  - Use of insulated tools
  - Minimum approach distances
  - Meter selection/testing/use
  - Electrical rescue/CPR
- Include a pre-task review of the following for supervision of selected electrical work:
  - Goals of the task
  - Task methodology (energized vs. lockout/tagout)
  - Qualifications of assigned personnel — proper instrumentation/tools
  - Adequate protective equipment and usage
  - Methods of preventing a fall should a shock occur
- Perform an inventory of energized electrical circuits with a goal of disconnecting unused circuits from the source and removing the wiring.

Employees must be provided training that includes information about electrical risks, such as inadequate grounding, reverse polarity, and probable electric shock-producing equipment, including extension cords, plugs, and portable power tools. The dangers of energized and unattended appliances should be stressed in this training as well as the theory behind lockout and tagout procedures. Employees working with electricity must also be informed on how to recognize electric shock victims, safe methods of rescue, and cardiopulmonary resuscitation.

G. Designing an electrical system for safety

It is advisable that the electrical safety program includes a process to consider improvements to existing electrical systems and better designs for worker safety for new systems. There are numerous electrical system and equipment design considerations that can improve safety for workers. Some ideas for system design and system upgrades are presented in Suggestions for Limiting the Arc-flash and Shock Hazards, Section X.

V. Electrical Hazards

Electricity has become such an integral part of our society that it often is taken for granted. Yet, electricity remains a very dangerous hazard for people working on or near it. Many electrical circuits do not directly pose serious shock or burn hazards by themselves. However, many of these circuits are found adjacent to circuits with potentially lethal levels of energy. Even a minor shock can cause a worker to rebound into a lethal circuit or cause the worker to drop a tool into the circuit. Involuntary reaction to a shock might also result in bruises, bone fractures, and even death from collisions or falls.

The following are recognized as common electrical hazards that can cause injury, and even death, while a person works on or near electrical equipment and systems:

- Electrical shock
- Electrical burns from contact (current) and flash (radiant)
- Arc-blast impact from expanding air and vaporized materials

In the next several sections, electrical shock, arc-flash, and arc-blast will be discussed in more depth.
In addition, a section on the term "electrically safe work condition" explains the steps necessary to achieve this condition. *NFPA 70E* 110.8(B)(1) requires an electrical hazard analysis if workers will be exposed to electrical parts that have not been placed in an electrically safe work condition. This shall include a Shock Hazard Analysis and Flash Hazard Analysis, which will also be covered in other sections.

> *OSHA 1910 Subpart S - 1910.333(a)*
>
> *Safety-related work practices shall be employed to prevent electric shock or other injuries resulting from either direct or indirect electrical contacts, when work is performed near or on equipment or circuits which are or may be energized. The specific safety-related work practices shall be consistent with the nature and extent of the associated electrical hazards...*

A. Electrical shock

More than 30,000 non-fatal electrical shock incidents are estimated to occur each year. The National Safety Council estimates that from 600 to 1,000 people die every year from electrocution. Of those killed with voltages less than 600V, nearly half were working on exposed energized circuits at the time the fatal injury occurred. Electrocution continues to rank as the fourth highest cause of industrial fatalities (behind traffic, violence/homicide, and construction incidents).

Most personnel are aware of the danger of electrical shock, even electrocution. It is the one electrical hazard around which most electrical safety standards have been built. However, few really understand just how little current is required to cause injury, even death. Actually, the current drawn by a 7½W, 120V lamp, passing across the chest, from hand-to-hand or hand-to-foot, is enough to cause fatal electrocution.

The effects of electric current on the human body depend on the following:

- Circuit characteristics (current, resistance, frequency, and voltage)
- Contact resistance and internal resistance of the body
- The current's pathway through the body, determined by contact location and internal body chemistry
- Duration of the contact
- Environmental conditions that affect the body's contact resistance

To understand the currents possible in the human body, it is important to understand the contact resistance of skin (see Table V(A)(1)). The skin's resistance can change as a function of the moisture present in its external and internal layers, with changes due to such factors as ambient temperatures, humidity, fright, and anxiety.

Table V(A)(1). Human Resistance Values for Skin-Contact Conditions*

	Resistance (ohms)	
Condition	Dry	Wet
Finger touch	40,000 to 1,000	4,000 to 15,000
Hand holding wire	15,000 to 50,000	3,000 to 6,000
Finger-thumb grasp	10,000 to 30,000	2,000 to 5,000
Hand holding pliers	5,000 to 10,000	1,000 to 3,000
Palm touch	3,000 to 8,000	1,000 to 2,000
Hand around 1½ inch pipe	1,000 to 3,000	500 to 1,500
Two hands around 1½ inch pipe	500 to 1,500	250 to 750
Hand immersed		200 to 500
Foot immersed		100 to 300
Human body, internal, excluding skin	200 to 1,000	

*This table was compiled from data developed by Kouwenhoven and Milnor.

Body tissue, vital organs, blood vessels and nerve (non-fat) tissue in the human body contain water and electrolytes, and are highly conductive with limited resistance to alternating electrical current. As the resistance of the skin is broken down by electrical current, resistance drops and current levels increase.

The human body could be considered as a resistor with hand-to-hand resistance (R) of only 1,000 Ohms. The voltage (V) determines the amount of current passing through the body.

While 1,000 Ohms might appear to be low, even lower levels can be approached by a person with sweat-soaked cloth gloves on both hands and a full-hand grasp of a large, energized conductor and a grounded pipe or conduit. Moreover, cuts, abrasions or blisters on hands can negate skin resistance, leaving only internal body resistance to oppose current flow. A circuit in the range of 50V could be dangerous in this instance.

Ohm's Law: I (amps) = V (volts) / R (ohms)

Example 1: I = 480 / 1000 = 480mA (or 0.480A)

Product standards consider 4 to 6mA to be the safe upper limit for children and adults (hence the reason a 5-milliamp-rated GFCI circuit).

Note: *GFCIs do not protect against a line-to-neutral or a line-to-line shock.*

Electrical currents can cause muscles to lock up, resulting in an inability of a person to release his or her grip from the current source. This is known as the "let-go" threshold current. This current level varies with the frequency (see Table V(A)(2)). DC currents usually cause a single twitch and are considered less dangerous at lower voltage levels. Alternating currents in the frequency range of skeletal muscles (40 to 150Hz) are more serious (e.g., 60Hz).

At 60Hz, most females have a "let-go" limit of about 6 milliamperes (mA), with an average of 10.5mA. Most males have a "let-go" limit above 9mA, with an average of 15.5mA. (These limits are based on smaller average size of females. Therefore, a small man could have a lower limit, or a larger woman a higher limit.)

Sensitivity, and potential injury, also increase with time. A victim who cannot "let go" of a current source is much more likely to be electrocuted than someone whose reaction removes them from the circuit more quickly. The victim who is exposed for only a fraction of a second is less likely to sustain an injury.

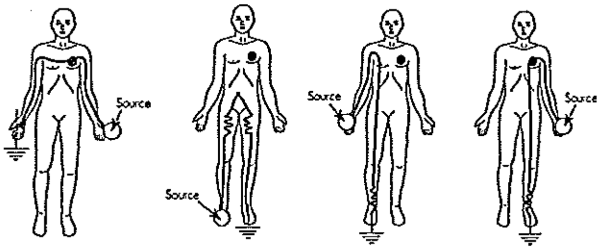
The most damaging path for electrical current is through the chest cavity (see A and D in Figure V(A)) and head. In short, any prolonged exposure to 60Hz current of 10mA or more might be fatal. Fatal ventricular fibrillation of the heart (stopping of rhythmic pumping action) can be initiated by a current flow of as little as several milliamps. These injuries can cause fatalities resulting from either direct paralysis of the respiratory system, failure of the rhythmic heart pumping action, or immediate heart stoppage.

Table V(A)(2). The Effects of Electrical Current on the Body*

Effects	Current (mA)					
	Direct Current		Alternating Current			
			60Hz		10Hz	
	Men	Women	Men	Women	Men	Women
Slight sensation on hand	1	0.6	0.4	0.3	7.0	5.0
Median perception threshold	6.2	3.5	1.1	0.7	12.0	8.0
Shock-not painful; without loss of muscular control	9.0	6.0	1.8	1.2	17.0	11.0
Painful shock-threshold for muscular control loss	62.0	41.0	9.0	6.0	55.0	37.0
Painful shock-median "let-go" threshold	76.0	51.0	16.0	10.5	75.0	50
Painful and severe shock-breathing difficult; loss of muscular control	90.0	60.0	23.0	15.0	94.0	63.0

* Modified from *Deleterious Effects of Electric Shock* by Charles F. Dalziel.

During fibrillation, the victim might become unconscious. On the other hand, he or she might be conscious, deny needing help, walk a few feet, and then collapse. Death could occur within a few minutes or take hours. Prompt medical attention is needed for anyone receiving electrical shock. Many of these people can be saved, provided they receive proper medical treatment, including cardiopulmonary resuscitation (CPR) quickly.



(A) Touch Potential (B) Step Potential (C and D) Touch/Step Potential

Figure V(A). Current Pathways through the Body

Table V(A)(3). Effects of Electrical Shock (60Hz AC)

Response*	60hz, AC Current
Tingling sensation	0.5 to 3mA
Muscle contraction and pain	3 to 10mA
"Let-go" threshold	10 to 40mA
Respiratory paralysis	30 to 75mA
Heart fibrillation; might clamp tight	100 to 200mA
Tissue and organs burn	More than 1,500mA

* The degree of injury also depends on the duration and frequency of the current.

Think of electrical shock injuries as "icebergs," where most of the injury is unseen, below the surface. Entrance and exit wounds are usually coagulated areas and might have some charring, or these areas might be missing, having "exploded" away from the body due to the level of energy present. The smaller the area of contact, the greater the heat produced. For a given current, damage in the limbs might be the greatest, due to the higher current flux per unit of cross-sectional area.

Within the body, the current can burn internal body parts in its path. This type of injury might be difficult to diagnose, as the only initial signs of injury are the entry and exit wounds. Damage to the internal tissues, while not apparent immediately, might cause delayed internal tissue swelling and irritation. Prompt medical attention can minimize possible loss of blood circulation and the potential for amputation of the affected extremity, and can prevent death.

All electrocutions are preventable. A significant part of the OSHA standard is dedicated to electrical safety. It would be an oversimplification to state that everyone should comply with the standards. However, OSHA standard compliance is considered a minimum requirement and seen as a very good place to start for improving the safety of the workplace.

Any time an electrocution occurs, potential for both a civil lawsuit and an OSHA citation exists. It is always a good proactive measure to review internal safety procedures when investigating industrial incidents. The investigator must make sure that he or she has an accurate set of facts to work with. Incidents are always costly, and most can be avoided.

Several standards offer guidance regarding safe approach distances to minimize the possibility of shock from exposed electrical conductors of different voltage levels. The most recent, and probably the most authoritative guidance, is presented in *NFPA 70E*. Safe approach distances to exposed energized electrical conductors are discussed in Section IX(D) of this handbook.

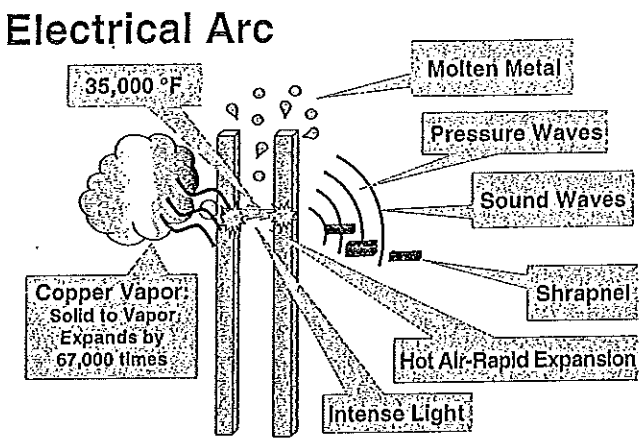
B. Arcing faults: arc-flash and arc-blast

1. Arc fault basics

Following is a graphical model of an arcing fault and the physical consequences that can occur. The unique aspect of an arcing fault is that the fault current flows through the air between conductors or a conductor(s) and a grounded part. The arc has an associated arc voltage because there is arc impedance. The product of the fault current and arc voltage in a concentrated area, results in tremendous energy being released in several forms.

The resulting energies can be in the form of radiant heat, intense light, and tremendous pressures. Intense radiant heat from the arcing source travels at the speed of light. The temperature of the arc terminals can reach approximately 35,000°F, or about four times as hot as the surface of the sun. No material on earth can withstand this temperature. The high arc temperature changes the state of conductors from solid to hot molten metal and to vapor. The immediate vaporization of the conductors is an explosive change in state from solid to vapor. Copper vapor expands to 67,000 times the volume of solid copper. Because of the expansive vaporization of conductive metal, a line-to-line or line-to-ground arcing fault can escalate into a three-phase arcing fault in less than a thousandth of a second.

The extremely high release of thermal energy superheats the immediate surrounding air. The air also expands in an explosive manner. The rapid vaporization of conductors and superheating of air result in high pressure waves and a conductive plasma cloud, that if large enough, can engulf a person. The thermal shock and pressures can violently destroy circuit components. The pressure waves hurl the destroyed, fragmented components like shrapnel at high velocity; shrapnel fragments can be expelled in excess of 700 miles-per-hour. Molten metal droplets at high temperatures typically are blown out from the event due to the pressure waves.



Testing has proven that the arcing fault current magnitude and time duration are the most critical variables in determining the energy released. It is important to note that the predictability of arc-faults and the energy released by an arc-fault is subject to significant variance. Some of the variables that affect the outcome include: available bolted short-circuit current, the time the fault is permitted to flow (speed of the overcurrent protective device), arc gap spacing, size of the enclosure or no enclosure, power factor of fault, system voltage, whether the arcing fault can sustain itself, type of system grounding scheme, and distance the worker's body parts are from the arc. Typically, engineering data that the industry provides concerning arcing faults is based on specific values of these variables. For instance, for 600V and less systems, much of the data has been gathered from testing on systems with an arc gap spacing of 1.25 inches and incident energy determined at 18 inches from the point of the arc-fault.

2. Arc-flash and arc-blast

As previously discussed an arcing fault releases thermal energies and pressure. The effects of arcing faults can be broadly categorized as arc-flash and arc-blast. The arc-flash is associated with the release of tremendous thermal energies and the arc-blast is associated with the release of tremendous pressure. The industry is devising ways to quantify the risks associated with arc-flash hazards. However, there is little or no information on arc-blast hazard risk assessment or on protecting workers due to the arc-blast hazard. Neither *NFPA 70E* nor the current edition of IEEE 1584 *Guide For Performing Arc-flash Hazard Calculations,* account for the pressure and shrapnel that can result due to an arcing fault.

3. How arc-faults can affect humans

Nearly everyone is aware that an electrical shock is a hazard that can ultimately lead to death. In fact, while many people have experienced minor shocks, few have realized any real consequences, making them somewhat complacent. In contrast, few people are aware of the extreme nature of electrical arc-faults; the potential of severe burns associated from arc-flash and the potential injuries due to high pressures from arc-blast. But this is starting to change, people are learning that the effects of an arcing fault can be devastating to humans.

In recent years, awareness of arc-flash hazards has been increasing. Recent studies of reported electrical injuries have indicated that as many as 80 percent of documented injury cases were burns resulting from exposure to electrical arcs. In addition, each year more than 2,000 people are admitted to burn centers in the U.S. with severe electrical burns. Electrical burns are considered extremely hazardous for a number of reasons. One important reason is that contact with the circuit is not necessary to incur a serious, even deadly, burn. Serious or fatal burns can occur at distances of more than 10 feet from the source of a flash.

Since burns are such a prevalent consequence of electrical incidents, the three basic types are mentioned below. These can be due to contact (shock hazard) or arc-flash.

- **Electrical burns due to current flow** — tissue damage (whether skin deep or deeper) occurs because the body is unable to dissipate the heat from the current flow through the body. The damage to a person's tissue can be internal and initially not obvious from external examination. Typically, electrical burns are slow to heal and frequently result in amputation.
- **Arc burns by radiant heat** — caused by electrical arcs. Temperatures generated by electric arcs can burn flesh and ignite clothing at distances of 10 feet or more.
- **Thermal contact burns** — normally experienced from skin contact with the hot surfaces of overheated electric conductors or a person's clothing apparel that ignites due to an arc-flash.

The human body survives in a relatively narrow temperature range around 97.7°F. Studies show that when the skin temperature is as low as 110°F, the body's temperature equilibrium begins to break down in about 6 hours. At 158°F, only one second duration is sufficient to cause total cell destruction. Human skin at temperatures of 205°F for more than one-tenth of one second can cause incurable, third-degree burns (see Table V(B)).

Table V(B). Skin Temperature Tolerance Relationship

Skin Temperature	Duration	Damage Caused
110°F	6.0 hours	Cell breakdown begins
158°F	1.0 second	Total cell destruction
176°F	0.1 second	Curable (second-degree) burn
205°F	0.1 second	Incurable (third-degree) burn

For evaluating burns, protective proprieties of personal protection equipment, and the thermal energy resulting from an arc-flash, the industry has progressed to utilizing calories/centimeters^2 (cal/cm^2) as a unit of measure. For instance, the incident energy is a measure of thermal energy at a specific distance from an arc-fault; the unit of measure is typically in cal/cm^2. Another example where cal/cm^2 is used as a measure is for various types of PPE with distinct levels of thermal protection capabilities rated in cal/cm^2.

1.2 cal/cm^2 is considered the threshold for a curable (second-degree) burn.

Note: *medical treatment may still be required if bare skin is exposed to this level of flash — full recovery would be expected.*

In addition to burn injuries, victims of arcing faults can experience damage to their sight, hearing, lungs, skeletal system, respiratory system, muscular system, and nervous system. The speed of an arcing fault event can be so rapid that the human system can not react quickly enough for a worker to take corrective measures. The radiant thermal waves, the high pressure waves, the spewing of hot molten metal, the intense light, the hurling shrapnel, and the hot, conductive plasma cloud can be devastating in a small fraction of a second. The intense thermal energy released can cause severe burns or ignite flammable clothing. Molten metal blown out can burn skin or ignite flammable clothing. Failure to remove or extinguish burning clothing quickly enough can cause serious burns over much of the body. A person can gasp and inhale hot air and vaporized metal sustaining severe injury to their respiratory system. The tremendous pressure blast from the vaporization of conducting materials and superheating of air can fracture ribs, collapse lungs and knock workers off ladders or blow them across a room.

What is difficult for people to comprehend is that the time in which the arcing fault event runs its course may only be a small fraction of a second. In a matter of only a thousandth of a second or so, a single phase arcing fault can escalate to a three phase arcing fault. Tremendous energies can be released in a few hundredths of a second. Humans can not detect, much less comprehend and react to events in these time frames.

There is a greater respect for arcing fault and shock hazards on medium and high voltage systems. However, injury reports show serious accidents are occurring at an alarming rate on systems of 600V or less (notably 480V systems and to a lesser degree 208V systems), in part because of the high fault currents that are possible. But also, designers, management and workers mistakenly tend not to take the necessary precautions that they take when designing or working on medium and high voltage systems.

VI. The Role of Overcurrent Protective Devices In Electrical Safety

If an arcing fault occurs while a worker is in close proximity, the survivability of the worker is mostly dependent upon (1) the characteristics of the overcurrent protective devices, (2) the arc-fault current, and (3) precautions the worker has taken prior to the event, such as wearing personal protective equipment appropriate for the hazard. The selection and performance of overcurrent protective devices play a significant role in electrical safety. Extensive tests and analysis by industry have shown that the energy released during an arcing fault is related to two characteristics of the overcurrent protective device protecting the affected circuit:

1. The time it takes the overcurrent protective device to open. The faster the fault is cleared by the overcurrent protective device, the lower the energy released.
2. The amount of fault current the overcurrent protective device lets through. Current-limiting overcurrent protective devices may reduce the current let-through (when the fault current is within the current-limiting range of the overcurrent protective device) and can reduce the energy released.

Lowering the energy released is better for both worker safety and equipment protection. The photos and recording sensor readings from actual arcing fault tests (next page) illustrate this point very well. An ad hoc electrical safety working group within the IEEE Petroleum and Chemical Industry Committee conducted these tests to investigate arc-fault hazards. These tests and others are detailed in "Staged Tests Increase Awareness of Arc-Fault Hazards in Electrical Equipment," *IEEE Petroleum and Chemical Industry Conference Record*, September 1997, pp. 313-322. This paper can be found at www.bussmann.com under Services/Safety BASICs. One finding of this IEEE paper is that current-limiting overcurrent protective devices reduce damage and arc-fault energy (provided the fault current is within the current-limiting range). To better assess the benefit of limiting the current of an arcing fault, it is important to note some key thresholds of injury for humans. Results of these tests were recorded by sensors on mannequins and can be compared to these parameters: