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Lightning Protection System for HE Facilities at LLNL - Certification Template

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Disclaimer

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Certification Template

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Preface

This document is meant as a template to assist in the development of your own lighting certification process. Aside from this introduction and the mock representative name of the building (Building A), this document is nearly identical to a lightning certification report issued by the Engineering Directorate at Lawrence Livermore National Laboratory. At the date of this release, we have certified over 70 HE processing and storage cells at our Site 300 facilities.

In Chapters 1 and 2 respectively, we address the need and methods of lightning certification for HE processing and storage facilities at LLNL. We present the *preferred* method of lightning protection in Chapter 3, as well as the likely building modifications that are needed to comply with this method. In Chapter 4, we present the threat assessment and resulting safe work areas within a cell. After certification, there may be changes to operations during a lightning alert, and this is discussed in Chapter 5. Chapter 6 lists the maintenance requirements for the continuation of lighting certification status. Appendices of this document are meant as an aid in developing your own certification process, and they include a bonding list, an inventory of measurement equipment, surge suppressors in use at LLNL, an Integrated Work and Safety form (IWS), and a template certification sign-off sheet.

The lightning certification process involves more that what is spelled out in this document. The first steps involve considerable planning, the securing of funds, and management and explosives safety *buy-in*. Permits must be obtained, measurement equipment must be assembled and tested, and engineers and technicians must be trained in their use. Cursory building inspections are also recommended, and surge suppression for power systems must be addressed. Upon completion of a certification report and its sign-off by management, additional work is required. Training will be needed in order to educate workers and facility managers of the requirements of lightning certification. Operating procedures will need to be generated and/or modified with additional controls. Engineering controls may also be implemented requiring the modification of cells. Careful planning should bring most of these issues to light, making it clear where this document is helpful and were additional assistance may be necessary.

1 Introduction

Lightning and high explosives (HE) don't mix. Many explosives will detonate if too much electrical current passes through them. For example, in modern detonators the safety limit for current must be less than 1 A to prevent an initiation of the explosive chain. A typical lightning strike has a peak current of 30 kA. Obviously, a very small fraction of this current is enough to fire a detonator. Extreme lightning that occurs only 1% of the time has a peak current of 200 kA. This is two hundred thousand times above the safety limit. Therefore, it is critical that explosive components be separated from the lightning current.

Currently due to this mixed hazard, HE processing and handling at Site 300 must be halted and personnel evacuated during a lightning alert. The shutdown delays work and affects others on the Site because of road closures next to HE process and storage facilities. The project described herein has been funded to improve the lightning protection system and allow work to safely proceed during lightning alerts and storms. This report describes the design approach, implementation of the safety system, operational modifications, and maintenance requirements that will allow HE processing to continue during a lightning alert. When the improvements meet the requirements of NEC 780 [1], and DOE M 440.1-1 [1] Chapter X, Section 5: Lightning Threat Detection, Section 6: Lightning Threat Actions, Section 7: Shutdown of Operations, and Section 8: Lightning Warning and Protection Plan, management will certify the faraday cage portion of the facility as safe during lightning alerts.

2 Methods of Lightning Protection

Based on conversations with the electricians at Site 300, lightning strikes to electrical power distribution equipment are rare, but they do happen. Support poles and switch/safety components have been damaged. Strikes to facilities have not been verified, however it is reasonable to believe that HE handling and storage facilities may be struck by lightning. Therefore, we must assure a high level of safety before asking personnel to work with HE during a lightning alert.

Three types of lightning protection have been identified to divert lightning currents away from explosives.

- Lightning rods on the roof connected to a grounding system via down-conductors.
- A Catenary system over the facility that will intercept lightning and carry the current away from the facility and into the earth.
- A *Faraday cage* can be built around the explosives using the metal components of the facility itself along with bonded metal penetrations. This method requires an appropriate *standoff* air space between the HE and lightning current that flows through the facility roof and walls.

An evaluation of the old lightning systems showed that the lightning protection safety needed upgrading. Many of our Site 300 facilities have lightning rods, down-conductors, and a ground grid. However, lightning rods are more appropriate for wooden structures, to prevent the lightning bolt from starting a fire. In facilities with rebar and metal frames, it has been shown that most of the current will flow through the lower impedance of the metal structure of the building rather than on the down-conductors. Additionally, metal pipes routinely penetrate the walls and ceilings of the facility, and may carry some portion of the lightning current. If these pipes are not *bonded* to the Faraday cage, high-voltages of an unknown magnitude could appear within the facility. Hence, the rod and down-conductor type of lightning protection system has serious limitations, but does provide some protection to the facility structure. We recommend leaving the lightning rods in place, even if a Faraday cage is installed. The lightning rod system does not create a problem but maintenance is NOT necessary.

Catenary systems may be as simple as a wire over a building, or may be as complex as a metal *net* over a group of facilities. The wires intercept the lightning, and down-conductors convey the current away from the facility to ground. The catenary system prevents lightning currents from reaching the facility, and hence the explosives. This type of system is effective, but requires a fair amount of construction effort and space, with tall poles, a wire net, down-conductors, and a good ground system. Also, the problem of the metallic penetrations still exists. We do not have catenary systems at Site 300.

The approach that we have selected to upgrade the lightning protection system is based on a Faraday cage. Lets assume a perfect cage were to be constructed of metal, without resistance or inductance, and without openings. If struck by lightning, the electrical potential would be the same everywhere inside the cage; therefore, even if HE touches the cage, no current will flow through it.

A real Faraday cage develops different voltages inside when struck by lightning. This is because the metal components of the cage have a small amount of resistance and inductance, and there are openings. The better cages have multiple layers of rebar that are tied together, minimizing the size of the openings. The maximum voltage inside a good cage occurs near the ceilings, walls, and wall openings, and will likely be less than 10 kV. This known residue voltage must be isolated from the explosives by an air gap, e.g., explosives are not allowed within a standoff distance of the walls, or other high potential areas. The separation distance between the explosives and the walls is determined by the quality of the Faraday cage. Good cages require smaller safety standoff distances.

Another concern is spalling of concrete that could hit explosive components. A large electrical arc could form within concrete if sections of rebar are not electrically connected. Examples include joints between the floor and wall, or wall and ceiling. An arc with sufficient energy might cause pieces of concrete to be violently expelled, which is called spalling. Good Faraday cages do not have these large electrical discontinuities.

3 Faraday Cages, Penetrations, and Bonding

A *perfect* Faraday cage is a completely enclosed box constructed of metal that has zero resistance and zero inductance. If the box were to be struck by lightning, the interior voltage will be zero. Of course, this does not exist in the real world. However some facilities, especially rebar reinforced concrete buildings, can become good Faraday cages with some modifications. The better the modifications, the lower the interior voltage will become.

This section will describe modifications that will lower and control interior voltages. Some facilities need major improvements, thus the modifications were determined not to be cost effective. These buildings were left unchanged and will not be certified as safe against lightning.

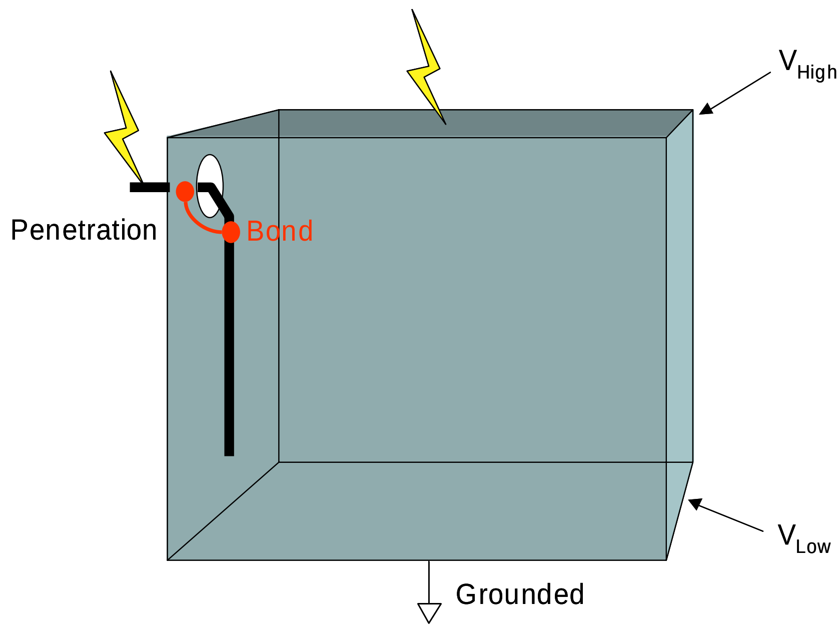


Fig. 3-1 Faraday Cage

3.1 Bonding of Metallic Penetrations

By measuring the transfer impedance of the Faraday cage, we can calculate the interior voltage caused by a lightning strike. We can control our processes to deal with this level of threat. However, metal penetrations such as pipes, conduits, and air vents to name a few, that pass through a wall, floor, or ceiling could increase the interior voltage of the cage at locations that are sometimes difficult to determine. These metal penetrations often originate from outside the facility, and if lightning were to strike them or near them, they will carry current into the facility (see Fig. 3-1).

This sneak path into the facility can be eliminated by *bonding* the metal pipes to the Faraday cage with a short wire or *pig tail* of a sufficient size. The first step in bonding is to identify all metal penetrations, such as metallic electrical conduits, water lines, air ducts, vacuum lines, and gas pipes. Often the Faraday cage includes rebar in a concrete structure, and therefore the penetration may be bonded to the rebar. To accomplish this, a rebar detector is used and a hole is drilled in the concrete over the rebar. A bolt anchor is driven into the hole and a stud is screwed into the anchor until it contacts the rebar. The quality of this bond is checked by measuring the resistance between the stud and an electrically exposed part of the Faraday cage, i.e., grounding wire or a door frame. The resistance must be less than 1 ohm. Over time there is a small risk that the anchors or studs could back out of the hole, and this can be detected by repeating the resistance measurement. The air space between the stud and rebar is very small, and the gap will electrically close with relatively low voltages. Therefore, the voltage on the penetration will still be controlled.

A wire that is at least 6 gauge or larger and no more that 12 inches long, connects the stud to a penetration via a metallic clamp or bolt depending on the nature of the penetration. Any paint on the penetration is scraped off before applying the clamp. The longer the wire, the higher will be the penetration voltage; therefore, the wire should be kept as short as possible. Bonds can be made on the inside or outside of the building, however, inside bonding is preferred because the connections are better protected from the elements.

Determination of the bond locations is normally done by electricians. A list is generated that shows the function of the metallic penetration, the location of the bonds in the room, and the bond resistance (See Appendix A - List of Bond Points and Resistance). The engineer that performs the transfer impedance measurements will verify the accuracy of this list.

3.2 Other Penetrations

Beside metal pipes, a Faraday cage can be penetrated by less obvious items. Examples include telephone lines, alarm lines, and power lines. Electrical power lines are covered separately in a later section.

Telephone lines normally originate from outside the facility where they are susceptible to lightning strikes. They are a concern because operators could move the telephone receiver away from the wall, outside the standoff distance and close to the HE. Thus, lightning current may be brought close to the HE. Because these wires are not normally enclosed in metal conduit or enclosures that can be bonded to the Faraday cage, it is difficult to properly add surge suppressors.

A compromise is to mount the telephone to a wall and use a short cord to the handset. An increased standoff distance can then be implemented to prevent the operator and phone receiver from getting too close to HE processing. If the telephone line is struck by lightning, the voltage spike is kept away from the HE. Telephone wires are small and delicate; therefore they cannot carry large currents or high-voltages without damage. The damage will likely occur outside of the Faraday cage, and limit the voltage exposure. Also, because phone lines are run through small openings and along the walls of the cell, any arcing is likely to occur directly to the cell wall, thus dropping the voltage that would otherwise be present at the receiver. Surge suppression and bonding of telephone lines is therefore not required. There is also a risk to personnel when using wired telephones during a lightning storm; however this risk is commensurate with risk to the general public.

Some facilities have security alarms with wiring that may originate from outside of the facility. However, they are normally enclosed in conduit and mounted solidly over doorframes. This type of cabling is not a concern because the conduit is bonded, the wiring is enclosed, and current cannot come near the HE.

Other types of wiring that penetrate the Faraday cage must be evaluated. One other example is the closed circuit cameras. Even if the cable stays within a Faraday cage, there may still be a problem. The camera equipment is grounded, usually through the power cord, and therefore must be considered to be an extension of the wall they are plugged into, and incur the same standoff requirements.

3.3 Wall, Floor, and Ceiling Joints

The walls, floor, and ceiling of the Faraday cage must be electrically well connected for two reasons. First, electrical arcing in these joints could cause spalling of concrete pieces, which could be prevented by good electrical connections in the joints. Second, the voltage at poorly connected joints will be high.

For the Faraday cage to function properly, the walls, floor and ceiling must be electrically connected or bonded at regular intervals. The interior voltage is inversely proportional to the bond spacing. A conservative spacing is 3 feet. This can be achieved easily if the rebar at the joints are tied together during construction. Many modern HE facilities are constructed in this manner. The spacing of the connections between these large structures can be greater, but this will result in a greater standoff distance between the wall and HE.

The electrical properties of the joints can be determined by examining the construction of the building or reviewing the facility drawings. This is feasible for new developments. Older buildings where historical information is difficult to find and verify will require analysis of facility transfer impedance as described in Section 4. Open or poorly connected joints will behave like a lossy capacitor, thus providing a path that is highly resistive at low frequencies. The transfer impedance is high at lower frequencies and drops at higher frequencies. A connected joint will behave like an inductor, where as the transfer impedance will start with a low resistance and will generally increase with frequencies.

3.4 Electrical Power

Electrical power is often used in equipment to process HE components. The power lines are either plugged into a wall receptacle, or come through a metal conduit for larger pieces of equipment. An electrical spike in the power line could be generated by a lightning strike to a nearby electrical distribution unit. The distribution lines are more likely to be struck than the facility because of the height of the wires as they cross long distances. The high-voltage distribution lines are isolated from the facility power by step-down transformers, causing the lightning current to be greatly attenuated in the facility. The residual current that enters the facility power line should be small, but is very difficult to quantify. Factors such as the distance from the strike, the presence of high-voltage surge suppressors, quality of the ground grid, type of transformers, design of the facility power system, and the type of facility loads influence the degree of attenuation. Therefore, surge suppression of electrical spikes is prudent.

Surge suppressors limit the level of the voltage spike created by a lightning strike so that electrical equipment is not damaged. It will also prevent electrical arcs from forming between the electrical equipment/wire to the HE items. Surge suppressors must be considered a part of the Faraday cage. The protected portion of the circuit is inside the cage, and the unprotected half is outside. Surge suppressors should be mounted on the Faraday cage wall or very nearby, with metal conduit protecting the wires. The electrical conduit is a penetration, and therefore must be bonded to the Faraday cage.

Extreme lightning may produce up to 200 kA of current. Reasonable size industrial surge suppressors cannot handle this much current, however realistically, it is not necessary because of the attenuation caused by the step-down transformer as mentioned previously in this section. National standards have not been established, therefore, our approach is to install suppression units using *best practice*.

Equipment with plug-in power cables must be assumed to be at the same potential as the wall it is connected to. Typically, the equipment is encased in a metal enclosure that is connected to the ground wire of the power cable. Therefore it is important for this equipment to be isolated from the HE via a standoff distance of the same value as the wall it is connected to. The surge suppressors do not eliminate the voltage pulse on a ground wire created by a lightning strike to the facility. It limits the voltage spike between the ground wire and the power carrying wires. It protects the components inside the enclosure. Large equipment powered by electrical wires enclosed by metal conduit must also be grounded at the work area to remove potential differences between the equipment and nearby HE.

The specifications of the surge suppressors are listed in Appendix C - Surge Suppressors. Plant Engineering electricians install the suppressors. The units include indicator lights that show the health of the voltage limiting components, and it is important for the users to understand the information from the indicators and know how to respond. The status lights should be checked whenever there is a lightning alert (lights on indicates surge protection circuit is operational), and if there has been a strike to the power distribution system, the facility should not be operated during the alert. The Plant electricians are responsible for repairs.

4 Lightning Threat Assessment

In this report, we apply a technique based on low-power measurements to assess the vulnerability of HE processing facilities against lightning. This technique is a subset of a more general methodology developed by Lawrence Livermore National Laboratory to quantify RF vulnerability.

The lightning threat assessment technique consists of a site survey, lower-power RF measurement, computer processing of the data, and computer simulation of the effect of a lightning strike. The result is a predictive tool as shown in Fig. 4-1. Voltages and currents in bays and cells can be calculated for different lightning profiles. It is important to estimate the possible cell voltages and currents for two reasons.

- The voltage level is needed to determine a safe standoff distance between the penetrations and walls, and any vulnerable HE component.

- The current level determines the amount of energy that could be delivered. This information is used in risk analysis and risk control.

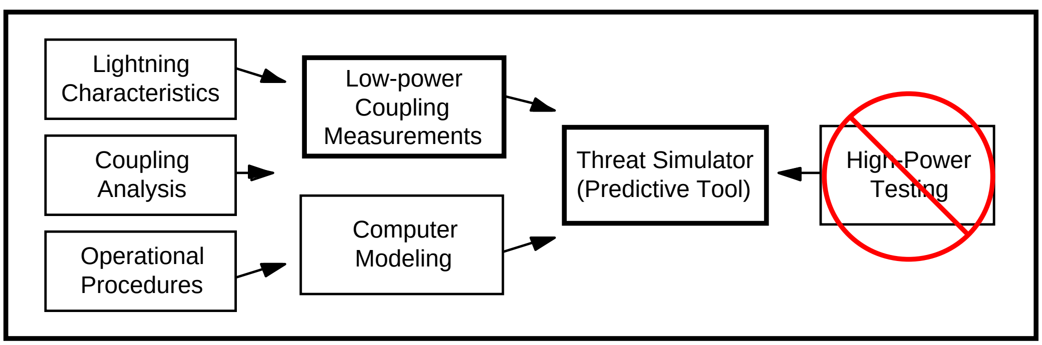


Fig. 4-1 Outline of the lightning assessment process.

Estimation of the lightning threat can be broken into three phases: low-power measurements, data processing to produce transfer functions, and extrapolation. They must all be considered in planning the measurement.

The accuracy of the predictions depends on a linear extrapolation from the low-power test levels to lightning energies. A good Faraday cage minimizes electrical arc creation, which is a non-linear response. Therefore, a good

Faraday cage can be modeled by a linear transfer function. This has been verified in rocket-triggered lightning studies conducted by Sandia National Laboratory.

4.1 Measurement Description

The entire measurement process is depicted in Fig. 4-2. Preliminary setup includes driving ground rods at least 3 ft. in the earth, establishing a sound strike point, and then connecting the rods to this point via cables. Continuity of the ground rod-earth-building-strike point-cable system is verified during the measurement phase of the experiments. All that is required is enough current to produce a measurable field within the cell. At least 3 ground rods are used and they are spread in as close to equally as possible about the building. The transmission station is established by placing an inductive loop around the ground wires and driving the loop via a function generator. The current magnitude and frequency is controlled by a software program on a laptop computer. The receiving station is established by connecting a broadband antenna to a spectrum analyzer which is again controlled by a laptop. Both laptops are synced in time, thus when the RF source is transmitting at a given frequency, the spectrum analyzer is tuned to a narrow band around this frequency. The measurement is performed from 10 khz to 2.5 Mhz using linear steps of 10 khz. It takes approximately 3 seconds to record each frequency measurement and the whole process totals approximately 13 minutes.

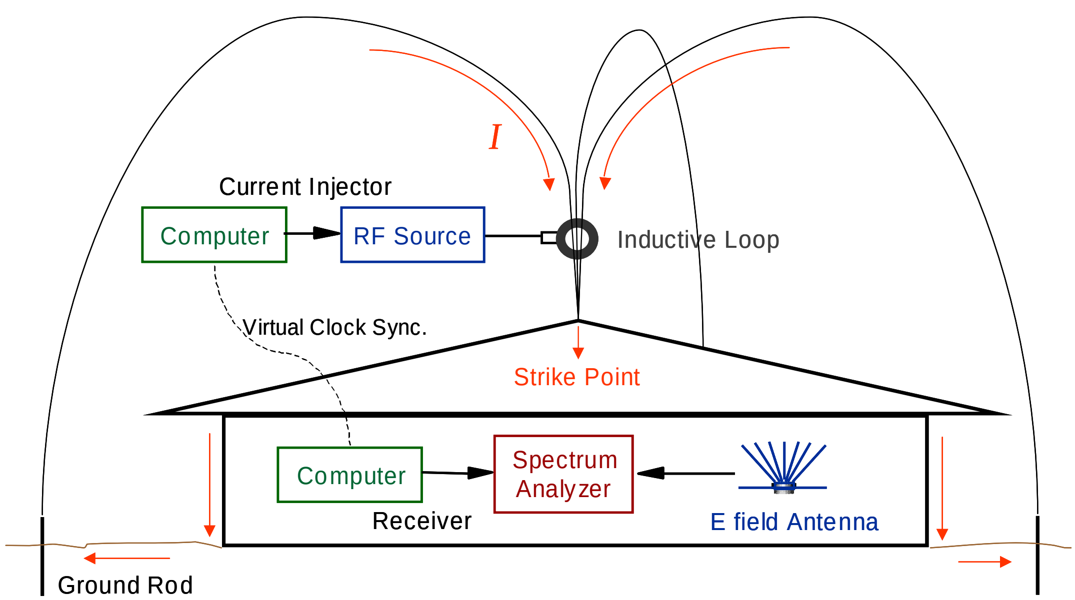


Fig. 4-2 Experimental Setup.

4.2 Lightning Parameters

The characteristics of a lightning strike can vary because of atmospheric conditions [3]. Our goal is to protect the facility against an extreme lightning strike; therefore we have selected parameters that will produce the worst-case voltages within the facility. Three important parameters are listed in Table 4-1, and will be used in determining interior voltages if the facility is directly struck by lightning.

Lightning Parameters	Level	Frequency of Occurrence	Notes
Peak Current	200 kA	1 %	Important parameter.
Rise Rate	400 kA / µs	1 %	Most important parameter.
Duration	100 µs	<50 %	Used to match max. action.

Table 4-1 These lightning parameters determine the magnitude of interior voltages in a Faraday cage.

4.3 Faraday Cage Model and Standoff Distance

The simplified equation to calculate the interior time-domain potential voltage of a Faraday cage is

$$V(t) = L\frac{di}{dt} + Ri(t)\,, \tag{3.1}$$

where L is the inductance and R is the resistance of the cage or facility in question. Typically, the resistive component of the voltage is negligible in comparison to the inductive. An exception would be a discontinuity in the cage that causes R and thus V to be large. Discontinuities in the cage must be corrected if the facility is to be certified for HE processing during lightning alerts.

The standoff distance between a wall and an HE component is determined from the maximum calculated interior voltage at the wall, and the dielectric strength (breakdown voltage) of air. The dielectric strength is dependent upon pulse duration. We use a dielectric strength of 5.5 kV/cm for a resistive-like voltage pulse, and 9.0 kV/cm for an inductive-like voltage pulse [4]. Our formula for calculating the safety standoff distance is

$$D = 2 \bullet \frac{V_{peak}}{V_b}\,, \tag{3.2}$$

where V_b is the breakdown voltage as described previously, V_{peak} is the peak interior voltage level due to a lightning strike, and the numeral 2 is a safety factor. Although inductive voltages usually dominate, because the interior voltage is a composite of both resistive and inductive voltages, we normally specify the resistive breakdown voltage as it is more conservative.

4.4 Transfer Impedance

For our purposes, we will define the transfer impedance of a Faraday cage or building as a measure of the ease of which current can flow from a likely lightning *strike point*, through the facility to ground, as a function of frequency. A low impedance cage provides little opposition to current flow, which lessens the voltage inside the building. Conversely, when current is obstructed by capacitive breaks, highly inductive paths, and generally low conductive materials, the voltage between the strike point and ground is high. Given that the strike point is usually on the roof of the facility or high on a wall, the cells interior voltage is between the ceiling and floor. It is this voltage difference that introduces a risk of arcing through HE components.

We determine the transfer impedance of a facility by injecting a current into the building and measuring the resulting electric field at various locations within the cells. A measure of the injected current and electric field, along with the geometric description of the cell is sufficient data to determine the transfer impedance.

In practice, transfer impedance is measured in the frequency domain. The frequency-domain version of (3.1) is given by

$$V(f) = Z \bullet I \, , \tag{3.3}$$

where Z and I are the frequency domain representations of the transfer impedance and current, and the impedance is given by $Z = j\omega L + R$. Thus, measured electric field levels are converted to a floor-to-ceiling voltage and the transfer impedance is calculated by

$$Z^i = \frac{V^i_{meas}}{I_{inj}} \, , \tag{3.4}$$

where V^i_{meas} is the measured floor-to-ceiling voltages at location *i*, and I_{inj} is the injected current.

4.5 Injection Point and Measurement Locations

The current is injected at a likely lightning strike point on the facility. Typically, this will be a prominent conductive protrusion on the roof of the facility. Examples include air exchangers and vents, power conduits, and lightning rods. Lightning rods that are bonded to the facility's metal structure are excellent strike points; however rods that are connected to down conductors and are not adequately bonded to the facility should be avoided. If these were used, injected current may bypass the building and go directly to ground. At first, this may seem desirable; however the bypass is only likely at our low voltage levels.

During a lightning strike, high voltage levels will arc from the down conductors to the facility's metal structure and cause significant currents and voltages within the building.

The electric field is measured within a cell at various locations, and for Building A, these locations are listed alphabetically in Fig. 4-5. Notice in (3.4) that we obtain a different transfer impedance for each location that is measured, and this will lead to different standoff distances. The field levels are expected to be the highest near the walls and doors of a cell, thus these locations are measured. We expect to find a lower field level at the center of the room and this is also measured. Other possible measurement locations include machinery that is connected in some way to the wall or ceiling, mobile cameras, or other anomalies. The resulting transfer impedance for Building A is shown in Fig. 4-3.

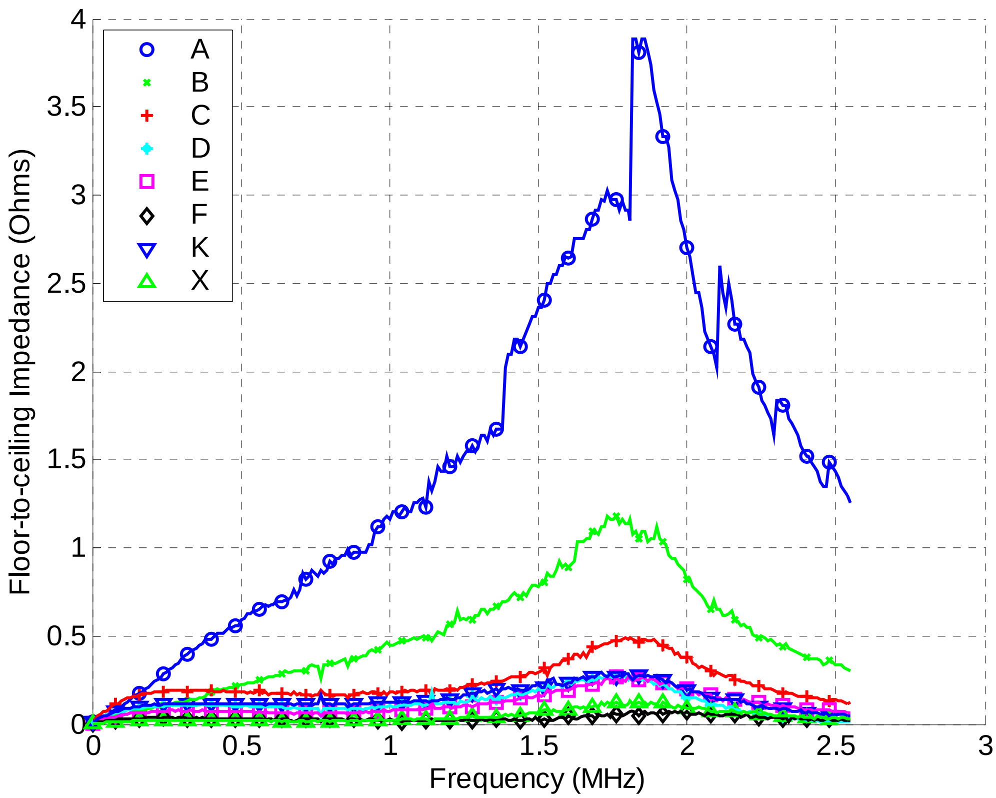


Fig. 4-3 Floor-to-ceiling transfer impedance for Building A.

4.6 Facility Voltage and Standoff Distance

The transfer impedance as determined in Sec. 4.4 is applied to a lightning model in order to obtain the peak voltage within the cell. Thus, the peak voltage, as a function of time, is calculated by inverse Fourier transforming the product of the frequency-domain impedance and the Fourier Transform of the time-domain lightning current model. This is given by

$$V(t)^{i}_{peak} = \mathcal{F}^{-1}\left(Z^{i} \bullet \mathcal{F}\left(I_{\text{model}}\right)\right). \tag{3.5}$$

The result of (3.5) is a time history of the lightning voltage within the cell at location *i*, and the actual peak is determined be taking the maximum absolute value. For Building A the resulting floor-to-ceiling voltage is shown in Fig. 4-4.

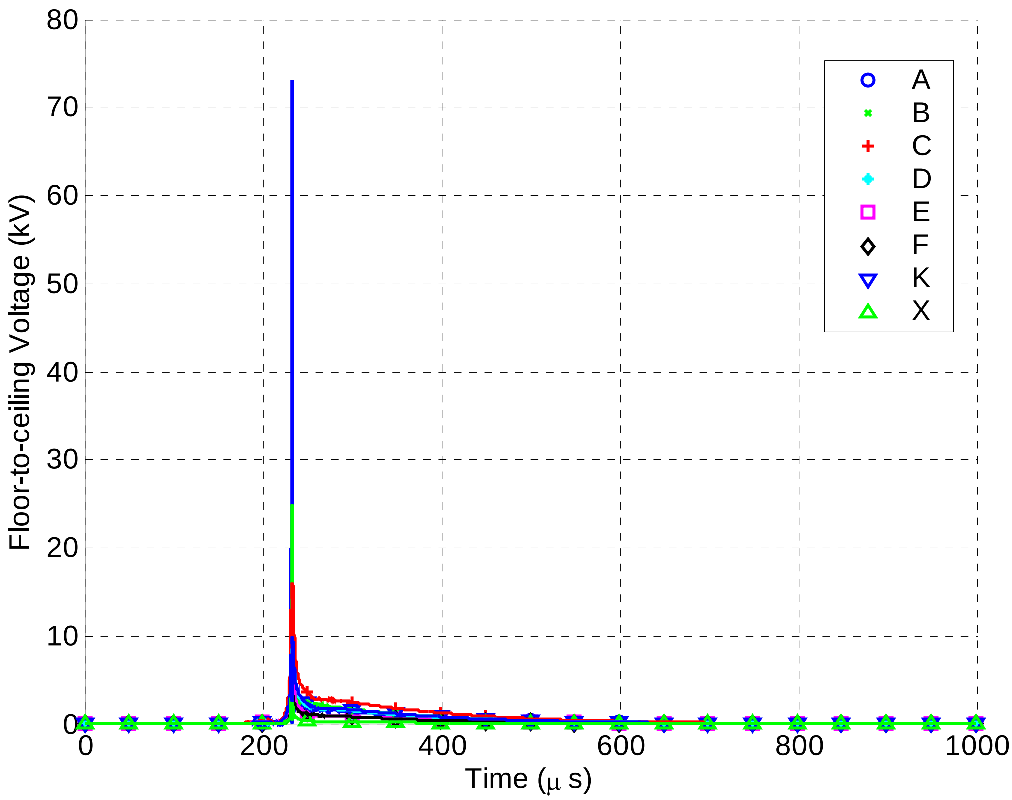


Fig. 4-4 Floor-to-ceiling voltage for Building A.

We then employ (3.2) to obtain the safe standoff distances for each location. For Building A, the resulting standoff distances are listed in Table 4-2 and shown graphically in Fig. 4-5. Note that a standoff distance should also be observed at the ceiling level. As a rule, we shall apply the largest standoff measured in the cell at the ceiling.

Location	Standoff
N.E. Wall	6 in.
S.E. Wall	1 ft.
S.W. Wall	6 in.
N.W. Wall	6 in.
S.W. Room Walls	6 in.
N.E. Room Walls	6 in.
Ceiling	1 ft.

Table 4-2 Standoff Distances

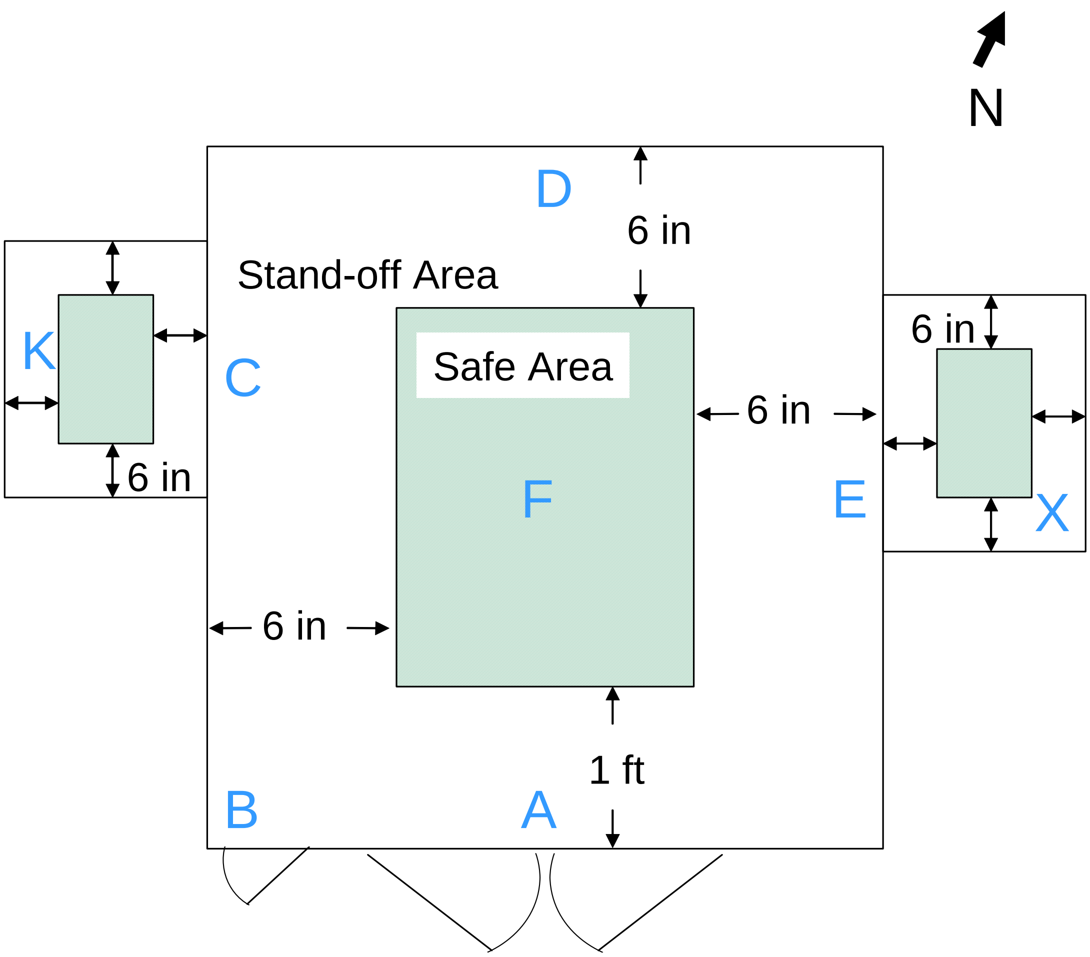


Fig. 4-5 Standoff diagram for Building A.

5 Operational Changes during a Lightning Alert

Observation of standoff distances requires operational changes that may not be immediately apparent. In this section we will outline general safety requirements as well as point to hazards specific to Building A that may compromise the designated standoff distance.

In general, environments which house HE and other hazardous material must be maintained with a high degree of cleanliness and organization. Lightning Safety Certification assumes the ongoing adherence to these standards for all buildings and magazines.

During a lightning alert, it is clear that HE must not be within the safety standoff distance. Items that may compromise this include, but are not limited to, personnel, electrical power cords, telephone receiver cords, overhead cranes and hoists and the controls for same, mobile cameras, and metal machinery and furniture that is bonded to or near a wall, such as desks, benches, tool cabinets, storage cabinets, presses, mixers, etc.

To determine the application of standoff distances to machinery, metal cabinets, or other conductive furniture items, one must evaluate the following criteria. If a standoff distance is not to be applied to the item and the item is *within* the standoff distance of any wall or ceiling, the following two conditions must be met:

- The item must be *well grounded* at its base. Grounding must be done in accordance with the same guidelines as bonding penetrations (See Section 3.1). Objects of extended size require more than a single bond. At a minimum, bonds should be placed every 3 ft. of horizontal perimeter of the equipment. For example: A machine that is 1 ft. wide by 4 ft. long has a perimeter of $2 \cdot 1 + 2 \cdot 4 = 10$ ft., and would require 4 bonds.
- Any conductive connections to a wall must be made at the floor level where they are to be grounded.

If a standoff distance is not to be applied to the item and the item is *outside* the standoff distance of any wall or ceiling then the following condition must be met:

- Any conductive connections to a wall must be made at the floor level where they are to be grounded.

If the above conditions are not met for conductive items either outside or within the standoff distance of a wall or ceiling, then the standoff distance must be transferred to the items as if they were part of the wall or ceiling. Note that personnel are considered conductive and as such will extend any standoff area they enter.

Electrical cords that span the floors and walls of a building present an added risk if they are not properly grounded to the building ground. Verification of grounding potential should be performed when laying permanent or temporary electrical lines. Otherwise, lines should be considered extensions of the wall they are plugged into and thus require the same safety standoff distance.

Overhead cranes, lifts, and controls increase the risk of arcing from these items through the HE and to the floor or any other item at a lower potential. Electric fields are intensified where these items reduce the overall distance between the floor and ceiling. Descending cranes, lifts, and controls bring the ceiling voltage closer to the operation area of the building, which is assumed to be the approximate height of personnel. These items must be stowed in their highest position or via a conductive contact to a wall, and away from HE.

Long telephone receiver cords may produce a hazard. The length of telephone receiver cords should be minimized in order to reduce the possibility of close contact with HE in the operational area of the building. Where applicable, the use of a speakerphone is encouraged. Telephone cords should be assumed to be at the same potential as the wall they are attached to, thus the safety standoff distance must extend from the farthest point that the receiver can reach plus 2 ft, which accounts for the person holding the receiver. For example, assume we have a telephone installed on a wall with a 3 ft cord. Let’s also assume that the required safety standoff distance from this wall is normally 1 ft. The total standoff distance would then be 3 + 1 + 2 = 6 ft, and this would be measured radially out from the telephone.

Standoff distances are determined from measurements of the cell with all external doors closed. Opening an external door compromises the faraday cage and will cause an increased hazard of an arc at this location. Thus, standoff distances near external doors must be increased if the door is opened. The general rule is to increase the standoff by the height of the opening. This increased standoff extends radially along the vertical dimension of the door.

In Building A, the following aforementioned operational hazards are present or have the potential to be present, and strict adherence to controls is required:

- [x] Housekeeping
- [ ] Power cords
- [x] Cranes/hoists
- [ ] Mobile Cameras
- [x] Machinery/equipment
- [x] Metal furniture/structures
- [x] Telephones

6 Maintenance and Inspection Schedule

The following section listed the required maintenance schedule for compliance with Lightning Safety Certification.

- Visual inspection of bonds and surge suppressors is required every 2 years.
- Resistance check of bonds is required every 5 years.
- Transfer impedance measurements as outlined in Section 4 are required every 15 years.
- If a lightning strike occurs or damage is suspected, transfer impedance measurements should be performed as outlined in Section 4.

7 References

[1] "NFPA 780, Standard for the Installation of Lightning Protection Systems", Massachusetts: National Fire Protection Assn, 2000.

[2] Dotts, J. E. and B. Kim, "DOE Explosives Safety Manual, LLNL Work Smart Standards Version", DOE M 440.1-1, Rev. 2, Nov 18, 2002, Chapter X.

[3] Fisher, R. J., M. A. Uman, "Recommended Baseline Direct-Strike Lightning Environment for Stockpile-to-Target Sequences", Sandia Report, May 1989, SAND89-0192.

[4] Martin, T.H., "An Empirical Formula for Gas Switch Breakdown Delay", Seventh IEEE Pulse Power Conference, Monterey, June 1989, pages 73-9.

Acknowledgements

We would like to thank all those who contributed to the lightning safety certification effort at LLNL, both in direct measure and otherwise. I therefore give recognition to Cal Dibble, Sue Byars, Emer Baluyot, John Scott, C.V. Vick, Jim Dotts, Grace Clark, Long Tran, Francisco Barbosa, Michael Paradiso, Troy Redford, Stephen Smith, Larry Sedlacek, Kristen J. Nave, Denise Hunter, Kristin Mercer, Jim Lane, Mike Chapin and crew. Thank you.

Appendix A - List of Bond Points and Resistance

Building A (Cell height = 11 ft.)					
Ref #	**Size**	**Elevation**	**Description**	**Location**	**Initial Reading**
1	3/8"	1'	1" galvanized.	North wall	.3 ohms
2	3/8"	1'	4" galvanized.	North wall	.1 ohms
3	3/8"	1'	2" galvanized, 1" copper	East wall	.5 ohms
4	3/8"	1'	1" copper	East wall	.5 ohms
5	3/8"	1'	1" galvanized.	North wall (right cell)	.4 ohms
6	3/8"	2'	vent	South wall (right cell)	.3 ohms
7	3/8"	3'	1 1/4" galvanized.	East wall	.3 ohms
8	3/8"	1'	1" galvanized.	East wall	.5 ohms
9	3/8"	10'	1" galvanized, vent	South wall (cell)	.3 ohms
10	3/8"	2'	4" pipe, 2" copper, 1/4" galvanized.	East wall	.2 ohms
11	3/8"	1'	1" galvanized.	East wall	.2 ohms
12	3/8"	10'	vent	East wall	.3 ohms
13	3/8"	10'	vent	East wall	.3 ohms
14	3/8"	1'	5- 1" galvanized, door frame	South wall	.2 ohms
15	3/8"	15'	1/2" copper	South wall	.1 ohms
16	3/8"	5'	door frame	South wall (left hand side)	.3 ohms
17	3/8"	7'	3/4" galvanized, frame, 3/4" galvanized.	South wall (right hand side)	.7 ohms
18	3/8"	8'	metal plate	South wall	.2 ohms

Appendix B - List of Equipment for Measuring Transfer Impedance

Qty.	Item	Use
2	12V DC car battery	Provides isolated power sources for transmitter and receiver stations.
1	Spectrum Analyzer Agilent 8560 series	Measures received antenna voltages.
1	Waveform Generator Agilent 33120A	Produces transmitter voltage signal.
2	50' RG223 coaxial cable with BNC-male connectors	Provides shielded transmission paths between Spectrum Analyzer/antenna and Waveform Generator/inductive loop.
2	Inductive loops (one for transmitting and one for receiving)	Converts Waveform Generator voltage signal to injected current at strike point.
1	10x Attenuator	Attenuates current signal measurement.
1	C-Clamp or pipe clamp	Provides ground wire connections to strike point.
1	E-field antenna kit – Tecom 201191A Ultra-Broadband Conical Monopole (20 Hz – 100 Mhz)	Converts cell interior electric fields to measured voltages at the Spectrum Analyzer.
2	Laptop computer	Provides control and data collection for both the Waveform Generator and Spectrum Analyzer.
2	Testmobile cart with Prosine inverter (12V DC to 120VAC)	Houses and provides power conversion for transmitter and receiver equipment.

Appendix C - Surge Suppressors

Building	Voltage Rating	Location of SPD	Status	SPD type
Building A	3 phase 120/208	Equipment room west wall	working	MMKC

NORTHERN TECHNOLOGIES

TCS-HW Series
Performance Specifications
& Product Characteristics

General Specifications

Enclosure Dimensions (not including tabs)	4H x 4W x 2.5D in., 10H x 10W x 6D cm
Weight	1.24 lbs, 562 grams
Enclosure Type	Extruded aluminum
Interface	Hardwire
Primary Technology	Silicon Avalanche Diode (SAD)
ANSI/IEEE C62.41-1991 Location Category	Category A
Line Configuration	1 phase, 2 wire & ground
Operating Temperature	-40°C to +50°C
Operating Frequency	50/60 Hz
Response Time	< 5 nsec
EMI/RFI Noise Attenuation	-13dB maximum, 150kHz - 200MHz
Remote Failure Indication	RJ-11 Jack/Form C Dry contact
Agency Approvals	UL 1449 TVSS, CUL 22.2

Power Specifications

Part Number	TCS-HWAR	TCS-HWD	TCS-HWL	TCS-HWR
Nominal Line Voltage				120 V
Max. Continuous Line Voltage				132 Vrms
Nominal Clamping Voltage†				216 Vpk
Protection Modes				L-N L-G N-G
Peak Pulse Energy Dissipation				L-N: 300 J L-G: 75 J N-G: 75 J
Max. Transient Current (8/20μs)				L-N: 32 kA L-G: 8 kA N-G: 8 kA

†Clamping Voltage reflect ANSI/IEEE C62.41-1991 Wave Shape Testing with 100 kHz ringwave 6 kV 200 A as parameters for static and dynamic testing.

23123 E. Mission
Liberty Lake, WA 99019 USA
800-727-9119 (U.S. & Canada)
509-927-0401 Fax 509-927-0435
www.northern-tech.com
D0032-A-0819
Rev. 1 (7/10/02)

ISO 9001 SGS ANSI-RAB QMS ACCREDITED

EMERSON Network Power

Figure C1. Surge suppressor TCS-HWR for 120 VAC circuits.

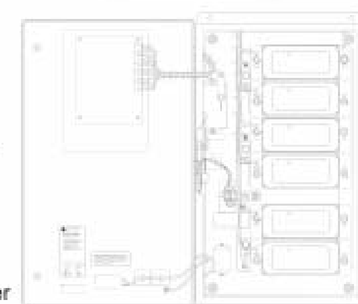
EMERSON
Network Power

MMK-C Series

NEW! V3 SHIELD™ Technology

Performance Specifications

Service Voltage	208/120 VAC, 3 Phase, 4 Wire & Gnd
Nominal Clamp Voltage	230 Vpk, ØA-N; 230 Vpk, ØB-N; 230 Vpk, ØC-N
Response-Time	≤20 nsec
Protection Modes	ØA-N; ØB-N; ØC-N
Operating Frequency	50/60 Hertz
Peak Pulse Current (8/20μs)	312 kA, ØA-N; 312 kA, ØB-N; 312 kA, ØC-N
Peak Pulse Energy	5040 J, ØA-N; 5040 J, ØB-N; 5040 J, ØC-N
Suppression Technology	Metal Oxide Varistor (MOV)
Suppression Status Visual Indicators	LEDs
Remote Status Interface	Hardwired & RJ-11 (Form C Dry Contact)
Enclosures	NEMA 1 or NEMA 4
Dimensions	
Inches	20H x 12W x 6D
Centimeters	51H x 31W x 15D
Weight	30 lbs. (13.6 kg)
Agency Approval (Listed)	UL 1449 Transient Voltage Surge Suppression CUL 22.2



N-G Option: This model is available with N-G protection mode.

Nominal Clamp	205 Vpk
Peak Pulse Current (8/20μs)	130 kA
Peak Pulse Energy	1300 J

Counter Option: This model is available with a Transient Counter (Interior Enclosure Only).

NORTHERN TECHNOLOGIES, INC.
Total Power Protection Solutions

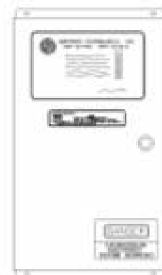
Figure C2. Surge suppressor for 208 VAC circuits.

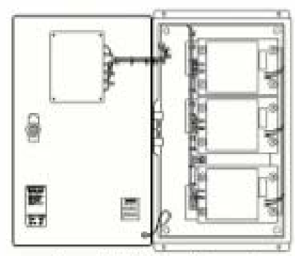
EMERSON
Network Power

MMK-Gx-S*
(x=I for Internal use or E for External Use)
(*=S for Standard or A for N-G Option)

Performance Specifications

Service Voltage	480/277 VAC, 3 Phase, 4 wire & Ground
Nominal Clamp Voltage	460Vpk, ØA-N; 460Vpk, ØB-N; 460Vpk, ØC-N
Suppression Technology	Metal Oxide Varistor
Response Time	< 20ns
Protection Mode	ØA-N; ØB-N; ØC-N
Operating Frequency	50/60 Hertz
Peak Pulse Energy (2ms)	7200J, ØA-N; 7200J, ØB-N; 7200J, ØC-N
Peak Pulse Current (8/20μs)	312kA, ØA-N; 312kA, ØB-N; 312kA, ØC-N
Suppression Status Indicators	LEDs
Remote Status Interface Suppression Modules	Hardwired & RJ-11 (Form C)
Dimensions	
Inches	20H x 12W x 6D
Centimeters	50.8H x 30.5W x 15.2D
Weight	30 lbs. (13.6kg)
Enclosure	NEMA 1 or NEMA 4
Agency Approvals	
UL/CUL (Listed)	UL 1449 Transient Voltage Surge Suppression





Front & Inside View of MMK-G Internal Unit

Note: As an option, this unit is available with N-G mode of protection. This option is recommended when N-G is not bonded.

Nominal Clamp	472 Vpk
Peak Pulse Energy (2ms)	1950 J
Peak Pulse Current (8/20μs)	84.5 kA

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D0166-A-0501

Figure C3. Surge suppressor for 480 VAC circuits.

Appendix D – Integrated Work Sheet

IWS #:	WAL:	IWS Status:	Date Created:
10684 r2	**B**	**Authorized** on **06-AUG-03**	**31-JUL-03**

Title:

Lightning Protection - RF Coupling Measurements

Scope of Work:

At Site 300, perform experiments in, around, and on the roof of facilities. Duties include setup and operation of RF coupling measurement equipment.

The RF coupling measurement equipment consists of two computer-control stations powered by batteries. The first is the transmitting station that consists of an RF source that will generate less than 1 amp at 10 Volts peak-to-peak. Current is driven into the facility, flows into the earth, and returns through ground rods and wires. This station is positioned outdoors near a likely lightning strike point, typically on the roof of the facility.

The second station is a receiver located in the building. The electric field levels in the facility are measured with an active antenna powered by a small battery. The levels are recorded with a spectrum analyzer with high noise immunity.

We are using commercial equipment (from HP, Tektronix, Dell, etc.) that has standard (e.g. UL) electrical safety certifications.

Intended Start Date:	Estimated Completion Date:
31-JUL-03	31-JUL-04

Location of the Activity:

1) Site 300-Facility - Add'l Info: All buildings that will process or store HE. - ES&H Team 1

Authorizing Organization:

Engineering-DSED

Management Chain for the Activity:

Name:	Title:	Phone:	Beeper:
CLANCY, TODD J	RI	28571	10024
ONG, MIKE M	Alt RI	20206	--
GALKOWSKI, JOSEPH J	AI	20602	--
--	AD-Engineering	--	--

Employees and Guests Assigned to this Activity:

1) BALUYOT, EMERALDO V
2) BARBOSA, FRANCISCO
3) CLANCY, TODD J
4) ONG, MIKE M
5) PARADISO, MICHEAL G
6) REDFEARN, TROY K
7) SMITH, STEPHEN D
8) TRAN, LONG H

Hazard Descriptions and Controls:

Construction/Equipment/Working Surfaces: Walking/working on irregular surfaces

Description:	Control:
Buildings may have uneven and/or slightly slanted roof surfaces.	General awareness of working environment.

Construction/Equipment/Working Surfaces: Work at heights > 6 ft

Description:	Control:

Personnel will work on roofs of buildings.	Whenever possible, work will be performed more than 6ft from the edge. Inspections will be allowed within 6ft of an edge without additional safety measures. If work is to be performed within 6ft from an edge, either a fall restraint system, or a safety watch will be implemented.
Construction/Equipment/Working Surfaces: Roof access	
Description:	**Control:**
Personnel will work on roofs of buildings.	Roof Access Permits will be obtained. Whenever possible, work will be performed more than 6ft from the edge. Inspections will be allowed within 6ft of an edge without additional safety measures. If work is to be performed within 6ft from an edge, either a fall restraint system, or a safety watch will be implemented.
Electrical: Batteries (short circuit >10 A or >50 V)	
Description:	**Control:**
Equipment includes 12 V lead acid batteries of standard automotive size.	Batteries are stored in plastic containers. Terminals will be covered to prevent inadvertent shorting by tools or personnel. Work on batteries is limited to connecting/disconnecting them to a regulator. A competent companion shall be positioned within visible and audible range of the worker during this activity. Batteries will not be charged on site.
Explosives/Firearms: Explosives, high explosives, propellants, pyrotechnic or similar energetic material	
Description:	**Control:**
H.E. may be present within rooms where work is performed.	If H.E. is present, an explosives handler will be required as a safety observer. Hazardous work permits will be obtained. It would be acceptable to have a battery inside the facility with HE present under the following conditions: Battery is enclosed in a non-combustible, non-metallic container; container lid is secured and openings sealed. Power cable connection(s) (outside container) is/are taped and, if possible, sealed in plastic bag. Instrument cart will be inspected by HE professionals and an "Electrical Authorization" tag will be attached prior to it going into any explosives facility. Additional controls include: Batteries will be checked for over charging. While inside a magazine with HE, personnel contact with the instrument cart and equipment there on will be limited to the cart handles only. The battery will not be sealed within the container for more than one hour.
Temperature/Weather: Weather exposure or temperature extremes (harsh weather, lightning, temperature extremes)	
Description:	**Control:**
Work may be performed in climates with high atmospheric temperatures.	Hydration and routine breaks.
Temperature/Weather: Exposure to intense sunlight	
Description:	**Control:**
Work may be performed in direct sunlight at high atmospheric temperatures.	Appropriate attire, sun block, and wide-brim hats will be worn.
Worker Capability/Motion: Lifting manually >30 pounds	
Description:	**Control:**

file://C:\DOCUME~1\clancy5\LOCALS~1\Temp\Z5AVI9P6.htm

Potential for sprains and strains due to improper lifting techniques.	Apply appropriate lifting techniques. Complete required back care training if lifting greater than 25 lbs.
Worker Capability/Motion: Hand tools	
Description:	**Control:**
Hand tools will be used.	Make sure you have the proper tool for the task and the tool is serviceable. Take damaged tools out of service. Hand tools will only be used for short periods, <15 minutes.

General Hazard Control Information:
No general hazard controls specified.

Required ES&H Training:	
Employee:	**Course Number:**
BALUYOT, EMERALDO V	HS0095-W, HS5300, HS5311, HS5959-CBT, HS5960
BARBOSA, FRANCISCO	HS0095-W, HS5300, HS5311, HS5959-CBT, HS5960
CLANCY, TODD J	HS0095-W, HS5300, HS5311, HS5959-CBT, HS5960
ONG, MIKE M	HS0095-W, HS5300, HS5311, HS5959-CBT, HS5960
PARADISO, MICHEAL G	HS0095-W, HS5300, HS5311, HS5959-CBT, HS5960
REDFEARN, TROY K	HS0095-W, HS5300, HS5311, HS5959-CBT, HS5960
SMITH, STEPHEN D	HS0095-W, HS5300, HS5311, HS5959-CBT, HS5960
TRAN, LONG H	HS0095-W, HS5300, HS5311, HS5959-CBT, HS5960
No additional training requirements specified.	

Attached or Referenced Files:		
Type:	**Name:**	**Location:**
No Documents are Attached or Referenced.		

Additional Site Location/Directorate-Specific Information: *Additional requirements that need to be met before work can commence*
FPOC - Contact and concurrence will be addressed on each individual job. See Sue Byars 25569.

LLNL Permits/Approvals/Consultations/Reporting:
1) Hazardous work permit
2) Roof access

Agency Work Permits/Approvals:
None Specified.

Medical Surveillance/Certification:	
Employee:	**Surveillance/Certification:**
BALUYOT, EMERALDO V	No Surveillance/Certification Assigned
BARBOSA, FRANCISCO	No Surveillance/Certification Assigned
CLANCY, TODD J	No Surveillance/Certification Assigned
ONG, MIKE M	No Surveillance/Certification Assigned
PARADISO, MICHEAL G	No Surveillance/Certification Assigned
REDFEARN, TROY K	No Surveillance/Certification Assigned
SMITH, STEPHEN D	No Surveillance/Certification Assigned
TRAN, LONG H	No Surveillance/Certification Assigned

Signatures:
As the RI, I have reviewed the hazards and agree to implement the controls identified in this IWS:

CLANCY, TODD J RESPONSIBLE INDIVIDUAL (RI)	08/05/2003 DATE
The proposed work falls within the safety envelope of the facility/area and may commence once authorized:	
SEDLACEK, LARRY E FPOC CONCURRENCE, Site 300-Facility - Add'l Info: All buildings that will process or store HE.	08/06/2003 DATE
The hazards and controls have been properly identified and the work may commence once authorized:	
BARDECKER, JERALD E ES&H CONCURRENCE, ES&H Team 1 - Site 300-Facility - Add'l Info: All buildings that will process or store HE.	08/06/2003 DATE
Approval: The controls have been confirmed and this proposed activity is authorized to proceed.	
GALKOWSKI, JOSEPH J AUTHORIZING INDIVIDUAL (AI)	08/06/2003 DATE

Appendix E – Certification Verification Sign-off Sheet

Lightning Protection Certification Verification Sign-off Sheet

Facility ________________

Room ________________

Name Subject Matter Expert Engineering	Date	Name Engineering Division Leader	Date
Name Authority Having Jurisdiction Explosive Safety	Date	Name Site Division Leader Plant Engineering	Date
Name Facility Manager	Date	Name Site Manager	Date