

The Hazards of Electricity – Do You Know What They Are?

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Abstract - OSHA statistics show that several hundred deaths occur annually as a result of electrical shock. Over one-half of these deaths are the result of contact with low-voltage, primarily 120-volts. Residential, commercial, industrial, farm, and utility accidents are included in these statistics. NIOSH statistics show that electrical contact results in 4,000 non-disabling and 3,600 disabling injuries annually in the United States, plus ONE death in the workplace every day.

Many of the electrical shock accidents that occur in commercial and industrial facilities are the result of contact with 277-volts. This is due to the extensive use of 277-volt fluorescent lighting. Employees generally perform maintenance on these light fixtures without performing a proper lockout/tagout of the circuit.

Studies also show that 10-15 employees are hospitalized every day with arc-flash burns, which are often catastrophic to the victims physically, psychologically, and financially. In reality, the hazards associated with the use of electricity are real and can affect anyone.

The three main hazards of electricity; electrical shock, electrical arc-flash, and electrical arc-blast, along with the physiological effects on the human body must be understood by everyone working on or near electrical circuits and equipment.

I. Introduction

Electricity is often referred to as a “silent killer” because it cannot be tasted, seen, heard, or smelled. It is essentially invisible. Electricity has long been recognized as a serious workplace hazard, exposing employees to electrical shock; which can result in electrocution, serious burns, or falls that result in additional injuries or even death; as well as electrical arc-flash and electrical arc-blast.

It is a well known fact that electricity is essential to everyday life, both at home and on the job. Perhaps because it has become such a familiar part of daily life, most people don't give much thought to it or how much our work depends on a reliable source of electricity. More importantly, people tend to overlook the hazards that electricity poses and fail to treat it with the respect it deserves.

Electricity is no respecter of persons; it will injure or kill a custodian, manager, president, or office worker just as fast as it will injure or kill an electrician. The laws of physics for electricity apply to everyone. Some employees work with electricity directly as part of their everyday jobs while

others work with it indirectly, primarily by the use of cord- and plug-connected equipment and tools.

As was noted above, there are several hundred workers injured or killed each year due to inadvertent contact with energized conductors. Surprisingly, over half of those killed are not in tradition electrical fields (i.e. linemen, electricians, technicians, etc.), but are from fields such as painters, laborers, and drivers. [Detailed surveillance data and investigative reports of fatal incidents involving workers who contacted energized electrical conductors or equipment are derived from the National Traumatic Occupational Fatalities (NTOF) surveillance system maintained by the National Institute for Occupational Safety and Health (NIOSH)].

This paper will address the three hazards of electricity mentioned above along with the physiological effects of each.

II. Electrical Shock

A basic understanding of the shock hazard, along with the physiological effects on the human body, is vital to an understanding of electrical safety. The following discussion will address the most common effects of electrical shock.

Electrical shock occurs when a person's body completes the current path between two energized conductors of an electrical circuit or between an energized conductor and a grounded surface or object. Essentially, when there is a difference in potential from one part of the body to another current will flow.

The effects of an electrical shock can vary from a slight tingle to immediate cardiac arrest. The severity depends on several factors:

- Body resistance (wet or dry skin are major factors of resistance)
- Circuit voltage
- Amount of current flowing through the body
- Current path through the body
- Area of contact
- Duration of contact

There have been many studies performed in this area with different values of current that causes each effect. Table 1 illustrates average values of current and the effects as taken from various published studies. [1] [2]. The values listed are average and are not meant to provide specific effects for every person.

Current	Effect
1 mA	barely perceptible
1-3 mA	perception threshold (most cases)
3-9 mA	painful sensations
9-25 mA	muscular contractions (can't let go)
25-60 mA	respiratory paralysis (may be fatal)
60 mA or more	ventricular fibrillation (probably fatal)
4 A or more	heart paralysis (probably fatal)
5 A or more	tissue burning (fatal if vital organ)

Table 1
Current Rang and Effect

Table 2 illustrates comparisons between AC and DC shock. Direct current shocks can be as hazardous as shocks received from alternating current. When working with battery systems, as well as other DC sources, there is also a potential for arc-flash burns or chemical burns.

AC (60 Hz) (mA)	DC (mA)	Effects
0.5 – 1.5	0 – 4	Perception
1 – 3	4 – 15	Surprise (Reaction)
3 – 22	15 – 88	Reflex Action (Let Go)
21 – 40	80 – 160	Muscular Inhibition
40 – 100	160 – 300	Respiratory Block
>100	>300	Usually Fatal

Table 2
AC and DC Shock Comparison

Although the majority of electrocutions are the result of ventricular fibrillation, burns are the most common shock-related injury. An electrical accident can result in an electrical burn, arc burn, thermal contact burn, or a combination of burns. Electrical burns are among the most serious burns and require immediate medical attention. They occur when an electric current flows through tissue or bone, generating heat that causes tissue damage. The body cannot dissipate the heat generated by current flowing through the resistance of the tissue therefore, burns occur. [1]

To further illustrate how easily a person can receive a fatal shock, consider a voltage that is common to every location in the United States, 120-volts. Under average working conditions where the person is perspiring and has a resistance of only 1000-ohms from hand-to-hand, using the simple Ohm's Law formula (current equals the voltage divided by the resistance) the current flow will be 0.12 amperes or 120 mA. Examination of Table 1 shows that this value of current will probably cause ventricular fibrillation which is, in most cases, fatal.

Figure 1 summarizes the overall effects of resistance, voltage, and current in a shock appraisal chart. Notice on this chart that the resistance values are set at a maximum

of 1000 ohms at and beyond the 600-volt level. This is due to the immediate penetration of the skin at the 600-volt shock level, thus allowing the current to travel through the body without the skin resistance being a factor. Entrance and exit wound injuries are generally present when this occurs.

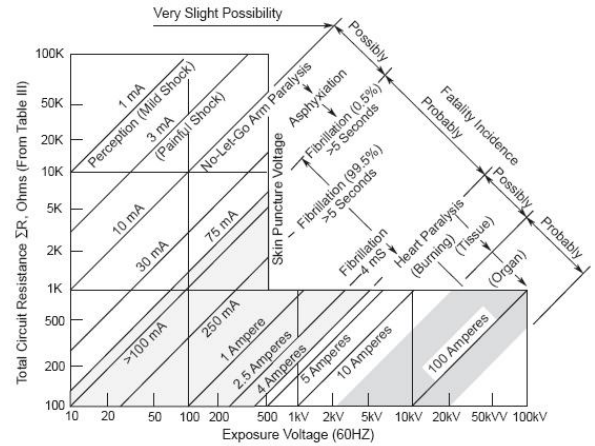


Figure 1
A Resistance-Voltage-Current Shock Appraisal Chart [1]

Some ways to prevent these accidents are through the use of insulation, guarding, grounding, electrical protective devices, and safe work practices.

It is very important that individuals exposed to the hazard of electrical shock be cognizant of the physiological effects of current flowing through the body. It is also important to understand the factors which will reduce or increase the body's resistance. The best practice overall is to STAY OUT OF THE CIRCUIT.

The "Shock Hazard Analysis" required by NFPA 70E-2004 provides the guidance needed to determine the level of shock hazard. This analysis also determines the shock protection boundaries as well as the approach limits for qualified and unqualified employees.

III. Electrical Arc-Flash

The second major hazard of electricity is the electrical arc-flash. Historically the shock hazard has been the most understood and addressed hazard of electricity. The physiological effects of current passing through the body are well documented and accepted by the general industry. However, studies on the causes of electrical injuries show that a large number of serious electrical injuries involve burns from electrical arcs.

There seems to be a serious misconception in the industry that electrical arcs are a product of only high voltage. Actually, the electrical arc-flash is not voltage sensitive but is more a product of short-circuit current and clearing time or arc duration. In some cases, it is possible to generate higher arc energy from a low-voltage source than from a

high-voltage source. The amount of energy will in turn determine the temperature of the arc, which can reach a temperature of 20,000⁰K (Kelvin) or about 35,540⁰F. Some studies report temperatures as high as 34,000⁰K (about 60,740⁰F). The only known source that can produce a higher temperature is the laser, which can produce a temperature of 100,000⁰K (about 179,540⁰F). [3]

There are actually three different issues with the arc-flash hazard, the arc temperature, the incident energy, and the pressure developed by the arc. The main concern with the arc temperature is the flash flame and ignition of clothing. At approximately 203⁰F (96⁰C) for one-tenth of a second (6 cycles), the skin is rendered incurable or in other words a third-degree burn (see Figure 2). The incident energy threshold for the onset of a second degree burn is 1.2 cal/cm². As can be seen by this, it does not take a very high temperature or very much incident energy to cause severe injury, which results in extreme pain and discomfort or death to the worker.

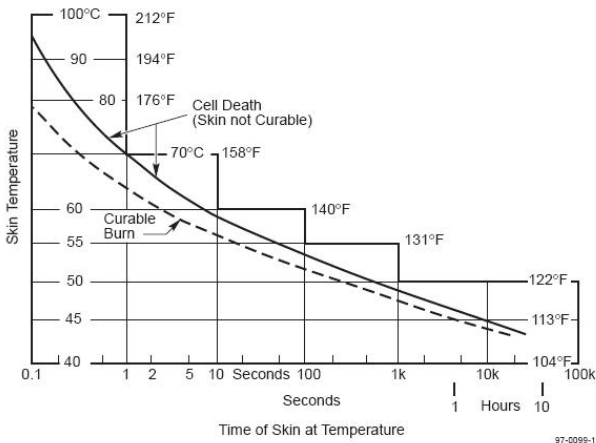


Figure 2
Human Tissue Tolerance [3]

The flash hazard analysis, required by NFPA 70E-2004, is used to determine the incident energy of an electrical arc and to establish the flash protection boundary. This document also requires that a flash hazard analysis be performed “in order to protect personnel from the possibility of being injured by an arc flash.” [5]

Treatment of burns associated with electrical arc is often lengthy. Third and fourth degree burns will usually require significant debridement (surgical removal of dead and damaged skin), skin grafting, and other reconstructive surgery. Other physical trauma, such as kidney damage and failure, heart damage, and infection are common in victims of severe burns. The possibility of infection is particularly great, as the necrotic skin both fosters infection and resists penetration of antibiotics.

The chance of survival of a major body burn, where a significant percentage of the body receives third degree burns, is often less than fifty-fifty. Another common rule of thumb, used by burn center physicians and nurses, is that if the sum of the percentage of the body burned and the

patient's age is greater than 100, the chances of survival are minimal. These grim statistics indicate why it is essential that personnel be trained to avoid the hazard, and how they can protect themselves in the event of an electrical arc-flash exposure. The American Burn Association provides additional statistics concerning the survivability of electrical burns, based on the age of the worker and the percentage of body burn (Figure 3).

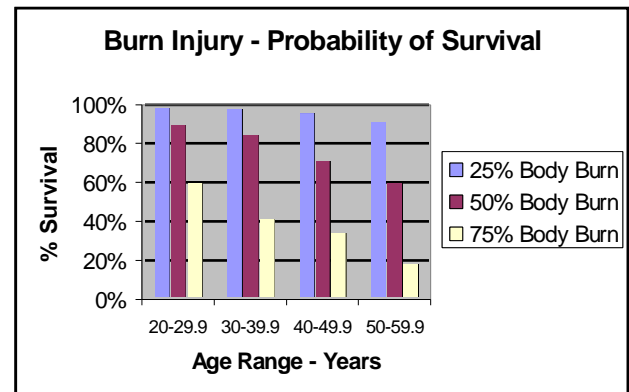


Figure 3
American Burn Association (1991-1993 Study)

The best way to avoid this hazard is to stay away from energized electrical equipment, especially when disconnecting devices are being operated. Never use electrical equipment rooms for storage, break rooms, offices, shops, etc. If a failure of the equipment was to occur and the room was occupied, injuries or fatalities could occur.

IV. Electrical Arc-Blast

The third major hazard of electricity is the rapid expansion of the air caused by an electrical arc. This occurrence is referred to as an electrical arc-blast or explosion.

According to studies on the subject, the pressures from an arc are developed from two sources, the expansion of the metal in boiling and vaporizing, and the heating of the air by passage of the arc through it. Copper expands by a factor of 67,000 times when it vaporizes. This accounts for the expulsion of near-vaporized droplets of molten metal from an arc. These droplets can be propelled for distances of up to 10-feet (3 m). Plasma (ionized vapor) is also generated outward from the arc for a distance proportional to the arc power. One inch³ (16.39 cm³) of copper vaporizes into 1.44 yards³ (1.098 m³) of vapor. The air in the arc stream expands in warming up from its ambient temperature to that of the arc, or about 20,000⁰K (35,540⁰F). The arc-blast created by the heating of the air is similar in nature to the generation of thunder by the passage of lightning through it. [4]

For example, measured pressure differentials from a 100 kA, 10 kV arc reached about 400 lb/ft² (2 x 10⁴ N/m²) at a distance of 3.3 ft. (1 m). This pressure is about ten times the value of wind resistance which walls are normally built to withstand, so such an arc could readily destroy a

conventional wall at a distance of about 33 ft. (10 m), or less. A 25 kA arc could similarly destroy a wall at a distance of 8 ft. (2.4 m). The pressures on an individual from the same 25 kA arc, at a distance of 2 ft. (0.6 m) would be about 160 lb/ft² (7750 N/m²). Since the average person is about three-square feet, this would result in a pressure of about 480 lbs. (2100 N) on the average person's body, Figure 4. [4]

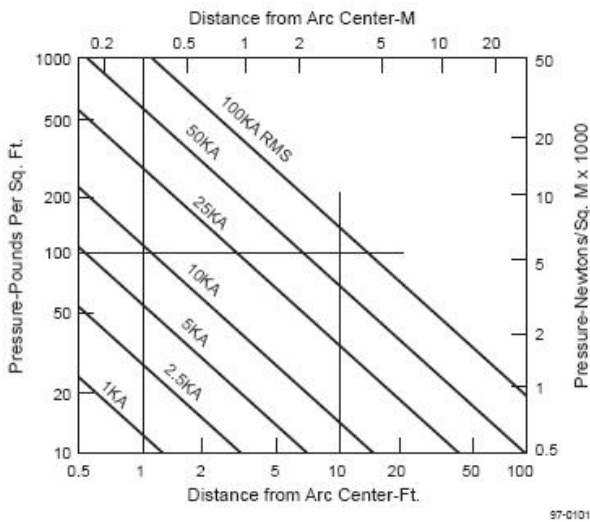


Figure 4
Pressure vs. Distance from Arc

OSHA states: *The pressures developed by high-energy arcs can damage equipment causing fragmented metal to fly in all directions. In atmospheres which contain explosive gases or vapors or combustible dusts, even low-energy arcs can cause violent explosions.* [1]

As in shock and arc-flash damage, the best way to avoid hazards from an arc-blast is to stay away from energized electrical equipment and systems, especially when they are being operated. Unfortunately, technicians that work in the electrical profession are often exposed to this hazard, but exposures can be reduced by not using switchgear rooms as offices, walkways, storage rooms, or for breaks.

Energized electrical systems deserve the same respect as high-pressure steam systems. High-pressure steam or liquid lines are rarely routed through control rooms, yet there are many permanently occupied rooms that contain motor control centers, which represent an equal hazard.

Ralph Lee's paper, entitled "Pressures Developed by Arcs" (IEEE 1987) [4], discusses methods that can be used to determine the amount of damage that a short circuit can cause in switchgear and the buildings where the gear is located.

V. Electrical Hazards Analysis

Due to the seriousness of these three major hazards of electricity, an electrical hazards analysis must be performed. NFPA 70E-2004, *Standard for Electrical Safety*

in the Workplace, contains the requirements for performing these analyses, which includes the Shock Hazard Analysis and the Flash Hazard Analysis.

The electrical hazards analysis will assist in identifying the "Limited Approach Boundary", "Restricted Approach Boundary", "Prohibited Approach Boundary", as well as the "Flash Protection Boundary" (See Figure 5). Understanding these terms is important to understanding electrical shock and electrical arc-flash hazard protection. Below are the definitions of these terms as found in NFPA 70E-2004, Article 100: [5]

Limited Approach Boundary: "An approach limit at a distance from an exposed live part within which a shock hazard exists." [5]

Restricted Approach Boundary: "An approach limit at a distance from an exposed live part within which there is an increased risk of shock, due to electric arc over combined with inadvertent movement, for personnel working in close proximity to the live part." [5]

Prohibited Approach Boundary: "An approach limit at a distance from an exposed live part within which work is considered the same as making contact with the live parts." [5]

Flash Protection Boundary: "An approach limit at a distance from exposed live parts within which a person could receive a second degree burn if an electrical arc flash were to occur." [5]

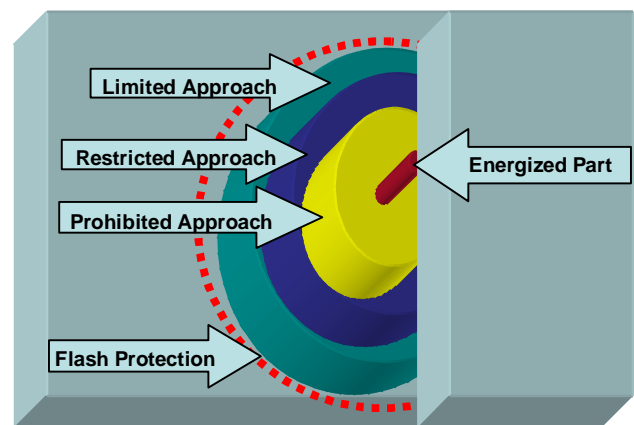


Figure 5
Illustration of Boundaries

VI. Conclusion

The NFPA 70E-2004 states that if circuits, operating at 50 volts or more, are not deenergized (placed in an electrically safe work condition) then other electrical safety-related work practices must be used. These work practices must protect the employee from inadvertent contact with live parts operating at 50 volts or more, as well as from an arc-flash. These analyses must also be

performed before an employee approaches exposed live parts within the Limited Approach Boundary. [5]

Each of the three hazards of electricity (electrical shock, electrical arc-flash and electrical arc-blast) has its own unique characteristics that require special protective measures. Once again, the best way to avoid exposure to these hazards is to STAY OUT OF THE CIRCUIT or to keep as far away as possible from electrical equipment and systems that have exposed live parts or where the electrical equipment is being operated.

Most electrical accidents result from one of the following [1]:

- Unsafe equipment or installation,
- Unsafe environment, or
- Unsafe work practices.

Investigations into these accidents have identified some of the causes of injuries and fatalities and point to several contributing factors [1]:

- Faulty insulation;
- Improper grounding;
- Loose connections;
- Defective parts;
- Ground faults in equipment;
- Unguarded live parts;
- Failure to deenergize electrical equipment when it is being repaired or inspected;
- Intentional use of obviously defective and unsafe tools; and/or,
- Use of tools or equipment too close to energized parts.

Protective equipment and measures have been developed to protect employees from the three hazards of electricity when working on or near 50-volts or more to ground.

As a reminder, more fatalities occur from 120-volts than from any other voltage. Knowledge of CPR and first aid, proper use of personal protective equipment, qualified personnel, and limiting access to electrical equipment can increase safety and decrease injuries and fatalities that occur when working around electrical equipment.

Additionally, electrical accidents are largely preventable through safe work practices. Examples of these practices include, but are not limited to, the following:

- Deenergizing electrical equipment before inspection or repair,
- Keeping electrical tools and equipment properly maintained,
- Exercising caution when working near exposed energized lines and equipment, and
- Using appropriate personal protective equipment and insulated tools.

References

- [1] Occupational Safety and Health Administration (OSHA), Federal Register, 29 CFR 1910, Subpart S, "Electrical Standards", Friday, January 16, 1981.
- [2] Ralph H. Lee, "Electrical Safety in Industrial Plants", IEEE Transactions on Industry and General Applications, Vol. IGA-7, p. 10-16, Jan./Feb. 1971.
- [3] Ralph H. Lee, "The Other Electrical Hazard; Electric Arc Blast Burns", IEEE Transactions on Industry Applications, Vol. IA-18, No. 3, May/June 1982.
- [4] Ralph H. Lee, "Pressures Developed by Arcs", IEEE Transactions on Industry Applications, Vol. IA-23, No. 4, p. 760, July/Aug. 1987.
- [5] National Fire Protection Association, NFPA 70E, Standard for Electrical Safety in the Workplace 2004 Edition.

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