps, National Fire Protection Association, 2013.

NFPA 70®: National Electrical Code®, National Fire Protection Association, 2014.

NFPA 70B: Electrical Equipment Maintenance, National Fire Protection Association, 2016.

NFPA 70E: Electrical Safety Requirements for Employee Workplaces, National Fire Protection Association, 2015.

NFPA 72: National Fire Alarm Code, National Fire Protection Association, 2016.

NFPA 75: Protection of Electronic Computer/Data Processing Equipment, National Fire Protection Association, 2013.

NFPA 85: Boiler and Combustion Systems Hazards Code, National Fire Protection Association, 2015.

NFPA 497: Recommended Practice for the Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas, National Fire Protection Association, 2008.

NFPA 499: Recommended Practice for the Classification of Combustible Dusts and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas, National Fire Protection Association, 2013.

Orange Book IEEE 446: IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications, Institute of Electrical and Electronics Engineers, 1996.

Red Book IEEE 141: IEEE Recommended Practice for Electric Power Distribution for Industrial Plants, Institute of Electrical and Electronics Engineers, 1993.