# ELECTROLYTIC CELL SAFETY

## GENERAL DESCRIPTION OF ELECTROLYTIC CELL PROCESS

Electrolytic cell processes exist typically in medium to large industrial environments to produce commodity materials, such as aluminum, cadmium, chlorine, copper, fluorine, hydrogen peroxide, magnesium, sodium, sodium chlorate, and zinc. The electrolytic cell process involves a chemical reaction that occurs through ionic mechanisms by adding electrical energy to a reactor or cell arrangement. The cell is a container made of suitable materials for the chemicals involved and has positive and negative electrodes, electrically isolated from each other but both in contact with an electrolyte of sufficiently high electrical resistance so as not to cause a short circuit when energy is applied. The ionic reactions occur at the cell electrodes, the anode and cathode, as electric energy is applied by an external circuit flowing direct current (dc) through the electrolyte. Then materials produced from this reaction are separated, combined, conditioned, or otherwise handled as required by the particular process involved. The reverse of the electrolytic cell process is known as the galvanic cell process where electric energy is produced at the electrodes through ionic reaction among the anode, cathode, and electrolyte. A familiar example of a galvanic process is the typical storage battery. Both electrolytic and galvanic cell processes can be reversed for a relatively short time by adding or removing electric energy.

All electrolytic cell processes utilize similar physical mechanisms at the ionic level. They differ widely, however, in physical and electrical characteristics from one industry to another as well as among the same or similar industry process. Many of these processes are proprietary. Electrolytic cell processes may be operated indoors or outdoors, in wet or dry locations, are electrically connected to auxiliary equipment, such as pumps, piping, or structures, may be located on the ground floor or above ground level, and may vary greatly in operating voltage and current. The installation and its associated attachments, process connections, electrical conductors, and process equipment, are custom designed for each facility. In terms of electrical circuits, electrolytic cell processes are unique in that their construction, operation, and maintenance methods are much different than those of other power distribution or control. Energized electrical conductors for the cell line, such as cell surfaces, attachment and intercell bus, and process piping are typically installed uninsulated and exposed. Normal maintenance and operation of the process requires that personnel contact these exposed energized surfaces on a regular basis. Maintenance and operating procedures involve intentionally shorting or grounding portions of the cell circuit for repair or equipment replacement, all with the circuit energized. Process control adjustments and sampling by personnel are accomplished by contact with electrically energized surfaces. Thus, exposure of personnel to electrical hazards in electrolytic cell processes is quite different from other processes having electrical circuits, and this exposure is more frequent. The electrolytic cell industry, however, is well established, and has been safely operating facilities for many years using proper hazard identification, personnel protection, education, and administrative controls. This protective and administrative control effort is as much a part of conducting this industry's business as quality control or cost management and is viewed as a responsibility that must be fulfilled both from legal or regulatory and from moral and ethical standpoints.

### Circuit Configurations

Electrolytic cell circuits generally are installed either in a monopolar or bipolar arrangement. A monopolar cell line consists of some number of single cells, each having a single anode and cathode, electrically connected in series much as the individual cells in a typical electrical storage battery. The number of cells is determined by several factors, such as the total cell line voltage and design production capacity of the facility. Each cell is electrically connected to each other cell, typically with large conductors. The first and last cells of the series circuit are connected to the external dc power source in a similar manner (see Fig. 1).

In a bipolar arrangement, the series connection of individual cells is replaced by a single cell block, or electrolyzer, connected to a single external power source. Each electrolyzer consists of some number of individual cells that have anodes and cathodes exposed to electrolytes, and all intercell electrical and process connections internal to the block. Then the electrolyzer unit is connected to the external power source using large conductors (see Fig. 2). In both cases the electrically energized surfaces are uninsulated and exposed and, with very few exceptions, the cell circuit is operated ungrounded. While energized, each cell or electrolyzer has a small leakage resistance to ground because of ground insulation leakage and process attachments or fluids leakage. It is important to detect these relatively small but potentially dangerous ground paths and to correct them.

### Power Supplies

Electrical energy for the electrolytic cell process is normally supplied by large capacity ac to dc (alternating current to direct current) rectifiers. Some older installations use diode rectifiers that have transformer tap changers for control. Newer units utilize thryistor technology. Cell line voltage and current vary widely depending on the cell type and the production capacity of the facility. Voltages range from less than 25 V dc to as high as 1000 V dc, and currents from a few thousand amperes dc to more than 400,000 A dc (1). Monopolar arrangements typically have more than one rectifier per cell line connected in parallel. The number and capacity depend on design cell line current. All operate at the desired dc voltage. When two or more rectifiers are connected in parallel, as in the monopolar arrangement, a disconnecting means is required for each rectifier unit on the dc side to allow removing it from the cell line circuit (2). Bipolar arrangements have an individual electrolyzer or cell block whose power is supplied from a single rectifier that has sufficient capacity for the design current and voltage. Because these units normally have high power capacity, they are connected to the facility's primary power distribution system, usually one level of transformation from the utility supply. Combined capacitor-reactor filter equipment is normally connected to the ac supply at the primary distribution level. This is done to eliminate harmful harmonics, inherent in ac to dc rectification installations and to correct the system power factor which is worsened when power and rectifier transformer impedances come into play

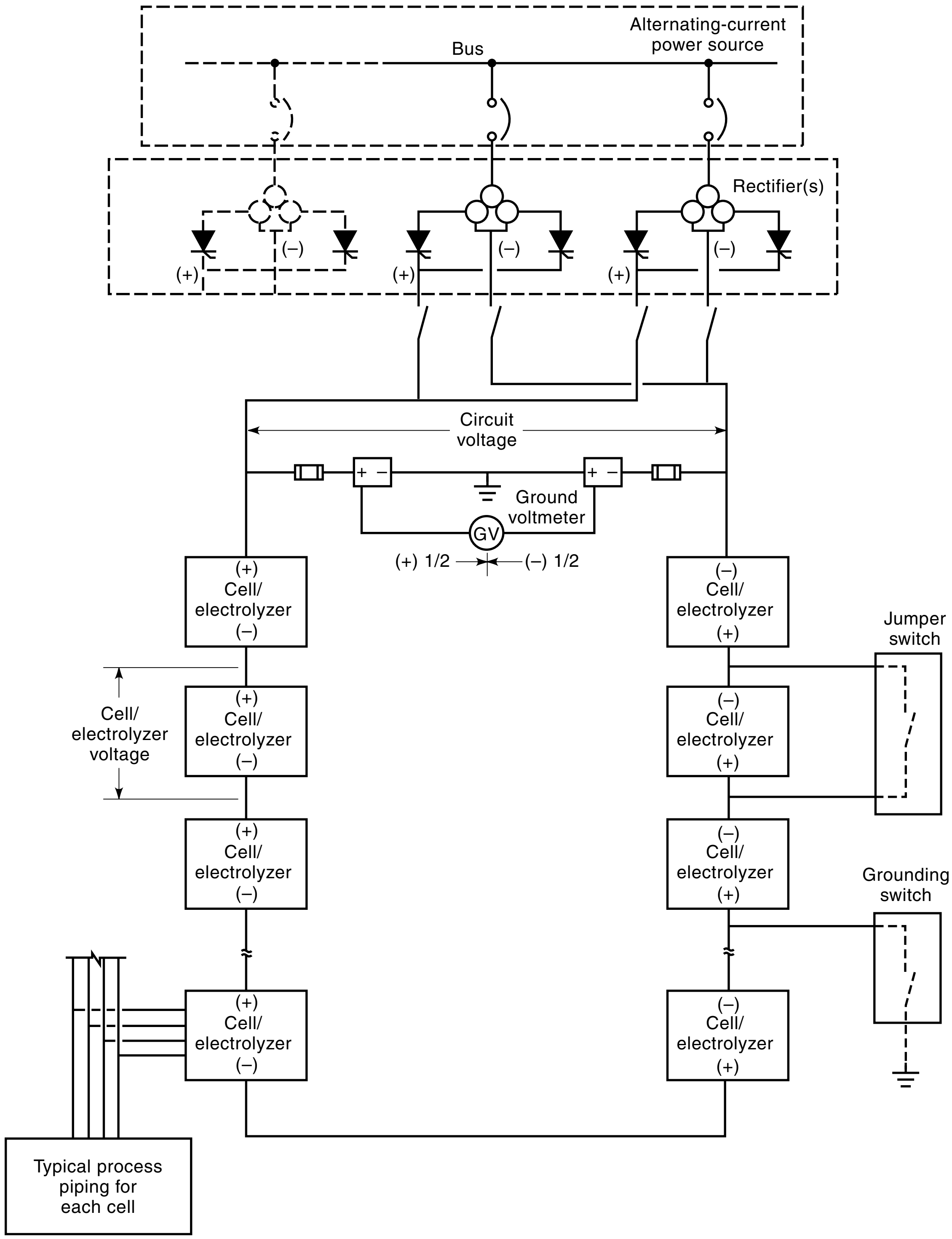


**Figure 1.** A typical monopolar cell/electrolyzer circuit configuration is illustrated. The circuit is made up of several single cells, each having a single anode and cathode connected in series. Typical jumper and grounding switch circuit connections are shown. A cell line ground detection circuit configuration, located at the dc power source, is also shown.

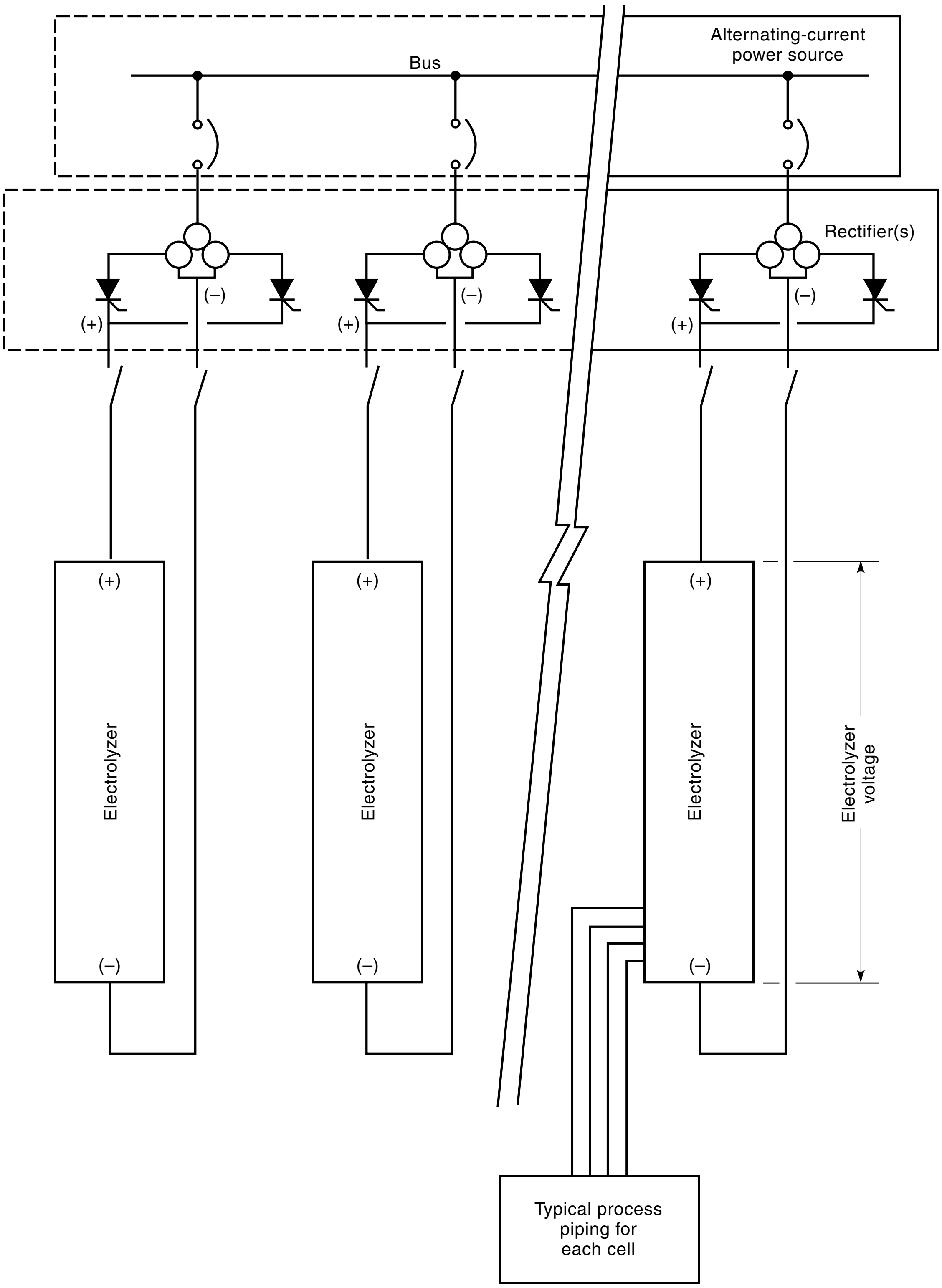


**Figure 2.** A typical bipolar electrolyzer circuit configuration is depicted. Each circuit contains a single electrolyzer or cell block connected to a single dc power source. Each electrolyzer is made of some number of individual cells, having anodes and cathodes and being in full contact with the electrolyte, with all intercell electrical and process connections internal to the electrolyzer. Note the ground detection circuits as well as jumper and grounding switches are absent, since they are not needed in a bipolar arrangement.

and as inductive motor load from auxiliary process equipment is added.

### Maintenance and Operating Activities

Individual cells in a monopolar cell line are bypassed or jumped out for maintenance or in the event of cell failure. This involves connecting a jumper switch, sometimes known as a cutout switch, in parallel with the cell being removed. The jumper switch is rated for full cell line current and has a voltage rating typically in the 10 V dc to 50 V dc range. Once the switch is connected, it is closed allowing the cell line current to flow through the switch and bypass the cell. Then intercell connections and the cell are removed for maintenance or replacement, and the cell line is totally dependent on the jumper switch to complete the circuit. Overhead cranes or hoists are normally provided for removing and replacing cells and equipment. In some processes, however, rather than bypassing a cell by shorting it, an intentional ground is applied to the cell line, only at one point where the maintenance activity is to take place (see Fig. 1). Once the cell is grounded, maintenance and operating activities are done at a ground potential condition. This does not allow opening the cell line circuit, to replace a cell, for example, because that would interrupt the total current. However, in some processes this method is quite acceptable. Intentionally grounding the cell at one point does not affect operations unless another ground already exists somewhere on the normally ungrounded circuit. Cell line ground monitoring methods are used to detect this condition (see Figs. 1, 3, 4).

Because the inter cell electrical and process connections in bipolar cell arrangements are internal to the electrolyzer unit, no cell shorting or grounded is needed or done. Maintenance or process changes in the bipolar arrangement that cannot be done when the unit is operating require deenergizing the individual rectifier and its associated electrolyzer. In both cases, however, by far the majority of adjustments, inter cell voltage tests, and other normal maintenance and operating activities are done while the circuit is energized.

## DESCRIPTION OF THE ELECTRICAL SAFETY HAZARDS

As with any installation involving electrically energized conductors, the safety hazards to personnel in contact or near such conductors are electric shock, falls or injuries due to a shock reaction, and electric arc flash burns or blast injury. Electrolytic cell installations have the same three overall categories of hazard, but because these processes are operated and maintained much differently from other installations that have electrically energized parts, specific details of these hazards and the methods of safeguarding personnel from them are much different. Electrical conductors in electrolytic cell processes are normally operated uninsulated and exposed, and grounding cell lines is not required (2). In fact cell lines are almost always operated ungrounded. Normal activities involve contact by personnel with energized surfaces and exposure to some areas with high fault current availability. Obviously this condition would not be allowed in a normal ac power distribution system, but controls and methods exist to properly protect personnel exposed.

Because of the typical resistance of human skin and the resulting effects of current flow, a voltage potential of 50 V ac or 100 V dc and higher is considered hazardous and must be protected against (3). Currents as low as 15 mA to 20 mA ac or 100 mA to 140 mA dc cause painful shocks and loss of muscular control (4). Currents as low as 200 mA ac or 1400 mA dc cause the heart to stop for the duration of exposure (4), a condition certain to cause death. Realizing that hazardous or even lethal current levels are relatively low compared to those available, the need and responsibility to safeguard personnel exposed is very apparent.

### Hazardous Voltage Sources

Voltage potentials arise from many sources in an electrolytic cell process. Many of these are not hazardous or are below 100 V dc, but many are well above 100 V dc. The voltage drop across individual cells is typically in the 3 to 4 V dc range. The voltage drop increases with the number of cells. The voltage drop across ten cells, for example, is in the 30 to 40 V dc range. The total voltage measured from the positive to the negative dc power supply connections yields the highest cell line voltage. This total voltage decreases by the individual cell voltages if measurements are made moving along the cell line away from the source voltage.

Because cell lines are normally operated ungrounded, a theoretical zero voltage point to ground exists at the cell-circuit midpoint. If all other ground sources are removed, the dc voltage measured to ground halfway around the circuit is zero (see Fig. 3). Voltage measured to ground becomes more and more positive as one moves from the midpoint to the positive main dc supply bus, and more and more negative as one moves to the negative. For example, the voltage to ground measured ten cells closer to the negative main dc supply bus than the midpoint for a cell line with cells each having a 3.5 V dc drop is −35 V dc. The worst case condition results from a cell line ground condition when a solid ground occurs at one of the dc supply main buses. In this case, the voltage to ground at that point is of course zero, and the full dc supply voltage is present at the other dc supply bus (see Fig. 4). This is the same voltage as the total dc supply voltage but now it appears at one of the dc supply main buses rather than at only half the voltage to ground as was the case before the ground was introduced. Normally sufficient distance exists between the positive and negative dc supply bus to make it difficult for personnel to bridge positive to negative. In this case, however, when full supply voltage appears at the dc supply bus, simultaneous contact by personnel with the bus and ground is readily achieved. Obviously if the cell line operates at voltages of 100 V dc and higher, hazardous conditions exist from cell to cell, cell to ground, and at the main dc supply. This hazardous condition may also extend beyond the actual cell line to all attached equipment, such as pumps, piping and/or jumper switches while attached, and to cranes or hoists while attached to the cell circuit. Any electrical conductor that is uninsulated and is energized by its connection to the cell circuit is a potential source of hazardous voltage.

### Battery Effect

The existence of hazardous voltages is further complicated by the fact that electrolytic cell lines exhibit characteristics similar to an electrical storage battery. Once the electrolyte is introduced into the cell and the external power supply has energized the circuit, a hazardous voltage exists on the cell line

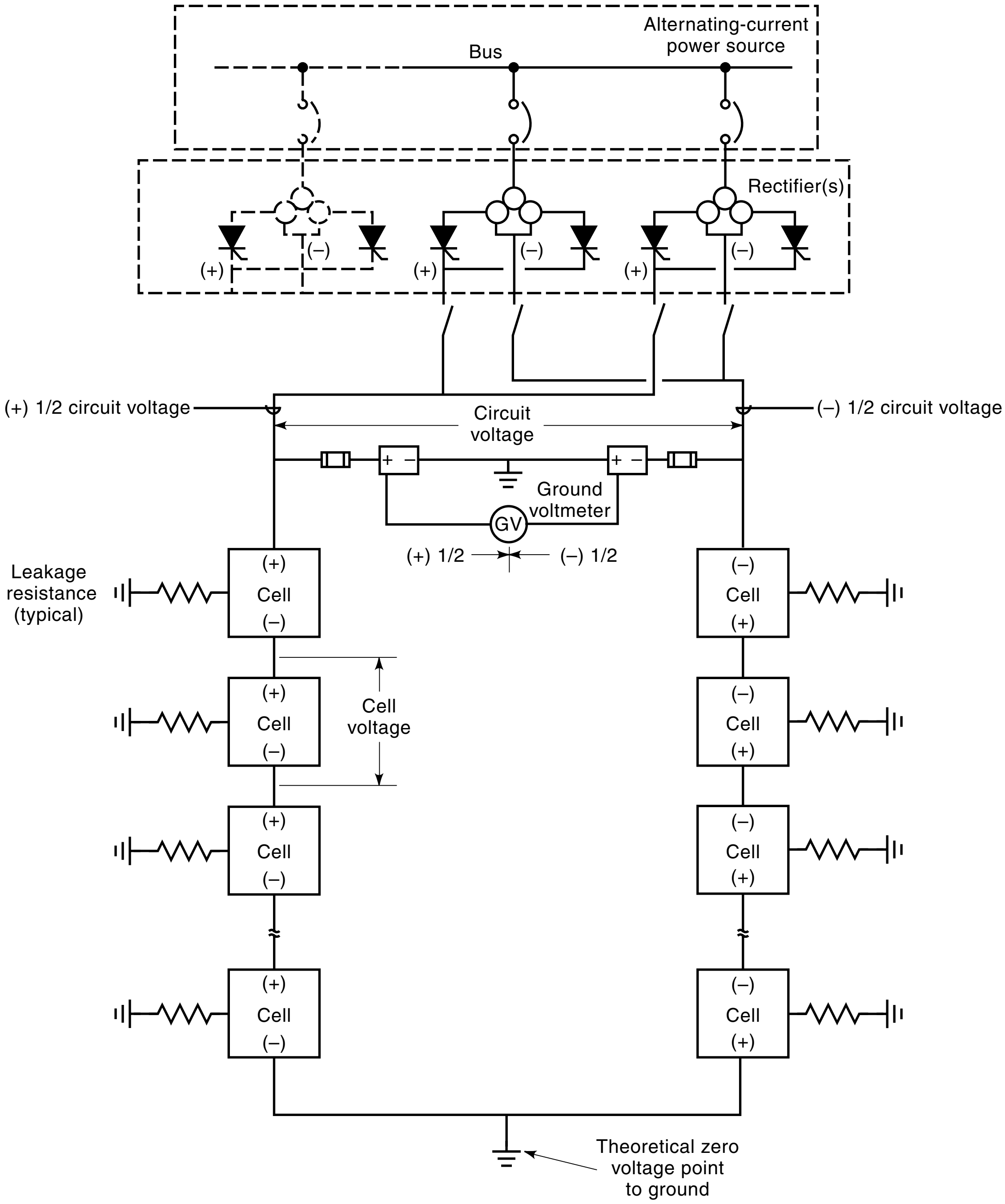


**Figure 3.** This figure shows the theoretical zero voltage point to ground, the cell line ground detection circuit arrangement, and typical cell leakage resistance to ground for a monopolar cell circuit. These concepts and the circuit arrangements do not apply to bipolar cell circuits.

and on individual cells, even after the dc power supply has been removed. The time required to produce this "battery effect" (4) and the time required for this condition to dissipate depends on the physical and chemical characteristics of the cells. Because of the normally large surface area of cell anodes and cathodes, the cell current available under the "battery effect" is also quite substantial. Thus it is common in electrolytic cell processes for hazardous voltages to exist and for personnel to come in contact with energized parts, even after normal and traditional deenergization and lock-out procedures are completed. But, when one considers that the hazards under this condition are the same as those under normal operating conditions, it is clear that the same safeguards must also be used.

### Auxiliary Ac Power

Along with hazardous dc voltages, sources of ac power are also normal in the area of the electrolytic cell circuit. Power for lighting, auxiliary power for cell line attachment equip-

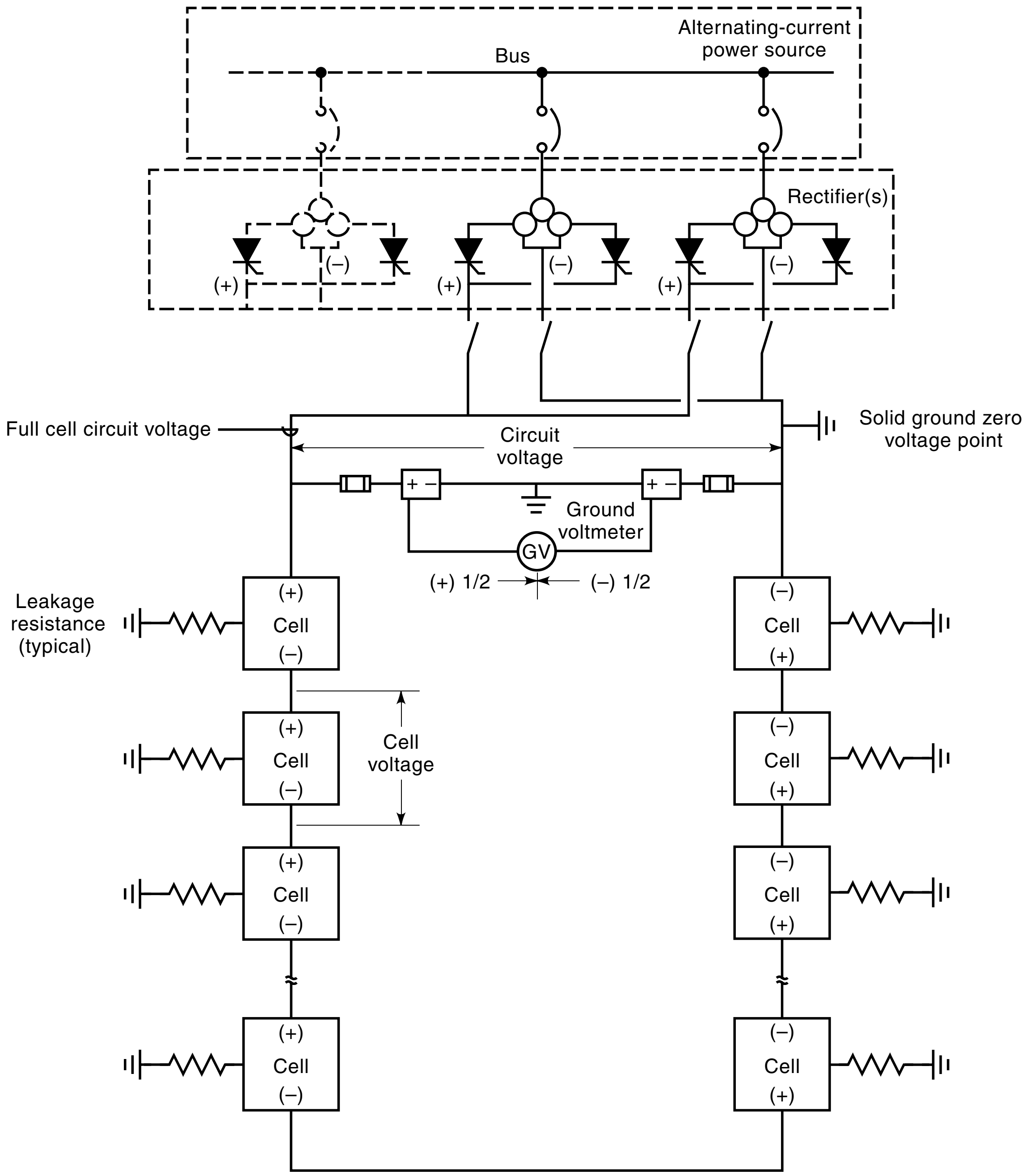


**Figure 4.** This figure illustrates the worst case voltage hazard condition for a solidly grounded cell circuit at one conductor of the dc source. Voltage to ground at the grounded point would, of course, be zero, and full cell line voltage would appear at the other, all with the cell line operating.

ment, such as pumps, and power for receptacles, control, and monitoring devices are also present. These operate normally above the 50 V ac limit considered hazardous and are also an additional source of contact with grounded surfaces while in contact with the dc circuit. Equipment, such as electrically operated tools, cord sets, and welding machines are also commonly present. A hazardous condition can exist if either the ac power energizes a part of the cell circuit or an attachment or if wiring for the auxiliary equipment contacts the cell circuit and conducts dc power to other locations not intended for that purpose.

## Arc Flash

Until recently the primary hazard considered in using electricity was electric shock and its effects on the human body. Most protective measures centered on insulating, guarding, or otherwise protecting personnel from contact with energized surfaces. The same was true in electrolytic cell processes, and in some cases today this may still be the primary hazard considered. Injuries relating to arc flash exposure were reported as burns and in almost all cases were not classified as related to electrical incidents. Over the last fifteen to twenty years a significant amount of testing and research has been done relating to "The other electrical hazard: electric arc blast burns (5)." As test methods improve and more data are gathered, the arc flash hazard at various levels of an electrical system is better understood and predicted (6). Only a relatively small amount of testing and data exist for electrolytic cell dc applications. The arc flash capability for dc circuits is quite different from ac, yet it cannot be ignored. The available fault current at many points along the cell circuit and certainly at the dc supply bus is high enough in most cases to generate enough heat and molten debris to cause injury. Arc flash injuries are just as potentially serious or fatal as shock injuries, and no actual contact with energized parts is required. Arc flash injuries occur many feet away from the source of the arc depending on the available fault and the duration of exposure. Safe approach distances have been determined for various faults in ac circuits and for various exposure times. These distances are calculated (5–7) for a specific application as follows:

$$D = (2.65 \times \mathrm{MVA}_{\mathrm{bf}} \times t)^{1/2}$$

or

$$D = (53 \times \mathrm{MVA} \times t)^{1/2}$$

where $D$ is the distance of the person from the arc for curable burn (feet), $\mathrm{MVA}_{\mathrm{bf}}$ is the bolted fault MVA at the point of the arc, MVA is the transformer MVA rating, and $t$ is duration of the arc in seconds.

The cell circuit resistances limit available fault currents, and the arc voltage diminishes relatively quickly in dc electrolytic cell circuits under fault conditions. Therefore most areas of the cell circuit are not likely to pose an arc flash problem, but it is likely that there are others that do. Contributions from stored energy in the cells caused by the large anode and cathode surface areas and from the rectifiers that supply several times full load current under fault conditions significantly increase both available fault and exposure times. Both of these factors increase arc flash injury risk.

### Magnetic Fields

Electrical hazards also exist as a result of the large dc magnetic fields typically present in electrolytic cell processes. The higher the cell line current, obviously the higher the resulting magnetic field. The American Conference of Government Industrial Hygienists (ACGIH) recommends that personnel exposure to magnetic fields not exceed 600 gauss whole body on a daily, time-weighted average basis. The ACGIH further recommends that personnel with implanted cardiac pacemakers should not be exposed to more than 10 gauss. The ACGIH further advises that persons with implanted ferromagnetic medical devices could be adversely affected at higher flux densities (4). Data indicate that levels in some electrolytic cell facilities are in the 200 gauss range (4). Any ferromagnetic materials, tools, or equipment also create hazardous conditions should they be drawn to the cell line and bridge from cell to cell, from cell to ground, or come in contact with cell line attachments or auxiliary ac power.

Portable or fixed analytical or test equipment is also affected by large magnetic fields if not suitable for the use. This equipment can be affected and gives false indications while in the fields although it appears to be functioning correctly. Once the magnetic field is removed, the unit appears to return to normal operation and gives the operator the appearance of a correct reading, when in fact it is not.

### Nonelectrical Hazards

There are also nonelectrical hazards which have to be considered that generally make the task of protecting personnel more difficult. Cells and most of their attached equipment operate at high temperatures. Reflex reactions by personnel who contact hot surfaces can cause inadvertent contact with energized conductors. Normally hazardous chemicals are present which affect personnel on contact. Most of these chemicals are obviously electrically conductive and thus can compromise the insulating properties of personal protective equipment.

### Electrical Classification

Normally electrolytic cell lines are classified electrically as nonhazardous, indicating that there is insufficient accumulation of flammable or combustible gases to create a hazardous environment from a fire or explosion. Although flammable and combustible gasses are typically produced as part of the chemical reaction, normally sufficient ventilation is provided to remove them safely. However, the electrical classification should be determined for each installation (8–10).

## SAFEGUARDING PERSONNEL

It is clear that unique electrical hazards exist in electrolytic cell processes. It follows, therefore, that to properly safeguard personnel who may be exposed to these hazards, protective measures must go beyond traditional methods to include those specific to electrolytic cell processes. Employers are legally required to provide adequate protection for personnel exposed to hazards in the workplace (3). Formal safety programs are in place for this purpose, and research and development continue as technology and data on the subject progress. The overall task of safeguarding personnel is made up of many parts, all needed to provide proper protection.

### Job Safety Analysis

Providing adequate protection involves many general issues and must include protection from hazards specific to the industry, the process, the location, and even the individual job task. Performing a Job Safety Analysis (JSA) is critical for successfully identifying and protecting against any hazard that may be present. A JSA is a formal review and analysis of each job task that can or will expose personnel to hazards. A group of knowledgeable individuals with varying experience and abilities generally gathers information needed to determine the exact hazards that exist for a specific job. This analysis includes hazards relating to shock, reaction injury due to shock, and arc flash. The result is a detailed listing of job tasks, identification of the hazards associated with each, and the adequate protective measures to be employed. The JSA is central to protecting personnel exposed to hazards. Because of the unique hazards involved with electrolytic cell processes, proper protection cannot be provided without it.

### Cell Line Working Zone

The JSA for electrolytic cell processes should include the establishment of a Cell Line Working Zone (CLWZ). The CLWZ is a defined physical area containing electrical hazards associated with electrolytic cell activities in which adequate safeguarding must be provided. The area is defined as a space envelope where operation and maintenance is normally performed on or in the vicinity of exposed energized surfaces or their attachments. The space envelope encompasses any space within 96 in. above or below and within 42 in. horizontally in both directions from all energized surfaces. The CLWZ is not made to extend through or beyond walls, floors, roofs, barriers, or the like (1). For simplicity or because of specific physical characteristics, there is no restriction on moving the CLWZ to a larger space to administer it more readily. Establishing a CLWZ aids in understanding protective requirements for personnel and eliminates the need to establish safe boundaries each time a task is performed.

### Flash Hazard Analysis

The arc flash hazard analysis requires a separate effort and normally requires engineering supervision. Several methods exist to determine flash hazard boundaries based on testing and research on the subject to date (5–7). Although most, if not all testing and research to date relates to ac circuits, these methods are also applied in electrolytic cell processes and, if anything, are considered conservative. The calculations yield an approach distance outside of which personnel would not be adversely exposed to the hazards of arc flash. Personnel at the approach distance or closer to the source of an arc must be provided with and must wear proper protective equipment suitable for the severity of the hazard present.

Guidance is also available for selecting and using arc flash protective clothing in various exposures (11). It should also be recognized that, depending on the available fault at the point in the cell circuit involved, the arc flash protective boundary may extend beyond the limits of the previously established CLWZ, thus requiring expansion of the CLWZ space envelope to the flash boundary.

### Qualified Personnel

Persons whose normal activities involve exposure to electrical hazards must be "qualified" to safely perform such duties. Qualified in this context does not mean that the individual is an accomplished craftsman normally capable of good job performance. A qualified person in this arena is one who is trained and knowledgeable in the operation and safety hazards involved with the equipment and the job task and in the proper methods to avoid such hazards. Further, a qualified person is also knowledgeable in using applicable precautionary techniques and personal protective equipment. It is possible and in fact likely that a person would be considered qualified to perform certain job tasks and unqualified to perform others. It is required by law that only qualified persons are allowed to work on or near exposed energized electrical conductors or circuit parts (3). It follows that an unqualified person is one who possesses little or no such knowledge and, therefore, must not be allowed to perform tasks of this type.

### Safe Approach Distance Concept

When analyzing specific jobs for various electrical hazards, it is helpful to utilize a concept for identifying and protecting against hazards as personnel move from a safe distance closer to an exposed energized conductor. Safe approach distance concepts have been developed by various groups (6,7) and individuals (5). They differ in content and detail, but all have the same basic elements. A relatively straightforward safe approach concept, offered here for illustration, consists of three boundaries (see Fig. 5). The first boundary reached, and the farthest from the conductor, is the closest distance at which unqualified persons are allowed to be. These persons have no knowledge of the hazards and are likely to make the job task more difficult and hazardous for themselves and others performing the work if they are allowed closer. As one moves closer to the conductor, the next boundary reached is the closest distance a qualified person is allowed without proper arc flash protection. If a flash hazard is present, that distance is normally farther away than the minimum distance for a qualified person without proper shock protection. This is the last boundary before actual contact with the conductor is made. Safe approach distances for shock and arc flash vary widely depending on the available fault and even the operating conditions at the time. For this reason, no listing of actual distances is offered here. With proper engineering supervision, the references noted have quite adequate information for this determination.

### Training

As discussed earlier, only qualified persons are allowed to work on or near exposed energized electrical conductors or circuit parts (3). Personnel are not considered qualified until they are properly trained. Qualified persons must be trained in the specific safety hazards relating to their job task and in how to protect against them. At a minimum, qualified persons must be trained in (1) the skills necessary to distinguish exposed energized parts from other parts of electrical equipment, (2) the skills and techniques necessary to determine

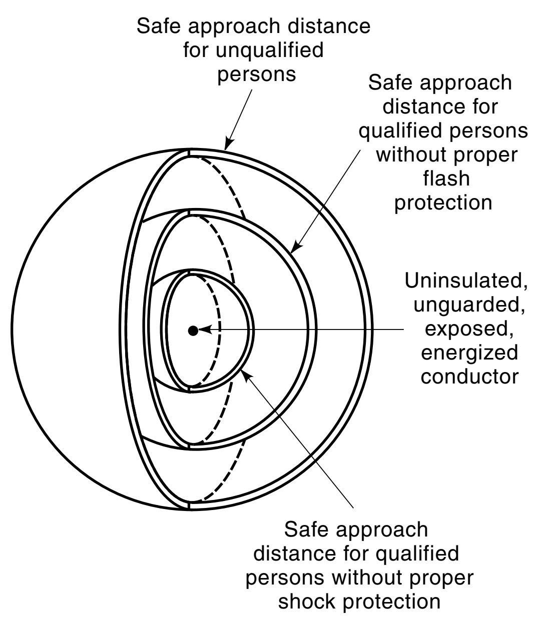


**Figure 5.** The safe approach distance concept is depicted as one where different hazards exist, and different methods are needed to protect personnel as one moves from a distant location toward an uninsulated, unguarded, exposed, energized conductor.

the nominal voltage of exposed energized parts, (3) the safe approach distances for the specific job task, and (4) the ability to determine the degree and extent of the hazard and the personal protective equipment needed (3,7). Further, qualified persons must be trained in the skills and techniques to avoid simultaneous contact with hazardous voltages between energized surfaces of the cell line and energized surfaces and ground and in the method of determining the cell line working zone boundaries (1). An appropriate number of persons must also be trained in emergency rescue and first aid procedures and the knowledgeable application of cardiopulmonary resuscitation (CPR) (3). This training should include methods for safely removing a victim from an energized circuit. The employer must certify the qualifications of the trainer(s), provide a method of confirming understanding of the training, and the training must be documented (3). The only requirement for unqualified persons is they are trained in recognizing electrical hazards and the proper methods of avoiding them.

### Personal Protective Equipment

Facilities operating in industrial environments normally have well-established requirements for minimum personal protective equipment that usually include items, such as nonconductive hard hats, steel-toed shoes, safety glasses, and escape respirators and/or full-face breathing devices. This minimum may vary depending on the facility and on the general hazards found throughout the facility. In electrolytic cell facilities, additional protective equipment is needed to safeguard personnel properly from the unique electrical hazards present. This equipment must be properly specified as appropriate for the application. Nonconductive footwear, suitable for the voltages present, should be worn by anyone entering the CLWZ. Personnel who perform job tasks in the CLWZ must wear nonconductive gloves suitable for the voltages present. Footwear and gloves must be tested prior to each use and at some appropriate regular interval if not in use, to verify integrity. Footwear or gloves found defective must be removed from service and destroyed. Other insulating materials, such as insulating blankets, mats, or sleeves that may be used depending on the facility needs, must also be tested prior to each use and periodically if not in use. While in use, care must also be taken not to compromise the insulating properties through contamination by contact with conductive process chemicals or other materials. Standards for specifying, testing, care, and use of nonconductive footwear, gloves, blankets, mats, and sleeves exist and should be referred to for this purpose (12).

Flash protective clothing appropriate for the hazard present must be worn if a flash hazard exists. One method of flash protection consists of a full switchman's hood with a polycarbonate face shield, cloak, and pants all manufactured from a nonflammable textile material. Information on specifying and on the performance of this equipment is limited in content but does exist (13) and should be used in combination with an analysis of the specific job to determine the appropriate protection. As with the flash hazard analysis, the specification and application of flash protective clothing should be done with engineering supervision.

### Maintenance and Operating Activities

Maintenance and operating activities conducted as a normal part of the electrolytic cell facility face significantly different hazardous conditions than in other installations that have normal power distribution and control equipment. Each job must be analyzed for its hazards, and appropriate safeguards must be put in place to protect personnel from those hazards.

**Jumper Switch.** Routine maintenance activity in electrolytic cell facilities involving intentionally shorting or bypassing a cell for repair or replacement should include a safe work procedure or task sequence to identify and avoid the hazards that this operation presents. While connected, the switch is an energized extension of the cell circuit and presents the same hazardous voltage concerns. Safety devices should be employed to prevent operating the switch while the cell is removed from the circuit. Although rated for full cell line current, if operated, this would create full dc supply voltage across the contacts of the switch, almost certain to cause a switch failure. Appropriate alarms, interlocks, and protective measures should also be employed consistent with proper jumper switch operation.

Similar concerns hold true for the cell grounding switch where used. Although its operation does not have the same hazards as the jumper switch, the hazards are equally important, and similar, safe, work procedures should be developed and followed.

**Cranes and Hoists.** Overhead cranes and hoists are typically used to aid in cell repair and replacement. While connected to an energized cell, the hook and cable block assembly may be electrically energized. Since the crane or hoist itself is normally attached to the grounded building structure, proper isolation must be provided to insulate the cell circuit voltage from ground. This is normally accomplished by using an insulated cable block assembly. This assembly then becomes a primary means for isolation and must be periodically tested to verify its integrity. Should the insulation be compromised, the cables would become energized and a failure is likely to occur. Support cables for operating pendant control enclosures should be nonconductive or electrically insulated from ground. The integrity of this insulation must also be verified periodically.

**Portable Electrically Operated Tools and Equipment.** Portable electrically operated tools and equipment used in the CLWZ must not be grounded. Further, power supply circuits and receptacles for portable electrically operated equipment used in the CLWZ must not be grounded. Receptacles and their mating plugs must not have provisions for a grounding conductor and must be configured to prevent their use for equipment required to be grounded (2). Portable electrically operated tools and equipment are required to be ungrounded to prevent accidental cell line grounding paths and to prevent personnel from being part of a circuit path from the cell line voltage to ground. This requirement is also intended to prevent two grounded portable devices from bridging across the cell circuit positive to negative through their ground conductors. No other power supply or receptacle circuits are allowed in the CLWZ from any outside source while the circuit is energized.

**Portable Nonelectrically Operated Tools and Equipment.** Portable, nonelectrically operated tools and equipment pose similar concerns. Air or hydraulically operated tools and equipment should have nonconductive supply hoses. Ferromagnetic materials should be avoided because of the difficulty of handling these items in large magnetic fields. Hand tools should be limited in length (4) to prevent bridging from cell to cell or cell to ground.

**Mobile Equipment.** Mobile equipment, such as welding machines, wagons, carts, vehicles, and bicycles should be prohibited from the CLWZ while the cell line is operating, unless given specific permission by the appropriate operations and electrical personnel.

**Fixed Equipment.** Fixed or permanently mounted electrically operated equipment located in the CLWZ must be supplied with an ungrounded supply and conductive surfaces must not be grounded. Examples are motor frames, light fixtures, and monitoring equipment enclosures.

**Ladders and Scaffolding.** Portable ladders used in the CLWZ must meet established specifications for being nonconductive (14). With proper engineering supervision, wooden ladders and scaffolding are permitted in the CLWZ. Then controls must be in place to verify that the unit is appropriate for the hazards involved and to prevent contamination during use.

**Materials.** Conductive materials that are part of maintenance or improvement activities and are of sufficient length to bridge from cell to cell, or cell to ground are not permitted in the CLWZ while the circuit is energized.

**Conductive Apparel.** Clothing and other apparel worn in the CLWZ must not bypass any protective measures used to protect personnel. Clothing contaminated with conductive fluids or solids can cause hazardous conditions by bypassing nonconductive gloves or footwear. Jewelry and other conductive apparel may bypass protection and become the source of arc faults. Jewelry and other conductive apparel are prohibited from being worn in the CLWZ. The single exception is a wedding ring, which must be properly insulated (3). Safety glasses worn in the CLWZ must also be nonconductive or plastic encapsulated.

**Isolation and Insulation.** Where possible and practical, personnel can be effectively safeguarded by isolating and insulating energized surfaces. When properly insulated or isolated to prevent contact, the voltage hazard no longer exists. Although impossible in most areas in the cell circuit, many areas can be properly protected thereby significantly reducing exposure of personnel. Process piping, structural members, and supports can be effectively insulated to prevent a conductive path if contacted by an energized part. However, if insulating or isolation methods are used, the integrity of these systems must be verified regularly and any deficiencies corrected when detected.

**Nonqualified Personnel and Visitors.** Nonqualified personnel and occasional visitors must be personally escorted by a qualified person while in the CLWZ. Such personnel and visitors must be provided with and trained in the use of proper protective equipment for the hazards to which they are exposed.

**Warning Signs.** The boundaries of the CLWZ must be clearly marked, and entrances to the CLWZ must be posted with warning signs prohibiting unqualified persons from entering. Warning signs for pacemaker wearers and for those with ferromagnetic medical devices, clearly identifying the hazards involved, must also be posed at entrances to the CLWZ.

### Administrative Controls

One of the most effective means of safeguarding personnel exposed to electrical hazards in electrolytic cell facilities is to establish an effective set of administrative controls. Safety by design can eliminate the need for protective measures by eliminating the hazard before the facility is constructed and operated. Many of the work methods used in normal daily activities can be made nonhazardous by removing exposure of personnel or by greatly minimizing it. Where possible, work can be scheduled when the circuit is deenergized and the battery effect is dissipated. Periodic inspections of insulating devices, isolation means, protective equipment, and other requirements must be properly administered and documented. The establishment and strict enforcement of established safety rules and policies and regulatory requirements are essential to safe operation. Proper administrative control provides the means for meeting these requirements.

## SUMMARY AND CONCLUSION

Electrical hazards in electrolytic cell facilities are unlike those in any other industry. Maintenance and operating methods in electrolytic cell facilities are unlike those in any other industry. Activities that would be strictly prohibited elsewhere are common practice and a part of normal daily operation. Because of the unique nature of maintenance and operating methods, exposure levels and the time of exposure to these hazards are greatly increased. The proper administration and management of the measures put in place to protect personnel against the electrical hazards associated with electrolytic cell facilities are very effective in safely operating facilities of this type.

## AREAS FOR FUTURE STUDY

### Dc Arc Flash Hazard Data

An analysis of electric arc flash hazards is an essential part of determining all hazards present and how to protect against them. Research and testing to date has been primarily in the area of ac distribution equipment. Although comparisons can be drawn and factors can be applied to reflect this information into dc circuits, actual testing and research on high current dc circuits is absent. The electrical safety community is applying the ac information for this purpose and if anything, the results are conservative. If error is present, it certainly is correct to utilize results more conservative than not, but because this is a relatively little known area, more testing data should be acquired to better define the actual hazard. On one hand, the question arises as to whether or not adequate protection is being provided. On the other, whether the calculations are conservative enough that possibly no flash hazard exists in most cases. Without the data the question remains.

### Health Effects of Large Magnetic Fields

Information from the medical community is limited relating to the short and long term health affects of exposure to high magnetic fields and their affect on medical devices in the human body. Obviously because this issue is serious, pacemaker wearers and those individuals with ferromagnetic medical devices are prohibited from the CLWZ as a conservative measure. The exact allowable exposure limits for various implanted devices and for health in general is an area where additional investigation is needed.

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## ELECTROMAGNETIC ABSORBER.

See ELECTROMAGNETIC FERRITE TILE ABSORBER.