NFPA 70E
Electrical Safety in the Workplace

Fundamentals of Electrical Safety / Safety Work Practices / Maintenance Safety / Special Equipment Concerns / Arc Flash Hazards & Mitigation

Future Courses

NEC: Special Occupancies
IEEE Standard 45: A Guide to Electrical Installations on Shipboard

by

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Nomenclature[1]

AHJ	Authority Having Jurisdiction	-
ANSI	American National Standards Institute	-
AR	Arc Rated	-
ASTM	American Society for Testing and Materials (International)	-
ATPV	Arc Thermal Performance Value	-
cal	calorie [g], Calorie [kg]	4.184 J
CC	Committee Comment	-
CFR	Code of Federal Regulations	-
ESWC	Electrically Safe Work Condition	-
ESA	Electrical Safety Authority	-
FR	First Revision	-
FR	Flame Resistant	-
GFCI	Ground-Fault Circuit-Interrupter	-
HoRC	Hierarchy of Risk Control	-
ICRP	International Commission on Radiological Protection	-
IEC	International Electrotechnical Commission	-
ISEA	International Safety Equipment Association	-
ISO	International Organization for Standardization	-
KAIC	Kilo-Ampere Interrupting Capacity	-
MRI	Magnetic Resonance Imaging	-
NETA	InterNational Electrical Testing Association	-
NFPA	National Fire Protection Association	-
NIOSH	National Institute for Occupation Safety and Health	-
OEM	Original Equipment Manufacturer	-
OSHA	Occupational & Safety Health Administration	29CFR1903(b)(1)
PPE	Personal Protective Equipment	-
SCR	Second Correlating Revision	-
SR	Second Revision	-
SCCR	Short-Circuit Current Rating	-
UL	Underwriters Laboratories, Inc.	-

[1] Not all the nomenclature, symbols, or subscripts may be used in this course—but they are related and may be found when reviewing the references listed for further information. Further, all the nomenclature, symbols, or subscripts will be found in of many electrical courses (on SunCam, PDH Academy, and also in many texts). For guidance on nomenclature, symbols, and electrical graphics: IEEE 280-2021. IEEE Standard Letter Symbols for Quantities Used in Electrical Science and Electrical Engineering. New York: IEEE; and IEEE 315-1975. Graphic Symbols for Electrical and Electronics Diagrams. New York: IEEE, approved 1975, reaffirmed 1993.

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Symbols

C	Capacitance	F
E, *E*	Energy	J
f	Frequency	Hz
I	Current	A
r	Distance	cm
V	Voltage, Potential	V

Subscripts

BT	Breakopen Threshold
f	fault
i	incident
oa	open air
s	step
t	touch

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COURSE INTRODUCTION

The information is primarily from Ref [A].[2] A great source for technical definitions is in Ref [B]. The standards for electrical diagram and symbols are in Ref [C] and Ref [D]. Explanations for many electrical phenomena are in the author's book, Ref [E]. The "standard" for electrical analysis is in Ref [F]. Appendices are provided with useful information for the electrical engineer.

HISTORY and CODE OVERVIEW[3]

Edison invented the first practical incandescent light bulb in 1879. In the very same year, the National Association of Fire Engineers met for the purpose of establishing requirements for electrical installations. As with many standards, in a few years there were six different standards in place. Therefore, in 1896 the various concerned groups convened a national meeting and one year later the National Electrical Code (NEC) (hereafter referred to as the "Code") was born.

The Code is official endorsed by ANSI (American National Standards Institute). The National Fire Protection Association (NFPA) committee responsible for the code is known as ANSI Standards Committee C1. The Code is utilized nationwide with local jurisdictions adoption en masse though with the occasional supplemental additions or deletions. The Code applies to electrical installations within or on public and private buildings up to and including connection to the providing power supply. Its overall purpose: prevent fires!

This is mentioned because from these beginnings the NFPA has expanded into multiple areas of concern for the Electrical Engineer, and others, including NFPA 70E, Electrical Safety in the Workplace. OSHA has been tied to the NFPA from the beginning. OSHA looks to NFPA 70E to fill out OSHA performance-based requirements in their standards.

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[2] This is a Handbook for NFPA 70E that contains the Code proper. Although not required, I highly recommend using NFPA's "Handbook" as the contain a wealth of interpretation and examples that will save and Engineer a great deal of research time.

[3] Paraphrased from the author's book published by Professional Publications Incorporated of Belmont, CA—now a Kaplan Company: John Camara, *Power Reference Manual for the PE Exam*, 3rd ed., (2018), (Kaplan, Inc., 2018), Chap. 56. In the 4th ed., the NEC is in. Chap. 44.

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This course will focus on requirements of 70E. Of note, in the 2024 edition the handbook aligns with the NEC Style Manual. This alignment makes reading 70E similar to reading the NEC Handbook. Because of that, those style features are reviewed here.

The course will refer directly to Code Chapters (1-3), Articles (###), Sections (A, A(1), B, B(1)…), and Informative Annexes (A–S).[4] While a copy of the code will be adequate for verification and usage, for those whose occupations require a deeper understanding of the Code and its three-year updates, I recommend the NFPA Handbook, Ref [A].[5]

The course will refer directly to Code Chapters (1-3), Articles (###), Sections (A, A(1), B, B(1)…), and Informative Annexes (A–S).[6] While a copy of the code will be adequate for verification and usage, for those whose occupations require a deeper understanding of the Code and its three-year updates, I recommend the NFPA Handbook, Ref [A].[7]

This is an official publication of the NFPA with numerous advantages over a mere copy of the Code. For instance, the Handbook contains commentary text in blue, which is used to explain the reasons for the requirement or its application. Revised Code text is shaded gray for ease of noting changes. A single circular bullet on an empty line space, such as that below, indicates deleted sections of the code.

•

The Greek delta symbol ("change"), Δ, when used by a section number indicates words were deleted; when used beside a table it signifies a revision of the data within. An italic *N* reveals a new article, section, table, or figure. The Handbook also contains a "See also" marking bringing

[4] Articles are single-subject entries and Sections and Sub-Sections contain the rules themselves. The word "Article" is often used for "Section" though technically the terminology "Section" should be used. Additionally, in this course, not all Sections are mentioned. They are mentioned when the topics are considered significant.
[5] The author is not associated with this text or the NFPA. I have simply found this handbook extremely useful throughout the years. Also, regardless of the NEC update year, the principles provided in this course will be useful guidance—some article locations may change with the occasional technical update or addition as well.
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to the reader's attention other Code areas where additional information is found.[8] Finally, and arguably the most useful features, are the Exhibits containing figures or pictures that bring the words to visual life, Calculation Examples providing scenarios for application of the Code requirements, and a Summary of Technical Changes listed prior to the Code itself.

The Code consists of an introduction followed by three chapters, which are further subdivided into articles and sections. It ends with "informative annexes" that provide useful information but no actual requirements.

- Summary of Technical Changes
-
- Introduction
- Chapter 1: Safety-Related Work Practices
- Chapter 2: Safety-Related Maintenance Requirements
- Chapter 3: Safety Requirements for Special Equipment
- Annex A: Informative Publications
- Annex B: Reserved
- Annex C: Limits of Approach
- Annex D: Incident Energy and Arc Flash Boundary Calculations
- Annex E: Electrical Safety Program
- Annex F: Risk Assessment and Risk Control
- Annex G: Sample Lockout/Tagout Program
- Annex H: Guidance on Selection of Protective Clothing and Other Personal Protective Equipment (PPE)
- Annex I: Job Briefing and Job Safety Planning Checklist
- Annex J: Energized Electrical Work Permit
- Annex K: General Categories of Electrical Hazards
- Annex L: Typical Applications of Safeguards in the Cell Line Working Zone
- Annex M: Layering of Protective Clothing and Total System Arc Rating
- Annex N: Example Industrial Procedures and Policies for Working Near Overhead Electrical Lines and Equipment
- Annex O: Employee Safety-Related Design Concepts and Facility Owner Responsibilities
- Annex P: Aligning Implementation of this Standard and Occupation Health and Safety Management Standards

[8] The "see also" feature is new and extremely helpful. This course will focus on the methodology of finding all the information required to ensure compliance. The Handbook's use of this feature is very much along these lines.

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- Annex Q: Human Performance and Workplace Electrical Safety
- Annex R: Working with Capacitors
- Annex S: Assessing the Condition of Maintenance

The breaks shown in the bullet list are to resolve the NEC into relevant areas. The Introduction is just that. Chapters 1–3 cover Work Practices, Maintenance Requirements, and Special Equipment in detail. The annexes are for information only and are not mandatory for compliance with the Code. Figure 1 provides an overview of the structure of the standard.

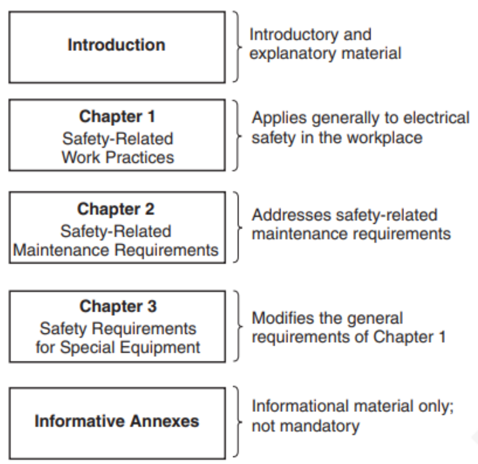

Figure 1: Overview

In summary, the ANSI-accredited standard for workplace safety and safe work practices is NFPA 70E. The standard covers both shock and arc-flash hazards. These hazards are categorized using terms and risk assessments that are consistent with national and international risk standards for personal protective equipment (PPE).

Ensuring electrical safety in the workplace requires the following measures, which are applicable to all types of work.

- performing shock and arc-flash analysis on the electrical installation
- establishing an electrical safety program for the installation
- training maintenance and operations workers, as well as those exposed to such work
- identifying the hazards and risks associated with any particular installation task
- obtaining appropriate work permit(s)
- using proper PPE

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SUMMARY OF TECHNICAL CHANGES

Major changes include alignment with the NEC Style Manual, definitions consolidating to Art. 100, and Informational Note structure changes for consistency, et cetera. Limited technical changes occurred. A review of this section is a good place to start when evaluating if any of the changes impact your work or documents.

Case Studies are included to provide real-world examples. Connections to OSHA standards are highlighted. Worker Alerts are used to near requirements crucial for employees to be aware of and understand. Employees in other than electrical trades may be exposed to such hazards and as such should be made aware of, and trained on, said hazards.

ARTICLE 90: INTRODUCTION

Basic safety is considered accomplished by installing electrical installation in accordance with the NFPA 70®, *National Electrical Code*® (NEC®)[9]; by maintaining systems per NFPA 70B®, *Standard for Electrical System Maintenance*[10]; and by following the safety guidance of NFPA 70E® summarized in this course.

It is often easier and more efficient to consider safety early in the design phase to aid in establishing a needed later *electrically safe work condition* (ESWC).

Section 90.1: Scope

This article covers the use, application (scope), and application of this standard.

Section 90.3: Workplaces Covered/Not Covered

Covered workplaces include conductors and equipment that connect to the supply of electricity. Additionally, installations used by the utility but that are NOT part of the generating plant, substation, or control center.[11]

[9] See course offerings in this area.
[10] This is in the absence of manufacturer's instruction, which always take precedence. NETA Maintenance Testing requirements are also a guide in this area [ANSI/NETA MTS-2023].
[11] This coverage is very similar to the NEC, which does not cover generation or distribution,

Those places NOT covered include ships, watercraft, floating buildings, railways, aircraft, and automotive vehicles—except for mobile homes and recreational vehicles (think, moving homes, hence the coverage). Also, not covered are communication equipment controlled by said utility and electric utility installations under the exclusive control of said utility.

Section 90.4: Standard Arrangement

The arrangement of 70E, as mentioned, is an Introduction and three chapters. Chapter 1 applies generally, while Chapter 2 addresses safety-related maintenance requirements. Chapter 3 supplements or modifies Chapter 1 (see Figure 1).

Section 90.5: Mandatory, Permissive, and Explanatory Rules

Mandatory Rules are those using the words *shall* or *shall not*. Permissive Rules are those permitted but NOT required. The words used are *shall be permitted* or *shall not be required*. Explanatory Material exist as information notes or informative annexes. Such material is informational only, exists as an aid, and is NOT an enforceable part of 70E.

CHAPTER 1: SAFETY-RELATED WORK PRACTICES

Article 100: Definitions

Definitions are meant to develop a common understanding fundamental to the requirements, and overall to improve safety on the basis of this understanding. The definitions include only those applicable to the proper application of 70E. Common electrical terms can be found in IEEE 100.[12]

Approved: Acceptable to the Authority having Jurisdiction [AHJ]

Arc Flash Suit: Arc-rated clothing and equipment that covers the body, with the exception of the hands and feet—which are protected by other means

[12] This standard, though in the status of "withdrawn" is still widely used and available. Reference [B] is wide ranging dictionary of engineering.

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Figure 2: Arc Flash Suit

Arc Rating: Value representing material performance against an arc. Measured in cal/cm^2.[13] Derived from the *arc thermal performance value* (ATPV) or *energy of breakopen threshold* (E_{BT}), whichever is lower. It should be noted that *arc rated* (AR) clothing is also *flame resistance* (FR) but the reverse is NOT always true.[14]

Balaclava: An arc-rated head protective fabric protecting most of the head and neck.

Figure 3: Balaclava Examples

[13] A calorie is the amount of heat required at 1 standard atmosphere to raise 1 g of water 1°C. It is a unit of energy or heat, now defined as 4.184 J. It comes from the Latin word “calor” meaning heat. In foods, there are small calories [1 gram of water…) and large Calories [one kg of water…].
[14] See ASTM F1506 and ASTM F1891 for more information, if desired. Testing of clothing is covered in ASTM F1959.

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Bonded (Bonding): A connection to establish electrical continuity.[15]

Boundary, Arc Flash: An approach limit where the incident energy equals 1.2 cal/cm^2 (5 J/cm^2). This is the limit where one is likely to receive second-degree burns should an incident occur.

Limited Approach Boundary: This boundary is at a given distance from exposed electrical parts where an electric shock hazard exists. It is NOT related to arc flash or incident energy,

Competent Person: A person meeting the requirements of a *qualified person*,[16] and who, is responsible for the work activities….

Conductor: A Covered Conductor has material or thickness NOT recognized by the NEC while an Insulated Conductor is recognized by the NEC.

Electrically Safe Working Condition: A state where the device is disconnected from its energizing supply, is locked/tagged, tested for absence of voltage, and if required, grounded.

Listed: Equipment, materials, or services included in a list maintained by an organization and approved by the AHJ.[17] Figure 4 shows an example. Should C, US, or EU be outside the circle, this indicates Canada, United States, or European Listing.

Figure 4: Example UL Marking

Overcurrent: Current in excess of the rated value. Such a condition may come from an overload, a short-circuit, or a ground fault.

[15] This is mentioned to differentiate a “bond” from a “ground”. A ground is a connection to Earth. A bonding is a connection made between components to ensure electrical conductivity.
[16] A *Qualified Person* has demonstrated skills and knowledge…related to…electrical equipment…and safety.
[17] Underwriters Laboratories is a common listing organization.

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Pilot Cell: A cell chosen to represent the entire properties of the battery.

Short-Circuit Current Rating: The symmetrical fault current at nominal voltage that flows at the point of the fault and to which the equipment will not sustain damage exceeding defined acceptance criteria.[18] [Examples include 22 kA, 42 kA, 65 kA, 100 kA, often labeled KAIC.]

Step-Potential: Ground potential gradient resulting in current flow from foot to foot through the body.

Time Constant: The time it takes for voltage to drop to ≈63% of its original value. This equals 1/e of the original value.

Touch-Potential: Ground potential gradient result in current flow from hand to hand, or hand to foot, or other path except foot to foot.

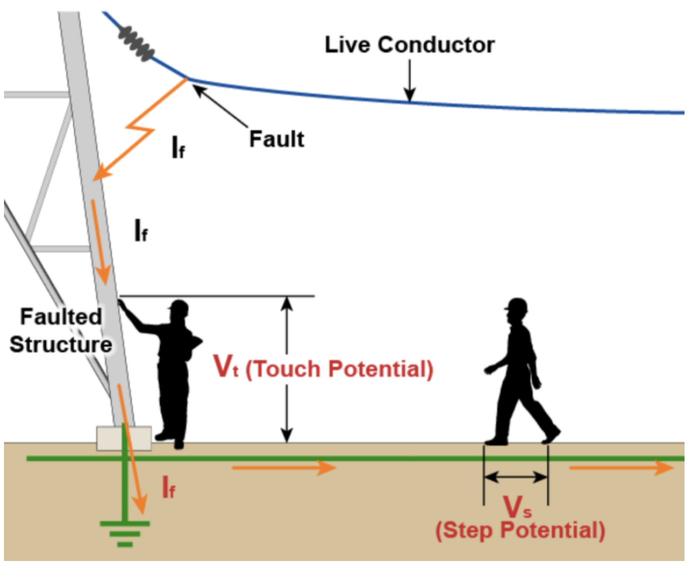

Figure 5: Touch and Step Potential
[*Source: www.aemc.com*]

[18] The equipment may not be able to be used again, but it will be able to contain the damage. It will not catch on fire or explode.

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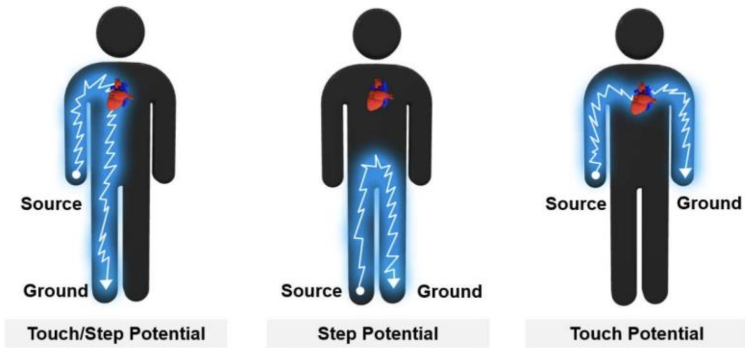

Figure 6: Alternate View of Touch/Step Potential
[*Source: safety.fsu.edu*]

Working Distance: The distance between the face and chest area and a potential arc source.

Article 105: Application of Safety-Related Work Practices and Procedures

Section 105.3: Purpose

The practices and procedures are intended to provide electrical safety for all employees with possible exposure to electrical hazards—not just electricians.

Section 105.3: Responsibility

The employer establishes, documents, and implements the practices and procedures and provides the training for same. The employee must comply—based on NFPA 70E and OSHA.

Article 110: General Requirements for Electrical Safety-Related Work Practices

Section 110.1: Scope

This article covers the overall requirements for safe work practices.

Section 110.2: Electrical Safe Work Condition (ESWC)

The employer is responsible to establish, document, implement the ESWC policy that makes hazard elimination the first priority for work on electrical conductors or parts at ≥50V before a)

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the employee is within the limited approach boundary (covered later) or b) or is at increased likelihood of exposure to an arc flash hazard.

Exception 1 to this requirement is when a *normal operating condition exists*. This is defined as including all of the following. The equipment:

- is properly installed [per industry codes and standards],
- is properly maintained [per manufacturer's instructions],
- doors are closed and secured,
- covers in place and secure,
- shows no signs of impending failure [such as arcing, loose parts, visible damage/deterioration, or water damage[19]].

Other exceptions exists though they should be applied in a thoughtful manner and evaluated using risk analysis. Of note, the above is only part of establishing an ESWC. The requirements of Sections 120.2 through 120.6 must also be met.

Section 110.3: Electrical Safety Program

110.3(A): General

The employer documents and implements the electrical safety program.

NOTE

Though the requirements contained in 70E are straight forward, the writing of specific requirements is not. Several specialized companies exist to write said documents to ensure compliance with NFPA 70E and OSHA.

Such a program includes safety procedures: job briefing, establishing an ESWC, testing before touching, work permits, auditing, program controls; and a risk management program—risk assessments, training, and a hierarchy of Risk Control Methods.

[19] See NEMA GD 1-2019, *Evaluating Water-Damaged Electrical Equipment* for guidance.

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Informative Annex P contains guidance along with IEEE 3007.1, *Recommended Practice for the Operation and Management of Industrial and Commercial Power Systems*, and IEEE 3007.3, *Recommended Practice for Electrical Safety in Industrial and Commercial Power Systems*.

110.3(B): Inspection

Inspections are required on new or modified equipment to ensure they are installed per codes and standards.

110.3(C): Condition of Maintenance

The program shall consider the condition of maintenance. Guidance for maintenance is in NFPA 70B, Standard for Electrical Equipment Maintenance.

110.3(D): Awareness and Self-Discipline

The program shall provide awareness, self-discipline, and instill safety principles and controls.[20]

110.3(G): Electrical Safety Program Procedures

The program shall identify the procedures to use *before* starting the job.

110.3(H): Risk Assessment Procedure

The program shall have a risk assessment procedure and comply with the subsections of this paragraph, (H)(1) through (H)(3).

The elements of a risk assessment procedure include a) identifying the hazard, b) assessing the risk, and c) implementing risk control using the hierarchy of risk control methods (HoRC). One example is shown in Fig. 7. (See Informative Annex F)

Also, a part of the assessment is the potential for human error and its consequences. (See Informative Annex Q)

[20] The program's goal must be to instill in employees such discipline so that they understand their own actions are often the causes of and accident or injury.

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The assessment will include preventative and risk control methods. (See Informative Annex F)

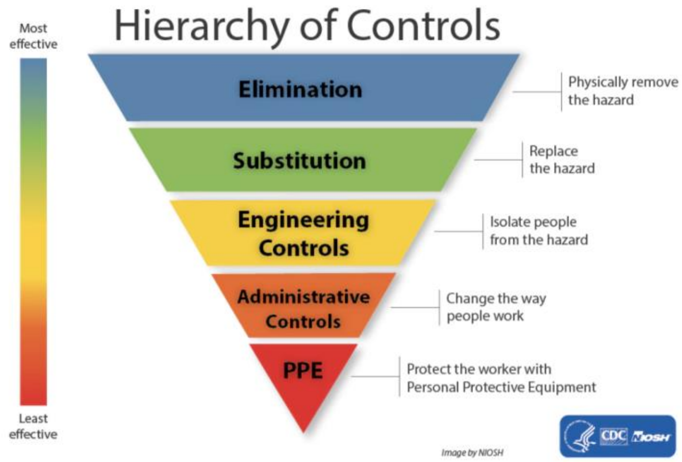

Figure 7: Hierarchy of Risk Control
[*Source: CDC, Image by NIOSH]*

110.3(I): Job Safety Planning and Job Briefing

The employee in charge shall complete a job plan and conduct a brief.[21] The planning must include an electric shock risk assessment and an arc flash assessment, if applicable. Additional planning and briefings are held if changes occur that might affect safety.

110.3(L): Auditing

The electrical safety program is audited a minimum of every 3 years to ensure compliance with 70E. Field Work Audits that ensure requirements are being followed are accomplished a minimum of every year. Lockout/Tagout Audits are also conducted every year.

Section 110.4: Training Requirements

110.4(A): Electrical Safety Training

[21] Having been to, and led, standard job briefings, they are extremely useful for getting all "on the same page" and for finding out information about the job or job site they one was completely unaware of initially.

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Employees are trained so they understand electrical hazards and the possible injuries from the same. Training includes practices and procedures.

110.4(A): Qualified Person

A qualified person is trained and knowledgeable on the equipment, both construction and operation, and in recognizing and avoiding electrical hazards. Necessarily, such training is very extensive.

The employer must, through regular supervision on at least an annual basis, ensure each employee is complying with safety-related practices. Unqualified persons are those trained only in electrical safety and not the full extent of that required of a qualified person.

Additional training to keep up to date, and any retraining in safety, is required at intervals not to exceed 3 years.[22] Such training is documented and retained for the duration of the employee's employment.

110.4(B): Lockout/Tagout Procedure Training

Training here is required to qualify to perform lockout/tagout, whenever the procedure changes, and at least every 3 years.

110.4(C): Emergency Response Training

Training in the *safe release* of victims in contact with energized conductors is required annually (see Fig. 8). Training in this area includes cardiopulmonary resuscitation (CPR), and use of the automated external defibrillator (AED). While the re-training times are per the certifying body, the verification that an employee is current, up to date, must occur annually.

[22] Notably, this is how often 70E is updated.

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Figure 8: Rescue Hook

Section 110.5: Host and Contractor Employer Responsibilities

The host employer must keep the contractor informed of known hazards and information that enable the contractor to perform the assessments mentioned in Chapter 1.

The contractor must ensure their employees are informed of the known hazards, inform the host of any hazards uncovered by its workers, and any measures taken to correct issues noted by the host.

Section 110.6: Test Instruments and Equipment

Test instruments should be standardized within an organization and procedures established for their use.

110.6(A): Testing

Only qualified person perform testing, troubleshooting, and use of voltage measuring equipment.

110.6(B): Rating

Test equipment must be rated for their area of utilization and used per the manufacturer's instruction.

There are four categories (Cat) of test equipment most often used. These can be found in UL 61010.

- Cat I: Electronic Equipment
- Cat II: Single Phase Receptacle Level [30 ft from Cat III and 60 ft from Cat IV Locations]
- Cat III: Inside Distribution [Feeders and Branch Circuits]
- Cat IV: Three-phase Utility Connections and Outside

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110.6(E): Operation Verification

For those working in the field, the author feels this is likely the most important rule to take under one's wing. When testing for the absence of voltage in circuits ≥50 V, always a) test the instrument using a known live source, then b) check the circuit deenergized, then c) check the instrument again with a known source to ensure it didn't fail, or a lead come loose during step b).

Section 110.7: Portable Cord- and Plug-Connected Electrical Equipment

Portable cord- and plug-connected equipment must be visually inspected before use, when moved from a semi-permanent location, or when repaired.

Section 110.8: Ground-Fault Circuit-Interrupter (GFCI) Protection

GFCI shall be provided on 120 V, 15-, 20-, or 30 A circuits. If circuits are using >120 V, either GFCI protection or an assured equipment grounding conductor program shall be implemented.

Article 120: Establishing an Electrically Safe Work Condition

Section 120.2 to 120.5: Lockout/Tagout Program

The employer shall establish, document, and implement the lockout/tagout program, which is to be applicable to all equipment: permanently installed, temporarily installed, and portable. Further, the employer must train personnel, provide the necessary equipment, and audit the program for compliance. Up to date drawings and diagrams are required to be available. Tags must be placed on the disconnecting means, not on pushbuttons.

Lock capable disconnecting means are required for any equipment installed after January 2, 1990. The lockout period should not extend beyond the work shift. This is referred to as a *simple lockout/tagout procedure*. Where one goes over a work shift, this is called a *complex lockout/tagout procedure* and requires a person in charge. Additionally, the procedure is complex if it involves multiple power sources, disconnecting means, multiple crews or employers, or requires a particular sequence to accomplish the task. Meaning, a written procedure/plan is required.

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Section 120.6: Process for Establishing an Electrically Safe Work Condition

Deenergizing the equipment is not the only prerequisite for establishing an ESWC. All the requirements in Article 120 must be met. One can tell the condition is established when no electrical energy is within the immediate vicinity of the work, no PPE is required, non-qualified personnel may perform work in the area (cleaning or painting). An example of a checklist is in Ref. [A] in Exhibit 120.5. The most important things in the list, by the author's estimation, is removing stored electrical energy and grounding equipment that could have induced voltage on it.[23]

Figure 9: Example Temporary Grounding Kit

Article 130: Work Involving Electrical Hazards

This article covers the requirements when work involving electrical hazards, such as energized equipment, when an ESWC cannot be established. Such work can occur (see 110.2(B)) if all of the conditions exist.

- Use of Qualified Persons
- An Energized Work Permit is Completed
- A Shock Risk Assessment is Performed
- An Arc Flash Assessment is Performed

The Work Permit elements are in Sec. 130.2(B) with exceptions to the same in 130.2(C).

[23] Admittedly, this importance is established by the author being shocked because of not following these rules.

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The focus in Art. 130 involves various boundaries and the requirements of each to be safe. Though divided into multiple section, what follows is a summary of the article with emphasis on the boundaries that define the hazards and safety precautions.

IEEE standards specify the methods used to determine arc-flash and shock hazard levels. These levels are given in terms of the energy per unit area that can be produced by any given equipment design and installation, usually in cal/cm^2. These levels are compared to the approach boundaries defined in NFPA 70E Art. 130 to determine the PPE required (using the guidance and tables in Annex H). The boundaries are shown in Fig. 7.

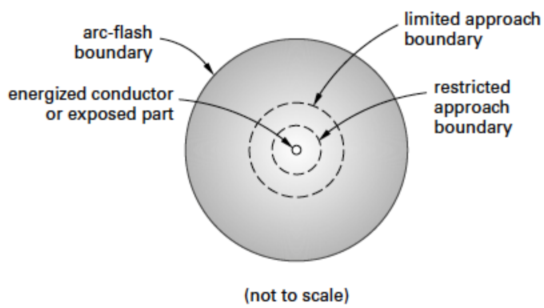

Figure 10: Shock & Arc Flash Protection Boundaries

The point in the center of Fig. 7 represents an energized conductor or exposed part from which the boundaries are measured. There are two types of approach boundaries: shock protection boundaries (which are either restricted or limited) and arc-flash boundaries.

Shock protection boundaries vary with voltage level (see 70E Table 130.4(E)(a) for AC and (E)(b) for DC) and whether the energized conductor is fixed (as in a panelboard) or movable (as in a high-voltage transmission line). See Table 1 for an excerpt. The 70E Tables also contain the approach boundary limits.

A recommendation for an electrical worker would be to memorize the distance for the voltage one works with the majority of the time. For example, if one works mostly on 120 V equipment, the limited approach distance is 10 ft for movable conductors—not usually the case. But for fixed conductors it's 3 ft 6 in, which the author would/did round to 4 ft and memorize.

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Table 1: Approach Boundary Limits[24]

nominal system voltage range, phase to phase	limited approach boundary: exposed movable conductor	limited approach boundary: exposed fixed circuit part	restricted approach boundary
AC < 50 V	not specified	not specified	not specified
50 V ≤ AC ≤ 150 V	3.0 m (10 ft 0 in)	1.0 m (3 ft 6 in)	avoid contact
DC < 100 V	not specified	not specified	not specified
100 V ≤ DC ≤ 300 V	3.0 m (10 ft 0 in)	1.0 m (3 ft 6 in)	avoid contact

The limited approach boundary is the boundary within which only qualified persons are allowed, 130.4(F). (Unqualified persons may be allowed if supervision requirements are met.) The restricted approach boundary is also limited to qualified persons, but only if one of the following conditions is met.

(a) The energized conductor or part is operating at 50 V or more, and the qualified person is insulated or guarded (physically protected) from it.

(b) The energized conductor or part is operating at 50 V or more, and it is insulated from the qualified person or from any other conductive object (for example, being insulated from the ground in a live-line, bare-handed work area).

As mentioned, a fixed, exposed part with an AC or DC voltage of 120 V has a *limited approach boundary* of 1 m (3 ft 6 in), and a restricted approach boundary of "avoid contact" rather than a specific distance. When a conductor or part such as a high-voltage transmission line is not under the control of a maintenance person, the part is considered "movable," and requires greater shock protection distances.

[24] These were taken from the 2018 version. In 2023, the 3.0 m is now 3.1 m without any changed to the Customary US Units. The DC value range of 100 V to 300 V is now 50 V to 300 V. This gives one and idea of the minimal changes over the years. It's most important to know where the information exists.

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A *restricted boundary limit* for 120 V is "avoid contact" while for voltages from 151 V – 750 V the limit is 1 foot.

Only qualified personnel with the proper PPE are allowed across the boundary. Requirements for PPE are divided into multiple ranges, according to the possible incident energy exposures: ≤ 1.2 cal/cm^2, >1.2 cal/cm^2 to ≤ 8 cal/cm^2, > 8 cal/cm^2, ≤ 4 cal/cm^2 and >4 cal/cm^2; >1.2 cal/cm^2 to ≤12 cal/cm^2, and > 12 cal/cm^2. Each range corresponds to certain PPE [see Table H.3 n 70E for specifics].[25]

In the lowest range, protective clothing is required; that is, clothing that is non-melting or untreated natural fiber. In the middle ranges, arc-rated clothing is required. In the upper ranges, additional arc-rated clothing is required, including an arc-flash suit with a hood. See the earlier Fig. 2 for an example of an arc-flash suit with gloves and long pants that cover the feet. All ranges require some common protection, including safety glasses or goggles, hearing protection, and gloves (though the requirements for gloves vary).

The arc-flash boundary is determined from arc-flash analysis, which is based on the energy level within the boundary and not on any particular voltage. Specifically, the arc-flash boundary is the distance at which the incident energy equals 1.2 cal/cm^2 (5 J/cm^2) [Sec. 130.5(E)(1)]. Two methods exist for determining what PPE is required: 1) incident energy analysis per Sec. 130.5(G) or 2) the arc flash PPE category method per Sec. 130.7(C)(15). Either method may be used, but NOT both.

When using the incident energy analysis 70E Table 130.5(G) is used to pick the PPE required. When using the category method, which depends upon the associated equipment, the 70E Tables in 130.7(C)(15) shall be used. Labeling is required on electrical equipment with the information differing depending upon whether incident energy or category method is used (Sec. 130.5(H)). Example labels of each type are shown in Fig. 11. The labels and accuracy of the data supporting them shall be reviewed every 5 years, as a minimum, per 130.5(H).

[25] On, older tables one may see the following markings. If marked "AN", the item is "as needed." If marked "SR" the "selection [is] required" of one of a number of items from a list. For example, when a list ending with "SR" includes heavy-duty leather gloves and rubber insulating gloves with leather protectors, one of the two choices must be used.

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Figure 11: Category Label & Incident Energy Label

CHAPTER 2: SAFETY RELATED MAINTENANCE REQUIREMENTS

Article 200: Introduction

Electrical work environments consist of three major elements. Proper installations guided by manufacturer's instruction and National Electrical Code® compliance (NFPA 70®); appropriate maintenance guided by manufacturer's instructions and NFPA 70B®, *Standard for Electrical Equipment Maintenance*; and of course, NFPA 70E®, *Standard for Electrical Safety in the Workplace*.

Chapter 2 focuses on the safety-related maintenance practices. This chapter does not tell one how to do the maintenance, this is left to manufacturer's [OEM] instructions, NETA or other guidance as selected by the employer.

Section 205.5: Overcurrent Protective Device

Over current protective devices shall be maintained as indicated by the manufacturer's instructions. All maintenance and tests of same shall be documented. When an overcurrent device trips one should not assume a false condition. Investigate before resetting.[26]

Section 205.10: Clear Spaces

Maintain access to working spaces and escape passages clear at all times.

[26] A Navy electrician thing, admittedly old: when things tripped on the submarine, we reset immediately. If it tripped again, then we investigated. Ah, memories!

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Article 250: Personal Safety and Protective Equipment

Section 230.3: Inspection and Testing of Protective Equipment and Protective Tools

Such equipment shall be inspected before use and at intervals not to exceed one year. Testing of electrical equipment meant to protect from shock shall be tested at intervals not to exceed 3 years. Grounding devices are tested before each use. (See IEEE C37.20.6, *Standard for 4.67 kV to 38 kV Rated Ground and Test Devices Use in Enclosures* for information on how to test.)

CHAPTER 3: SAFETY REQUIREMENTS FOR SPECIAL EQUIPMENT

Chapter 3 modifies the requirements of Chapter 1 for those whose use of electrical energy is unique or equipment is unique and thus requires differing safety practices.

Article 310: Electrolytic Cells

Work around an electrolytic cell line is always consider working around energized parts. Information beyond that in this article can be found in Informative Annex L, the NEC Art. 688, and IEEE 463, *Electrical Safety Practices in Electrolytic Cell Line Working Zones*.

Article 320: Batteries and Battery Rooms

Of interest here is the thresholds for implementation of these safety practices. Those thresholds are as follows.

- AC: 50 V and 5 mA
- DC: 100 V and 40 mA
- Thermal: 1000 W of Short-Circuit Power

In addition to the normal assessment add chemical and thermal. Additionally, battery rooms should only be accessible to qualified personnel. And, battery monitoring equipment looking for abnormal conditions should be tested annually.

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Article 330: Lasers

The threshold for laser safety are as follows.

- AC: 50 V and 5 mA
- DC: 100 V and 40 mA
- Capacitor Stored Energy
  - <100 V but >100 J of Stored Energy
  - ≥100 V and >1 J of Stored Energy
  - ≥400 V and >0.25 J of Stored Energy

The energy levels listed are those a system can store without being considered a hazard.

Additional training beyond that expected includes training on ionizing radiation involving X-rays.[27]

Article 340: Power Electronic Equipment

Such equipment can be thought of as that storing and holding electrical energy. This includes everything from arc welding equipment, radio and radar, motor drives, uninterruptible power supplies (UPS), lighting controllers, RF and inonizing radiation producing equipment, MRIs and more.

The thresholds for this equipment are as follows.[28]

- DC (0 Hz to 1 Hz): 100 V and 40 mA
- 60/50 Hz Power: 50 V and 50 mA
- AC (1 Hz to 3 kHz): 50 V and 3 mA
- AC (3 kHz to 100 kHz): 1 x f mA, f in Hz
- AC (100 kHz to 3 MHz): 100 mA
- AC (3 MHz to 30 MHz): 100 (f/3)*0.3, f in MHz
- AC (30 MHz to 110 MHz): 200 mA

[27] X-rays were so-called because they were unknown at the time of discovery. Now we know they come from electrons.
[28] The frequency ranges used do not correlate with the common frequency bands.

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Article 350: Research and Development Laboratories

The primary difference in R&D facilities is the assignment of an Electrical Safety Authority (ESA) who acts much like the AHJ (Authority Having Jurisdiction) to determine the necessary safety requirements. And, although equipment custom-built is likely not listed, it should still be marked sufficiently to note all the voltage entering and leaving.

Article 360: Capacitors

The thresholds for capacitors follow.

- <100 V and >100 J of Energy
- ≥100 V and >1J of Energy
- ≥400 V and >0.25J of Energy

Ground sticks shall be provided to discharge capacitor stored energy. (See Fig. 12.) Such sticks must have an impedance of < 0.1Ω verified every 2 years or every year if used outdoor.

Figure 12: Capacitor Grounding Stick

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INFORMATIVE ANNEXES

Annex A: Informative Publications

This annex contains a great list of references that may be of use to those working in the field of electrical safety.

Sources include NFPA, ANSI, ASTM, ICRP, IEC, ISEA, ISO, NIOSH, UL, CFR, and specific papers.

Annex B: Reserved

Annex C: Limits of Approach

This annex explains the reasoning behind the limits in the approach boundaries.

Annex D: Incident Energy & Arc Flash Boundary Calculation Methods

This annex explains the reasoning and calculation techniques for the subject calculations. For those performing such calculation, the annex is worthy of detailed study.

Annex E: Electrical Safety Program

This annex describes the principles, controls, and procedures in a compliant program.

Annex F: Risk Assessment and Risk Control

This annex describes methods for assessment and control. For those who have worked in a large company, much here will be familiar. The Hierarchy of Risk Control (HoRC) methods is discussed in detail. The hierarchy from most desirable to least is as follows.

- Elimination of the Risk
- Substitution (Reducing the Energy)
- Engineering Controls
- Awareness
- Administrative Controls
- PPE

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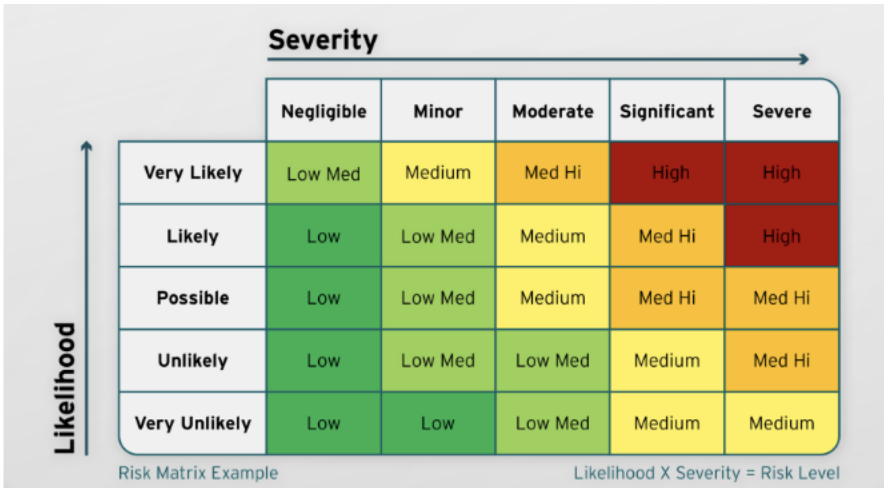
An example risk matrix is shown in Fig. 13. Terms vary, but the general structure is the same.



Severity →

Likelihood ↑	Negligible	Minor	Moderate	Significant	Severe
Very Likely	Low Med	Medium	Med Hi	High	High
Likely	Low	Low Med	Medium	Med Hi	High
Possible	Low	Low Med	Medium	Med Hi	Med Hi
Unlikely	Low	Low Med	Low Med	Medium	Med Hi
Very Unlikely	Low	Low	Low Med	Medium	Medium

Risk Matrix Example — Likelihood X Severity = Risk Level

Figure 13: Risk Assessment Matrix

Annex G: Sample Lockout/Tagout Program

This one is self-explanatory.

Annex H: Guidance on Selection of…PPE

This is worthy of study. It describes the selection of PPE when using the Arc Flash PPE Categories or when using the Simplified Two-Category Approach.

Annex I: Job Brief and Job Safety Planning Checklist

Great example checklist that will aid in ensuring nothing is missed.

Annex J: Energized Electrical Work Permit

Combines the requirements of 70E with those of OSHA to provide an example permit.

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Annex K: General Categories of Electrical Hazards

There are two general categories of electrical hazards: electric shock and electrical burns. Some 98 percent of fatal injuries are from shock. And, 40 percent of those occur with voltages of 250 V or less, while another 40% occur from contact with overhead power lines.

Arc flash is the source of the burns. Arc blast occurs during an arc flash, which is not surprising given that copper expands some 67,000 times in volume when solid copper becomes vapor copper. The result is high pressure, sound, and shrapnel.[29]

Annex L: Typical Application of Safeguards in the Cell Line Working Zone

Safeguards include rubber boots, gloves, insulating surface to stand on, and the energized cell can be bonded to ground. Power receptacles should be avoided and pneumatic-powered tools used instead.

Annex M: Layering of Protective Clothing and Total System Arc Rating

This sounds simpler than it is. One would think you'd add a layer and add the arc rating to the total—not so. If using such a method, detailed study of this short annex is warranted.

Annex N: Working Near Overhead Electrical Lines and Equipment

First, the obvious. Always assume the line is energized. At high voltages, greater than 1000 V, working clearances increase.

A thumb rule provided in the annex states that employees not place themselves in *close proximity* to overhead power lines, which is defined as 3 m (10 ft) at up to 50 kV and increase this distance 100 mm (4 in) for every 10 kV above 50 kV.

Also, use a spotter when working whose duty it is to observe these clearances and direct the operator as necessary.

[29] The author was able to witness a test on copper at a special lab in Boeing. A thin strip of copper was exposed to a high voltage and it disappeared in and instant. Such things make one a believer in the hazards.

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Annex O: Employee Safety-Related Design Concepts and Facility Owner Responsibilities

This annex covers the items in the title. But, of note, it does not cover specific design requirements. It is up to the facility owner to choose design option that eliminate or at least minimize risks. This annex is worthy of study for any new or redesigned installation.

Annex P: Alignment with OSHA

The standard 70E is not enough. Alignment with OSHA and other standards improves overall safety. Alignment with the framework of particular standards is the goal of 70E. Those standards are ANSI/AIHA Z10, *American National Standard for Occupational Health and Safety Management Systems* and ISO 45002, *Occupational Health and Safety Management Systems—Requirements and Guidance for Use*.

Collaboration with Subject Matter Experts and Safety Professionals is a must and is all part of what's called the Deming Cycle or PDCA; that is, plan-do-check-act. Optionally, the Shewart Cycle or PDSA, plan-do-study-act. Both are meant to enhance continual improvement.

Annex Q: Human Performance and Workplace Electrical Safety

Surprise, surprise, human are fallible. But knowing this, there are ways of minimizing errors. This annex is a short study into those methods. Also, warning signs when error is more likely are covered along with corrective/preventative action.

Annex R: Working with Capacitors

Capacitors store energy. The amount of energy with formulas for the same are provided here. For example, the incident energy assuming a) all the stored energy is dissipated, b) as radiant energy, c) in open air, d) in a spherical expansion follows.

Equation 1: Incident Energy Open Air in Joules

$$E_{\text{incident,open air}} = E_{i,oa} = \frac{Energy}{Area} = \frac{\frac{1}{2}CV^2}{4\pi r^2} = \frac{CV^2}{8\pi r^2} \quad \frac{\text{J}}{\text{cm}^2}$$

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Converting to calories (1 cal = 4.184 J) for use in determining protective gear gives the following.

Equation 2: Incident Energy Open Air in Calories

$$E_{\text{incident,open air}} = E_{i,oa} = \frac{Energy}{Area}$$

$$= \frac{\frac{1}{2}CV^2}{4pr^2} = \frac{CV^2}{8pr^2} \ \frac{\text{J}}{\text{cm}^2}$$

$$= \frac{CV^2}{(8p)\left(4.184 \ \frac{\text{J}}{\text{cal}}\right)r^2} = \frac{CV^2}{(105.1)r^2} \ \frac{\text{cal}}{\text{J}\cdot\text{cm}^2}$$

$$= \frac{E}{(52.6)r^2} \ \frac{\text{cal}}{\text{cm}^2}$$

Recall that the arc flash boundary (AFB) is defined as the distance where the incident energy is 1.2 cal/cm^2. Therefore,

Equation 3: Arc Flash Boundary in Open Air

$$AFB_{oa} = (0.126)\left(\sqrt{E}\right) \text{ cm} = (0.05)\left(\sqrt{E}\right) \text{ in}$$

Since the arc flash boundary could still fall inside the lung protection boundary, one should use the AFB for a box, which is three times that of open air.

Equation 4: Incident Energy in a Box (Enclosure)

$$E_{\text{box}} = (3)\left(E_{i,oa}\right)$$

Equation 5: Arc Flash Boundary from a Box (Enclosure)

$$AFB_{\text{box}} = \sqrt{3}AFB_{oa}$$

Equations are also provided for the arc blast boundary for the ears and lungs. Methods for safe discharge of capacitors are also covered.

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Annex S: Assessing the Condition of Maintenance

This annex is new. It's meant to provide information for qualified workers to assess the condition of maintenance. Visual inspection plays an important role. Periodic testing and inspection via a maintenance program helps one assess how well the equipment may have been maintained. Monitoring equipment is a useful tool to get an accurate picture of the health of the particular piece of gear.

Maintenance programs can be preventive, predictive (aka condition based), reactive, corrective, or the latest (using AI) prescriptive.

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Appendix A: Equivalent Units Of Derived And Common SI Units

Symbol	Equivalent Units			
A	C/s	W/V	V/W	J/(s ×V)
C	A ×s	J/V	(N ×m)/V	V ×F
F	C/V	C^2/J	s/W	(A ×s)/V
F/m	C/(V ×m)	C^2/(J ×m)	C^2/(N ×m^2)	s/(Ω ×m)
H	W/A	(V ×s)/A	Ω ×s	(T ×m^2)/A
Hz	1/s	s^{-1}	cycles/s	radians/(2p ×s)
J	N ×m	V ×C	W ×s	(kg ×m^2)/s^2
m^2/s^2	J/kg	(N ×m)/kg	(V ×C)/kg	(C ×m^2)/(A ×s^3)
N	J/m	(V ×C)/m	(W ×C)/(A ×m)	(kg ×m)/s^2
N/A^2	Wb/(N ×m^2)	(V ×s)/(N ×m^2)	T/N	1/(A ×m)
Pa	N/m^2	J/m^3	(W ×s)/m^3	kg/(m ×s^2)
W	V/A	W/A^2	V^2/W	(kg ×m^2)/(A^2 ×s^3)
S	A/V	1/W	A^2/W	(A^2 ×s^3)/(kg ×m^2)
T	Wb/m^2	N/(A ×m)	(N ×s)/(C ×m)	kg/(A ×s^2)
V	J/C	W/A	C/F	(kg ×m^2)/(A ×s^3)
V/m	N/C	W/(A ×m)	J/(A ×m ×s)	(kg ×m)/(A ×s^3)
W	J/s	V ×A	V^2/W	(kg ×m^2)/s^3
Wb	V ×s	H ×A	T/m^2	(kg ×m^2)/(A ×s^2)

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Appendix B: Fundamental Constants

Table Note 1

Quantity	Symbols	US Customary	SI Units
Avogadro's number	N_A, L		6.022×10^{23} mol^{-1}
Bohr magneton	μ_B		9.2732×10^{-24} J/T
Boltzmann constant	k	5.65×10^{-24} ft-lbf / R	1.3805×10^{-23} J/T
electron volt: $\left(\frac{e}{C}\right)$ J	eV		1.602×10^{-19} J
Faraday constant, $N_A e$	F		96 485 C/mol
fine structure constant, inverse α^{-1}	α α^{-1}		7.297×10^{-3} (≈1/137) 137.035
gravitational constant	g_c	32.174 lbm-ft/lbf-sec^2	
Newtonian gravitational constant	G	3.44×10^{-8} ft^4 / lbf-sec^4	6.672×10^{-11} N·m^2 / kg^2
nuclear magneton	μ_N		5.050×10^{-27} J/T
permeability of a vacuum	μ_0		1.2566×10^{-6} N/A^2 (H/m)
permittivity of a vacuum, electric constant $1/\mu_0 c^2$	ϵ_0		8.854×10^{-12} C^2 / N·m^2 (F/m)
Planck's constant	h		6.6256×10^{-34} J·s
Planck's constant: h/2π			1.0546×10^{-34} J·s
Rydberg constant	R_∞		1.097×10^{7} m^{-1}
specific gas constant, air	R	53.3 ft-lbf/lbm- R	287 J/kg·K
Stefan-Boltzmann constant		1.71×10^{-9} BTU/ft^2-hr-°R^4	5.670×10^{-8} W/m^2·K^4
triple point, water		32.02 F, 0.0888 psia	0.01109 C, 0.6123 kPa
universal gas constant	R*	1545 ft-lbf/lbmol- R 1.986 BTU/lbmol- R	8314 J/kmol·K

Table Notes

1. Units come from a variety of sources, but primarily from the Handbook of Chemistry and Physics, The Standard Handbook for Aeronautical and Astronautical Engineers, and the Electrical Engineering Reference Manual for the PE Exam. See also the NIST website at https://pml.nist.gov/cuu/Constants/. The unit in Volume of "lbmol" is an actual unit, not a misspelling.

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Appendix C: Mathematical Constants

Quantity	Symbol	Value
Archimedes' constant (pi)	p	3.1415926536
base of natural logs	*e*	2.7182818285
Euler's constant	*C* or t	0.5772156649

Appendix D: The Greek Alphabet

A	*a*	alpha	N	*u*	nu
B	*b*	beta	X	x	xi
G	*g*	gamma	O	*o*	omicron
D	*d*	delta	P	*p*	pi
E	*e*	epsilon	R	*r*	rho
Z	z	zeta	S	*s*	sigma
H	*h*	eta	T	*t*	tau
Q	*q*	theta	ϒ	*u*	upsilon
I	i	iota	F	*f*	phi
K	*k*	kappa	C	*c*	chi
L	*l*	lambda	Y	*y*	psi
M	*m*	mu	W	*w*	omega

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