Arc of Protection—Managing Electrical Risks

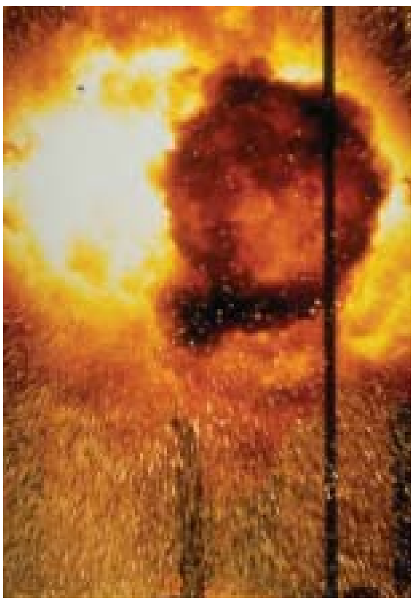
Strategies for employees who work on or near electrical systems

By Chip Malboeuf

Are you worried about an electric shock when you replace a light bulb? Most people have a false sense of security when it comes to electricity.

Electricity is essential to everyday life. It's all around us at our workplace and at home. It's perhaps due to this "familiarity" that electricity does not always receive the respect that it deserves. Electricity has long been known as the "silent killer." We cannot see it, taste it, hear it or smell it but electricity can kill you. Electricity doesn't discriminate against anyone; it will kill a soil room employee, custodian, supervisor, or office worker just as easy as it will kill a maintenance worker.

This article will discuss the basic principals of electricity, its effects on the human body when mishandled and how we can prevent injuries in our facilities due to electrical shock and arc flash/blast.

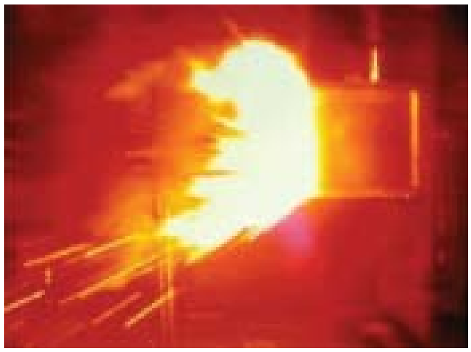


Three vivid examples of arc blasts that illustrate how failing to safeguard electical systems can lead to life-threatening accidents.

Electricity 101

To comprehend the power and dangers of electricity you must first understand some basic definitions and concepts (laws) of electricity. First, some basic electrical definitions:

- Electricity – the flow of atoms through a conductor.
- Voltage (V) – the fundamental force, or pressure, that allows electricity to flow through a conductor. Low voltage is defined as any voltage less than 600 V.
- Resistance (R) – anything that impedes the flow of electricity. Expressed in ohms.
- Current (I) – the flow of electrons from a source of voltage through a conductor (measured in amperes [amps]).
- Ohm's Law – used to relate voltage, resistance and current (I=V/R)
- Ground – a conducting connection, whether intentional or not, between an electric circuit or equipment and the earth or to some conducting body that serves in place of the earth.



With these basic definitions in mind, we can discuss how electricity works and some basic laws that electricity follows.

- The source of electricity is a power station. The electrical current is then transferred through wires and a generator forces the flow through these wires.
- Electricity always travels in a completed circuit. When you switch on equipment in your facility, you complete the circuit. Electricity flows along power lines to the outlet, through the power cord into the equipment, then back through the cord to the outlet and out to the power lines again.
- Electricity will always travel in the path of least resistance. Everything has a certain level of resistance when electricity tries to flow through it. When electricity is attempting to complete its circuit, it will always choose the path that provides the least amount of resistance.

- Electricity will always try to get to the ground. If electricity is traveling through a circuit and finds something that conducts electricity and will complete the circuit, such as metal, wood or water, it will try to pass through the conductor directly to ground.

Exposure and effects

Exposure to electricity can cause electrocution, electric shock, burns and/or falls. Injuries from electricity are caused in one of the following ways:

- Direct contact
- Arcs (Flash and Blast)
- Flash burns
- Flame burns

Direct contact injuries

Electrocution and electric shock are similar events that occur as a result of direct contact with electricity (with electrocution being fatal). The Bureau of Labor Statistics notes that 10% of all occupational fatalities are due to electrocutions. When you are electrocuted or shocked your body becomes an active part of the circuit. The severity of the injuries is a function of the current's magnitude and the duration of the exposure. Table 1 relates the amount of exposure and the potential outcome as a result of this exposure.

Water is a good conductor of electricity. Since our bodies are made up of mostly water, we too are good conductors of electricity. Water becomes an excellent conductor of electricity when mixed with salt and acid. Both salt and acid are present in our perspiration, thus the addition of these two elements can make us an even better conductor of electricity. The risk of electric shock increases greatly when water is present on your skin or in the environment around you.

The following is a simplified example of how water on the skin, exposed to low voltage is a potentially dangerous combination.

Given:

- Human body's resistance (dry) = 100,000 ohms
- Human body's resistance (wet) = 1,000 ohms
- 120 volt circuit

Recall Ohms Law I = V/R

Calculation of current under dry conditions:

- I = 120 volts / 100,000 ohms
- I = 1 mA (0.001 Amps)
- 1 mA is barely perceptible to the human body

Calculation of current under wet conditions:

- I = 120 volts / 1,000 ohms
- I = 120 mA (0.120 Amps)
- 120 mA is sufficient to cause ventricular fibrillation.

At this level of exposure the victim is unable to let go of the circuit. This is a common scenario in a low-voltage electrocution. 120 volt circuits are very common in our facilities and our homes. Consider the increased risk present in the higher voltages in our facilities.

Table 1: Exposure levels and their effect on the human body

Readings		Effects
Safe Current Values	1 mA or less	Causes no sensation – body does not feel the shock
	1 mA to 8 mA	Sensation of shock, not painful. Individual can let go at will since muscular control is not lost.
Unsafe Current Values	8 mA to 16 mA	Painful shock. Individual can let go at will since muscular control is not lost.
	16 mA to 20 mA	Painful shock. Control of adjacent muscles lost. The victim cannot let go.
	50 mA to 100 mA	Ventricular fibrillation is possible. Ventricular fibrillation is a heart condition that can result in death.
	100 mA to 200 mA	Ventricular fibrillation occurs.
	200 mA and over	Severe burns, severe muscle contractions. Contractions so severe that chest muscles clamp the heart and stop it for the duration of the shock.

Arcs, flash burns and flame burns

An electric arc is a phenomenon that occurs when electricity jumps (arcs) from a voltage source to a potential ground. The arc can occur when a conductive metal, i.e. a tool, is placed too close to the voltage source. The conductor does not have to come in contact with the voltage source, just get close enough for the current to "jump" over to the conductor. Arcs can even be caused by disturbing dust particles in an energized distribution system.

The temperature of an arc flash can reach more than 5,000° F as it creates a brilliant flash of light and a loud noise. The arc flash has an enormous amount of energy. The energy explodes outward from the electrical equipment, spreading hot gases and melting metal. The explosion creates extreme pressure waves that can damage hearing or brain function. The flash is so intense that it can damage eyesight. The fast moving pressure will also send loose material such as tools, pieces of equipment and other objects flying, injuring anyone standing nearby. All this takes place in less than one second. Secondary injuries from an arc flash include flash and flame burns. The flash and flame burns are usually very severe (second and third degree burns).

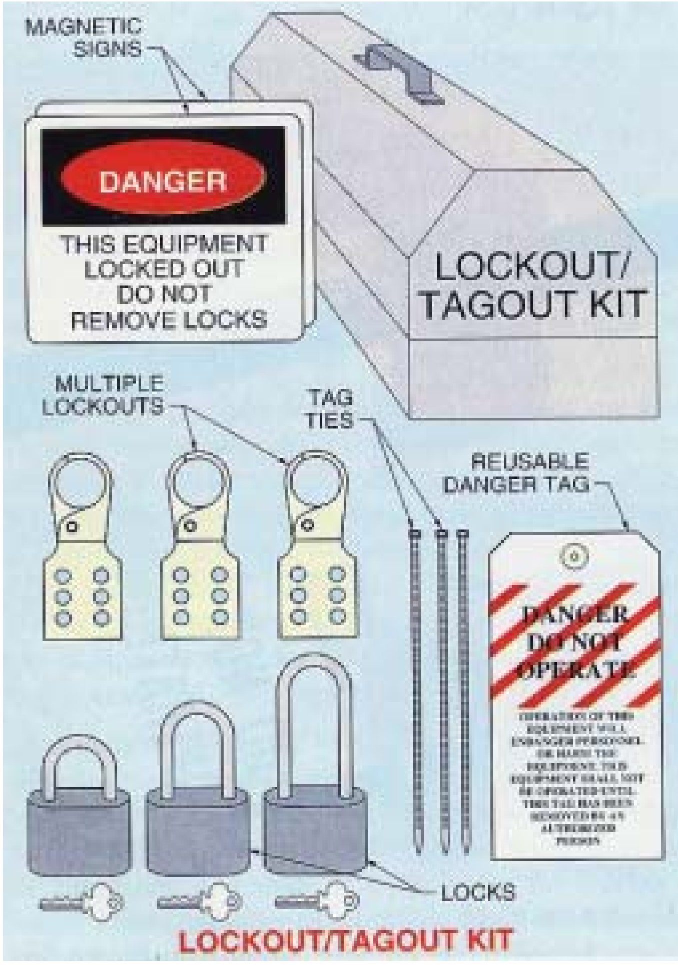
Electrical injury prevention

Working with, or around, electricity is dangerous. Therefore we must take the necessary precautions to protect ourselves and anyone else who's working around electricity. The first line of defense is to avoid working on or near live parts whenever possible. One of the key safety procedures in our facilities is Lockout/Tagout (LOTO). Following LOTO guidelines will ensure that all power sources for a piece of equipment are de-energized. Always treat equipment as if it were energized until you are certain it is not. After the equipment has been locked and tagged, check to see if energy is stored within any electrical storage device (capacitors) and release that energy. You can still be killed or injured by equipment that is shut down if all the electricity is not released from the system.

An improperly sized extension cord opens the door to arc or shock.

Very rarely in our industry do we *have* to work on live equipment. If you can't de-energize a piece of equipment or switchgear, you must take precautions to reduce the chances of accidental contact. Whenever possible, you need to isolate the live piece of equipment to prevent inadvertent contact by others. The live equipment can be

A damaged cable is a serious electrical hazard.



Following Lockout/Tagout procedures is an important way to avoid injuries when working with electrically powered equipment.

Cords without ground plugs expose individuals to becoming the ground path for electricity.

isolated either by moving the equipment to a locked room or by placing barriers around the equipment.

If you must work on live equipment or systems, regardless of the voltage, workers must follow the National Fire Protection Association's (NFPA) Electrical Safety Requirements for Employee Workplaces (NFPA 70E). NFPA 70E helps eliminate some of the risk that workers are exposed to when working on energized equipment.

If an employee works on energized equipment, NFPA 70E requires them to wear the proper personal protective equipment

(PPE). To determine the proper equipment, they must first know the hazard risk category of the equipment they are working on. NFPA 70E requires the employer to conduct a Flash Hazard Analysis in order to define the hazard risk category. The analysis is very technical and requires intimate knowledge of the electrical system. The following table is a summary taken from NFPA 70E describing the various Hazard Risks and the required PPE when working within the Flash Protection Boundary of energized equip-

Task (Assumes equipment is energized and work is done within Flash Protection Boundary)	Hazard/ Risk Category	Voltage Rated Gloves	Voltage Rated Tools
Panel boards rated less than 240V			
Work on energized parts, including voltage testing	1	Y	Y
Remove/install circuit breakers or fused switches	1	Y	Y
Panel boards or Switchboards rated between 240V and 600V			
Work on energized parts including voltage testing	2*	Y	Y
600V Motor Control Centers (MCC)			
Work on energized parts including voltage testing	2*	Y	Y
Work on control circuits with exposed energized parts 120 volts, or below	0	Y	Y
Work on control circuits with exposed energized parts 120V >	2*	Y	Y
Insertion or removal of individual starter “buckets” from MCC	3	Y	N
Application of safety grounds after voltage test	2*	Y	N
600V Switchgear			
Work on energized parts including voltage testing	2*	Y	Y
Work on control circuits with energized parts 120V or below, exposed	0	Y	Y
Work on control circuits with energized parts 120V >, exposed	2*	Y	Y

Hazard Category -1:	Will consist of T-shirt, long pants and undergarments all made of untreated 100% natural fibers and safety glasses.
Hazard Category 0:	Will consist of long sleeve shirt, long pants and undergarments all made of untreated 100% natural fibers and safety glasses.
Hazard Category 1:	Will consist of regular weight, untreated, denim cotton jeans in lieu of Flame Resistant (FR) pants with a minimum arc rating of 4 Cal/cm^2, long sleeved FR shirt with a minimum arc rating of 4 Cal/ cm^2, a hard hat and safety glasses. FR treated coveralls with a minimum arc rating of 4 Cal/ cm^2 may be used as an alternate to FR shirt and pants.
Hazard Category 2:	Will consist of untreated 100% natural fiber garments beneath either: A) FR treated long sleeve shirt and FR treated pants with a minimum arc rating of 8 Cal/cm^2 **or** B) FR treated coverall with a minimum arc rating of 4 Cal/cm^2 and a hard hat, safety glasses or goggles, an arc rated face shield with a minimum arc rating of 8 Cal/cm^2, hearing protection (ear canal inserts), leather gloves (protectors) and leather work shoes. The arc face shield must wrap-around, shielding not only the face but also the forehead, ears and neck.
Hazard Category 3 & 4	Will consist of the same requirements as Category 2*, but with the minimum arc rating of 25 Cal/cm^2 for Category 3 and a minimum arc rating of 40 Cal/cm^2 for Category 4.

Where 2* is indicated, hard hat and face shield are replaced by an appropriately rated double layer switching hood, in addition to the rest of the prescribed category 2 PPE.

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ment.

For electrical systems less than 600 volts, NFPA 70E defines the default flash protection boundary as four feet. Anyone within this boundary must wear the proper PPE as defined in the above tables. The PPE required for Hazard Categories 1, 2, 3 and 4 is not always comfortable to wear. The use of large uncomfortable PPE is a small price to pay to ensure that the worker returns home safely on any given day. No matter how uncomfortable the PPE is, you must wear it.

Other NFPA 70E guidelines:

- Employees also need to use the proper tools. All tools should be rated for working on electrical equipment. You should conduct tool audits to ensure that employees have safe tools for the job and to determine whether new tools need to be purchased.
- NFPA 70E also requires that you place a label on any piece of equipment or system where an arc flash is possible. You must place a label on the equipment warning that such a hazard exists.
- Not only is a company responsible for ensuring that its own employees comply with NFPA 70E, they are also responsible for any hired electrician and other installers in their facility.

The easiest way to comply with the requirements of NFPA 70E is to de-energize all equipment before working on it.

Recognizing workplace hazards

Below are some steps you can take to protect yourself and others around the facility:

- **Periodic inspections of portable equipment—**Portable electrical equipment must be handled in a manner that will not damage the cord. Working with damaged cords can cause electric shocks and fires. If there is evidence of damage to the cord, the damaged equipment must be removed from service, and no one should be allowed to use the equipment until it's repaired and tested for safety. Never use portable equipment if you or the environment is wet.
- **Properly size and install cable per the National Electric Code—**Ensure the cables are properly sized for voltage drop and ambient temperatures around the cable. Undersizing cable can result in failure to the cable's insulation and increase the likelihood of shock, arcing and/or cable failure.
- **Ensure proper use of extension cords—**Unsafe use of extension cords is one of the most frequently violated electrical standards. There is a definite need and place for extension cords, but there is a temptation to misuse them because they offer a quick and easy way to carry electricity. Extension cords are only a temporary solution. Extension cords are more vulnerable than fixed wiring and are more likely to be damaged by carts. Before each shift, all extension cords should be visually inspected for exposed wiring. Never use a damaged extension cord. If an extension cord has been in continuous use for more than a week, replace the extension cord with a properly installed, permanent fixed circuit.
- **Equipment grounds—**Ensure all equipment and cords are properly grounded. A proper ground prevents dangerous electrical currents from flowing through your body. Do not allow employees to cut off the ground plug on a three-prong plug. The ground plug provides a path to ground for any electricity that strays or leaks from the equipment. If the prong is removed, this eliminates the ground path and exposes you to becoming that ground.

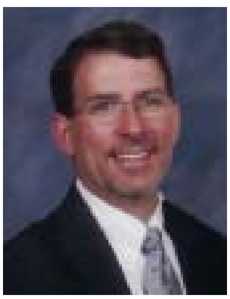
What should I do?

If a co-worker is shocked or burned by electricity, the first course of action should be to turn off the electric circuit if the victim is still in contact with the energized circuit. This is why it is so important to place labels on each piece of equipment. The labels should indicate where all power sources of the equipment originate from. When someone is being shocked, time is of the essence. A properly labeled piece of equipment will instruct a co-worker where to find the disconnect switch that will de-energize the circuit. Without proper labeling, it could take many minutes for the co-worker to find the disconnect switch. Minutes that could cost the victim his or her life.

If someone is being shocked by electricity do not touch the victim if he is still in contact with the energized circuit. If he is still in contact with the energized circuit and you touch him, you'll become a path to ground and will also be shocked. If you cannot de-energize the circuit, use a non-conductive item to pry the victim from the circuit. Do not use a metal rod or wet piece of wood to pry them away.

As soon as the victim is removed from the energized circuit, call emergency medical services. If the person is conscious, tell them not to move. Keep the victim calm until help arrives. If the victim is not breathing, administer CPR.

Electricity is commonplace in our facilities and in everyday life. When working around electricity, do not become complacent. Remember, more fatalities occur from 120 volts than any other voltage. Electrical accidents are preventable through safe work practices. *Respect all voltages*, have knowledge of the principles of electricity and follow safe work procedures. *Do not take chances.* TR



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