

IEEE Recommended Practice for Electrical Installations on Shipboard— Safety Considerations

IEEE Industry Applications Society

Sponsored by the
Petroleum & Chemical Industry Committee

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USA

IEEE Std 45.5™-2014

IEEE Recommended Practice for Electrical Installations on Shipboard— Safety Considerations

Sponsor

Petroleum & Chemical Industry Committee
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IEEE Industry Applications Society

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Abstract: Electrical safety considerations for shipboard electrical systems and equipment are covered, including a review of fundamental concepts pertaining to electrical safety and establishing electrical safety programs and work practices associated with the operation and maintenance of shipboard electrical power distribution systems.

Keywords: electrical hazards, electrical safety program, electrical safety-related maintenance, IEEE 45.5™, personal protective equipment, PPE, safe electrical work practices, safety single-line diagrams

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Introduction

This introduction is not part of IEEE Std 45.5-2014, IEEE Recommended Practice for Electrical Installations on Shipboard—Safety Considerations.

The IEEE 45™ series comprises nine recommended practices addressing electrical installations on vessels and marine platforms. IEEE Std 45.5™ provides recommended practice electrical safety considerations and is intended for use with the IEEE 45 series of documents. The topics covered in this document should be considered from the beginning of the project and throughout the design and construction processes; thereby, they should facilitate the integration of electrical systems at the shipyard level. The IEEE Std 45.5 electrical safety recommendations provide a foundation for an electrical safety program but should be supplemented with additional safety practices as appropriate.

Previous editions of IEEE Std 45™ were developed as single documents addressing all areas. On June 9, 2005, Project Authorization Request (PAR) P45™ for the Revision of IEEE Std 45™-2002 was approved, and the revision of IEEE Std 45 as a single document began. It soon became apparent that attempting to cover all issues in a single document would produce a document that was very large and, therefore, difficult to ballot due to the wide range of issues needed to be addressed. In September 2008, it was decided that the revision of IEEE Std 45 should be developed as a base document with separate associated documents addressing specific areas.

On December 10, 2008, the IEEE-SA Standards Board approved separate PARs for eight separate recommended practices. Subsequently, it was recognized that two areas were very close to balloting and contained important information. Additional PARs were then prepared and approved on September 11, 2009 (for switchboards), and December 9, 2009 (for cable systems), bringing the total number of standards in the IEEE 45 series to nine:

- a) IEEE Std P45, IEEE Recommended Practice for Electrical Installations on Shipboard
- b) IEEE Std P45.1™, IEEE Recommended Practice for Electrical Installations on Shipboard—Design
- c) IEEE Std P45.2™, IEEE Recommended Practice for Electrical Installations on Shipboard—Controls and Automation
- d) IEEE Std P45.3™, IEEE Recommended Practice for Electrical Installations on Shipboard—Systems Engineering
- e) IEEE Std P45.4™, IEEE Recommended Practice for Electrical Installations on Shipboard—Marine Sectors and Mission Systems
- f) IEEE Std P45.5, IEEE Recommended Practice for Electrical Installations on Shipboard—Safety Considerations
- g) IEEE Std P45.6™, IEEE Recommended Practice for Electrical Installations on Shipboard—Electrical Testing
- h) IEEE Std P45.7™, IEEE Recommended Practice for Electrical Installations on Shipboard—Switchboards
- i) IEEE Std P45.8™, IEEE Recommended Practice for Electrical Installations on Shipboard—Cable Systems

Several other IEEE standards have been prepared or are currently being developed to support the IEEE Std 45 series. These include the following:

- IEEE Std 1580™, IEEE Recommended Practice for Marine Cable for Use on Shipboard and Fixed or Floating Facilities

- IEEE P1580.1™, Draft Recommended Practice for Insulated Bus Pipe for Use on Shipboard and Fixed or Floating Platforms
- IEEE Std 1662™, IEEE Guide for the Design and Application of Power Electronics in Electrical Power Systems on Ships
- IEEE Std 1709™, IEEE Recommended Practice for 1 to 35 kV Medium Voltage DC Power Systems on Ships
- IEEE Std 1826™, IEEE Standard for Power Electronics Open System Interfaces in Zonal Electrical Distribution Systems Rated Above 100 kW
- IEC/PAS 60092-510, Electrical Installations in Ships—Part 510: High Voltage Shore Connection Systems (HVSC)

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1. Overview

1.1 Scope

The recommendations for the design to improve electrical safety on shipboards are established by this document. These recommendations reflect the technologies, engineering methods, and engineering practices in effect when this document is issued.

1.2 Purpose

An extension of the baseline technology and methods covered in IEEE Std 45™, IEEE Std 45.5™ provides a consensus of recommended practices for improved safety in marine electrical engineering as applied specifically to ships, shipboard systems, and equipment.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is

explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

ABS Rules for Building and Classing Steel Vessels, 5C-1-7/31, Specific Vessel Types—Vessels Intended to Carry Oil in Bulk (150 meters (492 feet) or more in Length)—Cargo Oil and Associated Systems—Electrical Installations.¹

ANSI Z535.5, Safety Tags and Barricade Tapes (for Temporary Hazards).²

ASTM F496, Standard Specification for In-Service Care of Insulating Gloves and Sleeves.³

ASTM F1505, Standard Specification for Insulated and Insulating Hand Tools.

Code of Federal Regulations Title 29 Part 1910 Section 147 (29CFR1910.147), Occupational Safety and Health Standards—General Environmental Controls—The control of hazardous energy (lockout/tagout).⁴

Code of Federal Regulations Title 29 Part 1910 Sections 331–335 (29CFR1910.331–335), Occupational Safety and Health Standards—Electrical—Safety-Related Work Practices.

Code of Federal Regulations Title 29 Part 1910 Subpart S (29CFR1910.301–399), Occupational Safety and Health Standards—Electrical.

Code of Federal Regulations Title 29 Part 1915 Section 89 (29CFR1915.89), Occupational Safety and Health Standards for Shipyard Employment—Control of hazardous energy (lockout/tags-plus).

Code of Federal Regulations Title 46 Part 111 Section 70-3 (46CFR111.70-3), Electric Systems—Motor controllers and motor-control centers.

IEC 60900, Live working—Hand tools for use up to 1 000 V a.c. and 1 500 V d.c.⁵

IEEE Std 45™, IEEE Recommended Practice for Electrical Installations on Shipboard.^{6, 7}

IEEE Std 1584™, IEEE Guide for Performing Arc-Flash Hazard Calculations.

NFPA 70E, Standard for Electrical Safety in the Workplace.⁸

NFPA 70B, Recommended Practice for Electrical Equipment Maintenance.

OSHA CPL 02-00-142, Shipyard Equipment “Tool Bag” Directive, Appendix A, Application of the 29 CFR Part 1910 Standard When a 29 CFR Part 1915 Standard Does Not Address a Recognized Hazard in Shipyard Employment.⁹

OSHA STD 01-16-007, Electrical Safety-Related Work Practices—Inspection Procedures and Interpretive Guidelines.

¹ ABS steel vessel rules are available from the American Bureau of Shipping (<http://www.eagle.org/absdownloads/getpub.cfm?pub=2>).

² ANSI publications are available from the American National Standards Institute (<http://www.ansi.org/>).

³ ASTM publications are available from the American Society for Testing and Materials (<http://www.astm.org/>).

⁴ CFR publications are available from the U.S. Government Printing Office (<http://www.gpo.gov/>).

⁵ IEC publications are available from the International Electrotechnical Commission (<http://www.iec.ch/>). IEC publications are also available in the United States from the American National Standards Institute (<http://www.ansi.org/>).

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⁸ NFPA publications are available from the National Fire Protection Association (<http://www.nfpa.org>).

⁹ OSHA directives and instructions are available from the Occupational Safety and Health Administration (<https://www.osha.gov/>).

UL 61010-1, Electrical Equipment for Measurement, Control, and Laboratory Use; Part 1: General Requirements.¹⁰

United States Coast Guard (USCG) Marine Safety Alert 03-13b, Surge Protective Devices Onboard Vessels.

3. Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.¹¹

affected employee: An employee whose job requires him or her to operate or use a machine or equipment on which servicing or maintenance is being performed under lockout or tags-plus, or whose job requires him or her to work in an area in which such servicing or maintenance is being performed.

arc-over voltage (electrical arc): The minimum voltage required to cause an arc between electrodes separated by a gas or liquid insulation.

arc blast: A release of mechanical, acoustical, thermal, and optical energy from an electric arc.

arc flash: A release of thermal energy from an electric arc by the vaporization and ionization of materials, reaching temperatures up to 35,000 °F. *See also:* **incident energy**.

arc-flash hazard: A dangerous condition associated with the release of energy caused by an arc.

arc-flash hazard analysis: A method to determine the risk of personal injury as a result of exposure to incident energy from an electrical arc flash.

arc-flash protective equipment: Equipment designed to safeguard personnel from momentary electrical arcs.

arc thermal performance value (ATPV): In arc testing, the incident energy on a fabric or material that results in sufficient heat transfer through the fabric or material to cause the onset of a second-degree burn based on the Stoll curve, measured in cal/cm². ASTM F1959 is the standard test method for determining arc thermal performance (value) of textile materials for clothing by electric arc and related thermal hazards.

arcing fault current: A fault current flowing through an electrical arc plasma, also called “arc fault current” and “arc current.”

attendant: An employee assigned to remain immediately outside the entrance to an enclosed or other barricaded space to render assistance as needed to employees inside the space.

authorized employee: An employee who locks out or tags out machines or equipment in order to perform servicing or maintenance on that machine or equipment. An **affected employee** becomes an authorized employee when that employee is properly trained and his or her duties include performing servicing or maintenance.

¹⁰ UL standards are available from Global Engineering Documents (<http://www.global.ihs.com/>).

¹¹ *IEEE Standards Dictionary Online* subscription is available at:
http://www.ieee.org/portal/innovate/products/standard/standards_dictionary.html.

available fault current: The electrical current that can be provided by the serving generation equipment or shore power connection equipment and contributions from large electric motors, considering the amount of impedance in the current path.

barricade: A physical obstruction such as tapes, cones, or A-frame-type wood or metal structures intended to provide a warning about and to limit access to a hazardous area.

bolted fault current: A short-circuit or electrical contact between two conductors at different potentials in which the impedance or resistance between the conductors is essentially zero.

boundary, arc flash: An approach limit at a distance from live parts that is uninsulated or exposed within which a person could receive a second-degree burn (1.2 cal/cm^2).

boundary, limited approach: An approach limit at a distance from an exposed live part within which a shock hazard exists.

boundary, prohibited approach: An approach limit at a distance from an exposed live part within which work is considered the same as making contact with the live part.

boundary, restricted approach: An approach limit at a distance from an exposed live part within which there is an increased risk of shock due to electrical arc-over combined with inadvertent movement for personnel working in close proximity to the live part.

critical systems: Those systems that would result in increased or additional hazards if de-energized. (e.g., life support equipment, emergency alarm systems, hazardous location ventilation equipment, area lighting, systems maintaining national security).

de-energized: Free from any electrical connection to a source of potential difference and from electrical charge; not having a potential different from that of earth.

designated employee (designated person): An employee (or person) who is designated by the employer to perform specific duties and who is knowledgeable in the construction and operation of the equipment and the hazards involved.

electrical hazard: A dangerous condition in which inadvertent or unintentional contact or equipment failure can result in shock, arc-flash burn, thermal burn, or blast.

electrical safety: Recognizing hazards associated with the use of electrical energy and taking precautions to reduce the risk of hazards that could cause injury or death.

electrical shock: The physical stimulation that occurs when electrical current passes through the body (a difference in current potential, line-to-line or line-to-ground, from entry point through the body to an exit point).

electrical work: a) Working on or near energized or non-energized electrical parts; b) assembly or fabrication of potentially hazardous electrical equipment; or c) both.

electrically safe work condition: A state in which the conductor or circuit part to be worked on or near has been disconnected from energized parts, locked/tagged out (or equivalent) in accordance with established standards, tested to ensure the absence of voltage, and grounded if determined necessary.

energized (live): Electrically connected to or having a source of voltage, or electrically charged to have a potential significantly different from that of earth in the vicinity.

energy break-open threshold (EBT): Arc-rated material may have an EBT rating. EBT is defined as the average of the five highest incident energy exposure values below the Stoll curve where the specimen did not exhibit break-open. EBT is reported when ATPV cannot be measured due to arc-rated fabric break-open.

exposed (as applied to live parts): Capable of being inadvertently touched or approached nearer than a safe distance by a person. It is applied to parts that are not suitably guarded, isolated, or insulated.

exposed: Not isolated or guarded.

fault current: A current that flows from one conductor to ground or to another conductor due to an abnormal connection (including an arc) between the two.

ground: A conducting connection, whether intentional or accidental, between an electric circuit or equipment and the earth, or to some conducting body that serves in place of the earth.

grounded: Connected to earth or to some conducting body that serves in place of the earth.

guarded: Covered, fenced, enclosed, or otherwise protected, by means of suitable covers or casings, barrier rails or screens, mats, or platforms, designed to minimize the possibility, under normal conditions, of dangerous approach or accidental contact by persons or objects.

incident energy: The amount of energy impressed on a surface, a certain distance from the source, generated during an electrical arc event. Incident energy is measured in J/cm^2 . To convert J/cm^2 to cal/cm^2 , multiply by 0.239.

insulated: Separated from other conducting surfaces by a dielectric (including air space) offering a high resistance to the passage of current.

insulation (cable): That which is relied upon to insulate the conductor from other conductors or conducting parts or from ground.

left-hand rule: Stand to the right side of the equipment and operate the disconnect switch with the left hand.

live parts: Energized conductive components.

personal protective equipment (PPE): Clothing and equipment that is designed and constructed to protect workers from electrical shock or to reduce the burns that would be sustained from an electrical arc flash.

qualified person: One who has received training in and has demonstrated skills and knowledge in the construction and operation of electric equipment and installations and in the hazards involved.

NOTE 1—Whether an employee is considered to be a qualified person will depend upon various circumstances in the workplace. For example, it is possible and, in fact, likely for an individual to be considered qualified with regard to certain equipment in the workplace, but unqualified for other equipment.¹²

NOTE 2—An employee who is undergoing on-the-job training and who, in the course of such training, has demonstrated an ability to perform duties safely at his or her level of training and who is under the direct supervision of a qualified person is considered to be a qualified person for the performance of those duties.

shipyard employment: Ship repairing, shipbuilding, shipbreaking, and related employments.

¹² Notes to text, tables, and figures are for information only and do not contain requirements needed to implement the standard.

shock hazard: A dangerous condition associated with the release of energy caused by contact or approach to exposed energized parts.

Stoll curve: A prediction at which one would expect to receive a second-degree burn, based on a function of time and heat.

4. Introduction to electrical safety

4.1 General discussion

An electrical hazard is a dangerous condition such that contact or equipment failure can result in electric shock, arc-flash burn, thermal burn, or blast. Electrical safety includes recognizing hazards associated with the use of electrical energy and taking precautions to respond to hazards that could cause injury or death. According to government requirements, such as the U.S. Occupational Safety and Health Act [B35],¹³ the employer is required to provide a place of employment that is free from recognized hazards. The electrical hazards that are identified in this recommended practice are industry-recognized hazards and, therefore, should be understood and addressed in developing electrical safety programs and procedures.

Some explanation is necessary to fully appreciate what constitutes an electrical hazard, and what electrical safety is. For that reason, electrical hazards are discussed in 4.3.

The four main phases of protection from electrical hazards are:

- a) First, unless de-energizing is infeasible due to the nature of the task, or if de-energizing creates a more hazardous situation or condition, potentially energized electrical conductors and circuit parts should be placed in an electrically safe work condition (de-energized) before personnel work within the limited approach boundary. Safe practices should be used to establish an electrically safe work condition. An electrically safe work condition is discussed in 7.4.
- b) Second, electrical installations should be designed and constructed to be safe by complying with the criteria as stipulated in national and international consensus standards and codes. This subject is discussed in Clause 6.
- c) Third, the integrity of electrical equipment should be maintained with particular emphasis on enclosures, insulation, operating mechanisms, grounding, and circuit protective devices. Maintenance is discussed in Clause 6.
- d) Fourth, safe work practices and adequate protective equipment, insulated and insulating tools, and test equipment should be understood and used when working on or near exposed energized conductors or circuit parts of electrical equipment. Safe practices are covered in Clause 4. Personal protective equipment, appropriate tools, and other protective methods are discussed in Clause 5. The safety of use of electrical equipment is discussed in Clause 8.

The details of these concepts should be implemented and documented into a cohesive electrical safety program. Clause 5 discusses establishing such a program.

These electrical safety sections (Clause 4 through Clause 8) provide guidance on how to reduce hazardous conditions. Hazardous conditions should be recognized when they exist, and appropriate measures should be taken to avoid human injury from exposure to such conditions.

This recommended practice is designed to help ensure that electrical work is performed safely by qualified workers (i.e., qualified persons) who are trained and provided with the appropriate safe work procedures,

¹³ The numbers in brackets correspond to those of the bibliography in Annex A.

protective equipment, and other electrical safety hazard controls. This recommended practice is intended to help provide protection methods for personnel against electrical shock, arc flash, and other potential electrical safety hazards. Regulations and standards referenced in this document are primarily related to the United States. Always verify specific requirements with local regulations and standards, as applicable.

4.2 Definition of safe

The term “safe,” as used throughout this document, is intended to describe a condition in which electrical safety risks are minimized. The use of the term safe is not intended to suggest or guarantee that absolute electrical safety can be achieved in any situation by compliance with the recommended practices set forth herein.

4.3 Exposure to electrical hazards

The physics of electricity do not change or vary from one type of industry to another. Therefore, whether the application is on shipboard equipment, in a shipyard, or in office buildings, warehouses, shops, manufacturing facilities, etc., the electrical hazards are the same.

Electrical hazards can result from unsafe conditions; i.e., poor physical condition or poor arrangements of equipment or facilities. Environment also plays an important role in electrical safety. The environmental conditions on vessels are dramatically different from those of a shipyard or other location and should be considered when evaluating the electrical hazards, personal protective equipment (PPE), and safe work procedures. Injuries can result from unsafe acts; i.e., the careless or inadvertent actions of people. Taking precautions to minimize electrical hazards implies that safety considerations regarding such conditions and actions should be given to all aspects of electrical work, including design, installation, commissioning, operating, and maintenance activities.

There are essentially three recognized hazards associated with electricity. They are as follows:

- a) Electrical shock
- b) Electrical arc flash
- c) Electrical arc blast

These hazards are described in 4.3.1 through 4.3.3.

4.3.1 Electrical shock

The electrical shock hazard is the most common and well-known electrical hazard; historically, many electrical safety standards have been structured to address the shock hazard. An electrical shock is a reflex response to the passage of electric current through the body caused by a difference of potential across parts of the body. Electrical shock is referred to as non-fatal, and electrocution is referred to as fatal or a fatal shock. Electrical shock typically affects human beings in the following ways:

- a) Electrical current, as little as a few milliamperes, through the heart can cause disruption of the natural electrical signals that the heart uses to perform its normal functions. Voltage levels as low as 50 V with low skin resistance and electrical current flowing through the chest area can cause fibrillation, which can result in death. This is why all personnel who routinely work on or near exposed energized electrical conductors and circuit parts should be familiar with cardiopulmonary

resuscitation (CPR) and the use of the automated external defibrillator (AED). They may be required to perform CPR or use an AED on a coworker who has experienced an electrical shock.

- b) Electrical shock can also damage human tissue where the electrical current enters, passes through, and exits the body. These types of injuries are under the broad category of burn injuries. Within the body, electrical current can also damage internal body parts and organs in its path. The degree of damage is dependent on the amount of the electrical current, the condition of contact points, the duration of the current flow, and the path of the electrical current through the body.
- c) Electrical shock normally causes the muscles to contract. Due to muscle contraction, the person experiencing the shock may not be able to release the conductor from which he or she was receiving the shock. This involuntary grasping may lead to longer exposure to the electrical shock and could increase the extent of injury.

Several standards offer guidance on safe approach distances in order to reduce the possibility of shock from exposed energized electrical conductors and circuit parts of different voltage levels. One of the most commonly used and referenced standards is National Fire Protection Association (NFPA) 70E. The limits of approach to exposed energized electrical conductors and circuit parts are discussed in Clause 7 of this recommended practice.

The results of a sensitivity study from exposure to different values of 60 Hz ac current on a 68-kg (150-lb) human are listed in Table 1. This table provides a ready means of evaluating the physiological effects of current on the human body.

Table 1—Current range and effect on a 68-kg (150-lb) human [B10][B3]

Current (60 Hz)	Physiological phenomena	Feeling or lethal incidents
<1.0 mA	None	Imperceptible.
1.0 mA	Perception threshold	—
0.5–2.0 mA	—	Mild sensation.
1.0–4.0 mA	—	Painful sensation.
6.0–22 mA	Paralysis threshold of arms	Cannot release hand grip. If no grip, victim may be thrown clear. (May progress to higher current and be fatal.)
18–30 mA	Respiratory paralysis	Stoppage of breathing (frequently fatal).
90 mA	Fibrillation threshold, 0.5% (greater than or equal to 3-s exposure)	Heart action disorganized (probably fatal).
250 mA	Fibrillation threshold, 99.5% (greater than or equal to 3-s exposure)	Heart action disorganized (probably fatal).
4 A	Heart paralysis threshold (no fibrillation)	Heart stops for duration of current passage. For short shocks, heart may restart on interruption of current (usually not fatal from heart dysfunction).
≥5 A	Tissue burning	Not fatal unless vital organs are burned.

As mentioned previously, the effects of shock are dependent upon the amount and path of current that flows through the human body. Typically, the magnitude of electrical current is a function of the applied voltage and the resistance of the path of the current through the body. Table 2 shows some typical values of skin-contact resistance under various conditions. Table 3 shows typical resistance values of various materials.

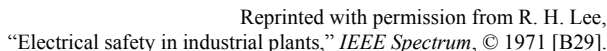
Table 2—Human resistance values for various skin-contact conditions [B29]

Condition (Area to Suit)	Resistance (in Ω)	
	Dry	Wet
Finger touch	40 000–1 000 000	4 000–15 000
Hand holding wire	15 000–50 000	3 000–6 000
Finger-thumb grasp	10 000–30 000	2 000–5 000
Hand holding pliers	5 000–10 000	1 000–3 000
Palm touch	3 000–8 000	1 000–2 000
Hand around 3.8 cm (1.5 in) pipe (or drill handle)	1 000–3 000	500–1 500
Two hands around 3.8 cm (1.5 in) pipe	500–1 500	250–750
Hand immersed	—	200–500
Foot immersed	—	100–300
Human body, internal, excluding skin resistance	200–1 000	

Table 3—Resistance values for 130 cm² areas of various materials [B29]

Material	Resistance (in Ω)
Rubber gloves or soles	>20 000 000
Dry concrete above grade	1 000 000–5 000 000
Dry concrete on grade	200 000–1 000 000
Leather sole, dry, including foot	100 000–500 000
Leather sole, damp, including foot	5 000–20 000
Wet concrete on grade	1 000–5 000

In fibrillation, the victim may not recover consciousness or the victim may be conscious, deny needing help, walk a few feet, and then collapse. Death may occur within a few minutes or may take hours, with vulnerability possible up to a week later. Detection of the fibrillation condition requires medical skill and training. An AED is often available at the workplace or in public buildings; this can be used to stabilize the heartbeat of a victim who has gone into fibrillation. Many of these units provide vocalized step-by-step directions on their use and are suitable for use by nonprofessionals.



In Figure 1, the fibrillation line for an exposure time of 5 s or more is 75 mA. For shorter times, the threshold current is higher. If the duration of shock is only 0.004 s, or one-quarter cycle of 60 Hz, the fibrillation threshold current is determined by the energy in the impulse, i.e., Energy = VI(t).

This sensitivity, increasing with time, explains why a victim who is frozen to a current source is much more likely to be electrocuted than one whose contact does not involve hand grasp. A full hand grasp can immobilize the victim such that he cannot let go; hence, the exposure time may extend long enough to place it in range of the 90-mA threshold. In comparison, a casual contact (such as with a fingertip) causes a reflexive retraction of the arm, thereby interrupting the shock current path. In this case, the victim is exposed for only a few thousandths of a second and is much less likely to sustain an injury.

Defibrillation involves placing electrodes and conductive jelly on the chest. A pulse of higher than 1000 V dc is applied; this results in current flow up to a few tens of amperes, but only for several milliseconds. These numbers vary with the type of instrument, settings, and other factors. This pulse of dc causes a violent muscle contraction in the chest. Such defibrillation places the heart in asystole: a complete stoppage

of electrical activity of the heart. Within a few seconds, the heart will usually resume a normal pattern of beating.

Once the heart goes into ventricular fibrillation, it usually does not spontaneously revert to a normal heart rhythm, though it may do so. As a general rule, a defibrillator is required in order to restore the normal heartbeat.

4.3.2 Electrical arc flash

Approximately half of serious electrical injuries involve burns. Electrical burns include not only burns from contact but also radiation burns from the extreme temperatures of electric arcs that result from short-circuits and ground faults due to unintentional electrical contact with grounding and bonding pathways or due to insulation failure. The electric arc between metals is, next to the laser, the hottest known phenomenon on earth. It is about four times as hot as the sun's surface, or about 19,400 °C (35,000 °F). Where high arc currents are involved, burns from such arcs can be fatal, even when the victim is some distance from the arc. In addition to burns from the arc flash itself, clothing is often ignited. Fatal burns can result because the clothing cannot be removed or extinguished quickly enough to prevent serious burns. Wearing clothing made of meltable fibers adds to the problem. Workers who are exposed to flames or electric arcs should wear only clothing that will not increase the extent of injury. Clothing that is made of acetate, nylon, polyester, or rayon, either alone or in blends, should not be worn unless the fabric has been treated to withstand the conditions that may be encountered.

Only the relative infrequency of electrical arcs has limited the number of injuries to electrical workers who are frequently in the vicinity of energized electrical conductors or circuit parts. Examples of exposure are working on open panelboards, switchboards, or motor control centers; racking in or out circuit breakers or contactors; hook-stick operation of medium-voltage fuses; testing of cable terminals; grounding before testing; or working in manholes near energized cables.

Several studies, tests, and technical papers have been written on the subject of electrical shock and arc-flash hazards (see the bibliography in Annex A). Safety standards and procedure requirements are continuing to be developed to recognize the fact that arcs can cause serious injuries at significant distances from energized sources. Equally important in these new safety standards is the fact that only trained and qualified people with shock and arc-rated clothing and protective equipment are permitted to approach energized electrical conductors or circuit parts. Spectators, or unqualified persons, should remain clear of the established arc-fault boundaries because, even though they think they are far enough away, they typically do not have an understanding of what constitutes a safe approach distance. The arc-flash boundary is defined as, when an arc flash exists, an approach limit at a distance from a prospective arc source within which a person could receive a second-degree burn if an electrical arc flash were to occur (a second-degree burn is typically at 5 J/cm² (1.2 cal/cm²) of energy). The arc-flash boundary can be calculated using the equations given in IEEE Std 1584, or guidance can be found in NFPA 70E. Depending on the short-circuit current available along with the arc-clearing time, spectators can be seriously injured or killed at great distances from the initiation point of an arc.

4.3.2.1 Nature of electric arcs

“Electrical arcing” is the term that is applied to the passage of substantial electrical currents through what had previously been air. It is initiated by flashover or the introduction of some conductive material. Current passage is through ionized air and the vapor of the arc terminal material, which is usually a conductive metal or carbon. In contrast to current flow through low-pressure gases such as neon, arcing involves high temperatures of up to, or beyond, 19,400 °C (35,000 °F) at the arc terminals (see 4.3.2). No materials on earth can withstand these temperatures; all materials are not only melted but also vaporized, reaching a plasma state. The vapor of the terminal material has substantially higher resistance than solid metal, to the extent that the voltage drop in the arc ranges from 29.53 V/cm (75 V/in) to 39.37 V/cm (100 V/in), which is