

## EFCOG Best Practice #143

**Best Practice Title:** Lightning Protection and Grounding Systems Design, Installation, Testing, Maintenance and Inspection Safety

**Facility:** DOE Complex

**Points of Contact:** Dave McAfee, PE, SFPE Phone: 865-574-1635, email: [mcafeede@y12.doe.gov](mailto:mcafeede@y12.doe.gov)

Jackie McAlhaney, PE, Phone: 803-557-9002, email: [jackie.mcalhaney@srs.gov](mailto:jackie.mcalhaney@srs.gov)

**Brief Description of Best Practice:** This best practice provides clarification for Department of Energy facilities lightning protection requirements outlined in the National Fire Protection Association (NFPA) 780, Standard for the Installation of Lightning Protection Systems.

**Why the best practice was used:** This document provides consistent criteria for applying lightning protection design, installation, maintenance and inspection into safety programs against the NFPA and DOE requirements.

**What are the benefits of the best practice:** Use of this best practice provides a consistent method for assessing and improving lightning safety programs and field implementation to help reduce lightning induced safety events across the complex.

**What problems/issues were associated with the best practice:** No consistent guidance applied to complex.

**How the success of the Best Practice was measured:** Success will be measured by the use of this Best Practice into each sites design and operating procedures.

**Description of process experience using the Best Practice:** N/A

**Attachment:** Lightning Protection and Grounding Systems Best Practice

**LIGHTNING PROTECTION AND GROUNDING  
SYSTEMS**

**BEST PRACTICE**

**DESIGN AND INSTALLATION**

**TESTING, MAINTENANCE, AND INSPECTION**

**SAFETY**

**Revised June 2017**

**EFCOG Lightning Safety Original Working Group Members**

**David McAfee, Chairman – Y-12**

**Rick Baca – LANL**

**Terry Crutchfield – Y-12**

**Robert Daley - LANL**

**Samuel Garcia – LANL**

**Ajit Gwal – DNFSB**

**Rebecca Lopez – Sandia**

**Jackie McAlhaney – SRNS**

**Kimball Merewether – Sandia**

**Mike Robertson – Schneider Electric**

**Brian Sautter – DOE SRS**

**Sal Sferrazza – NREL**

**James Wright – BNL**

**Max Wright – Pantex**

## Table of Contents

Abbreviations and Acronyms .....	5
Definitions .....	5
Chapter 1 Introduction .....	6
1.1 Objectives .....	6
1.2 Background .....	6
1.3 Requirements .....	8
CHAPTER 2 LIGHTNING HAZARDS AND PROTECTION .....	10
2.1 Lightning Hazards .....	10
2.2 Protection .....	10
CHAPTER 3 CHARACTERISTICS OF LIGHTNING .....	12
3.1 General .....	12
3.2 Current in a Lightning Flash .....	14
3.3 Voltage .....	14
3.4 Effects of a Lightning Strike on an LPS .....	15
CHAPTER 4 DESIGN BASIS .....	16
4.1 General Criteria .....	16
4.2 Risk Assessment/Need for a LPS .....	17
4.3 Design Requirements .....	18
CHAPTER 5 TESTING, MAINTENANCE AND INSPECTION .....	21
5.1 Inspection Overview .....	21
5.2 Inspection Criteria .....	21
5.3 Acceptance Criteria .....	22
Chapter 6 Personnel Safety .....	25
6.1 General .....	25
6.2 Planning for Personnel Warning .....	25
6.3 General Guidance for Outdoor Workers .....	26
6.4 General Guidance for Safe Shelters and Indoors .....	27

Energy Facilities Contractor's Group (EFCOG)

6.5 Guidance for Organized Outdoor Events ..... 27

6.6 First Aid for Lightning Victims ..... 28

REFERENCES ..... 29

Appendix B Recommended Work Steps for Inspection of Facility Lightning Protection System ..... 30

## **Abbreviations and Acronyms**

**°F – Degree Fahrenheit**

**°C – Degrees Celsius**

**AHJ – Authority Having Jurisdiction**

**DOD – Department of Defense**

**DOE – Department of Energy**

**EFCOG – Energy Facilities Contractor's Group**

**LPI – Lightning Protection Institute**

**LPS – Lightning Protection System**

**NFPA – National Fire Protection Association**

**NLDN – National Lightning Detection Network**

**NOAA – National Oceanic & Atmospheric Administration**

**SPD – Surge Protective Device**

**TM&I – Testing, Maintenance & Inspection**

**UL – Underwriter's Laboratory**

## **Definitions**

**Definitions are as found in NFPA 780, Chapter 3**

## Chapter 1 Introduction

### 1.1 Objectives

1.1.1 The primary focus of this EFCOG best practice is to provide clarification for Department of Energy (DOE) facilities lightning protection requirements outlined in the National Fire Protection Association (NFPA) 780, *Standard for the Installation of Lightning Protection Systems*. This document addresses requirements for providing protection to facilities and to personnel within or near these facilities from the consequences of a lightning-induced event. This document does not apply to explosive facilities as defined in DOE 1212 or structures housing explosives as defined by NFPA 780.

1.1.2 The fundamental principle in protection of life and property against lightning is provision of a means by which lightning discharge can enter or leave earth with no resulting damage or loss to the facility or occupants. A low-impedance path to ground is necessary to ensure this continuous discharge, and to attempt to manage the path of currents, minimizing undesirable current flow through building materials, equipment or personnel. The low impedance path to ground is achieved by providing strike termination devices on the high point of the structure, multiple interconnecting conductors, and a ground electrode system.

### 1.2 Background

1.2.1. Lightning is an atmospheric discharge of electricity that typically occurs during thunderstorms, and sometimes during volcanic eruptions or dust storms. Lightning can also be caused by violent forest fires that generate sufficient dust or wind to create a static charge. A bolt of lightning can travel at a speed of 136,000 miles per hour (220,000 kilometer per hour) and can reach temperatures approaching 54,000 degrees Fahrenheit (°F) [30,000 degrees Celsius (°C)], hot enough to fuse soil or sand into glass.

1.2.2. Over 16 million lightning storms occur every year. How lightning initially forms is still a matter of debate. Scientists have studied root causes ranging from atmospheric perturbations (wind, humidity, and atmospheric pressure) to the impact of solar wind and accumulation of charged solar particles. Ice inside a cloud is thought to be a key element in lightning development, and may cause a forcible separation of positive and negative charges within the cloud, thus assisting in the formation of lightning.

1.2.3. In any U.S. geographical location, lightning storms occur as few as five times or as many as 100 times per year. Figure 1.1 illustrates typical US distribution of lightning flashes from 2007 to 2016 from the National Lightning Detection Network<sup>®</sup> (NLDN<sup>®</sup>) by Vaisala.

1.2.3.1 A single lightning flash (event) will typically consist of from one to twenty or more individual current strokes with the average being between four and seven.

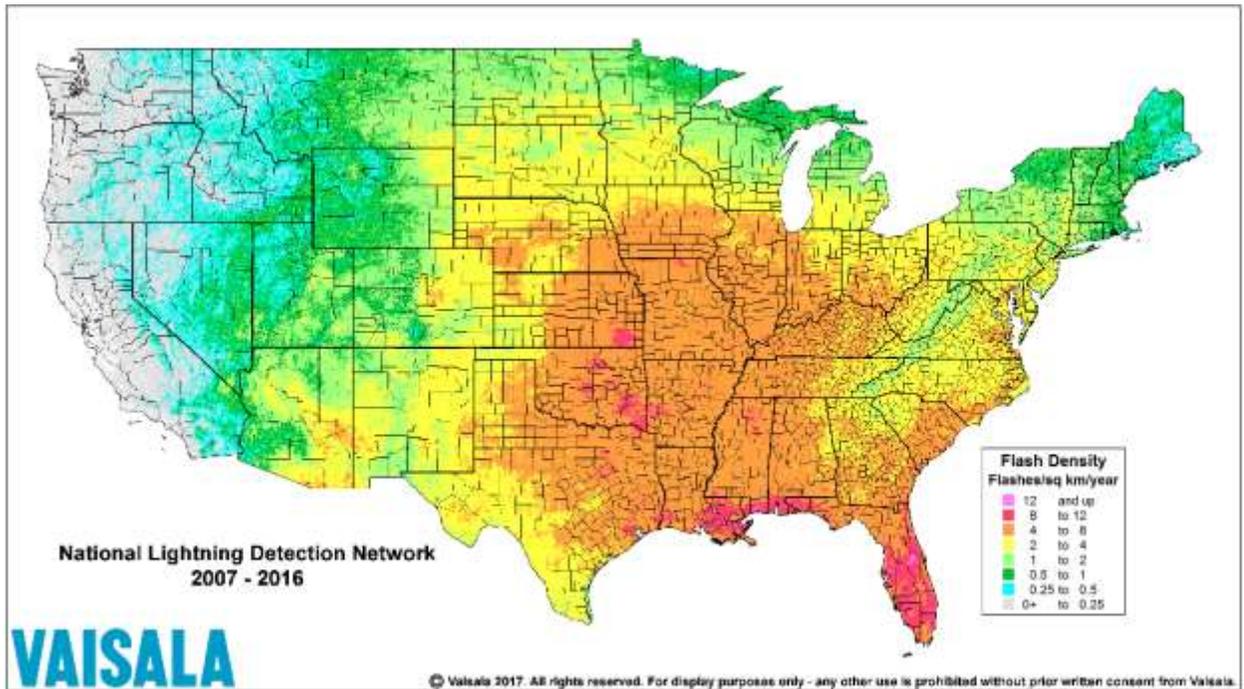
1.2.3.2. Some of the most powerful and dangerous thunderstorms occur over the United States, particularly in the Midwest and the southern states. These storms can also produce large hail and powerful tornadoes.

1.2.3.3. Thunderstorms are relatively uncommon along much of the West Coast of the United States, but they occur with greater frequency in the inland areas, particularly the

Sacramento Valley and San Joaquin Valley. Furthermore, in spring and summer, they occur nearly daily in certain areas of the Rocky Mountains.

1.2.3.4. In the Northeast, storms take on similar characteristics and patterns as the Midwest, only less frequently and severely. Probably the most thunderous region outside of the Tropics is Florida. During the summer, violent thunderstorms are an almost daily occurrence over central and southern parts of that state.

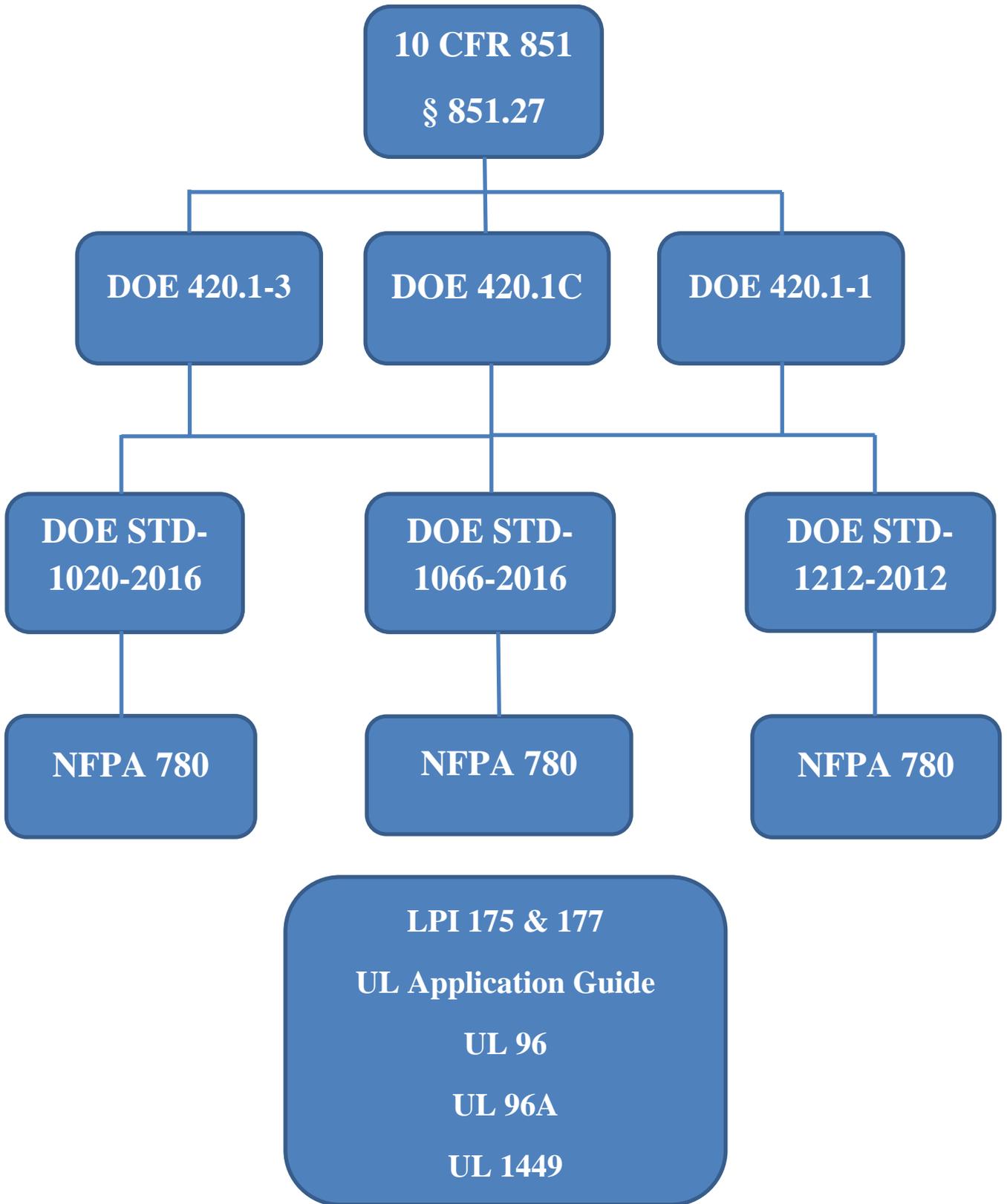
1.2.3.5. Each year, thousands of industrial, commercial, residential, and other properties are damaged or destroyed by lightning. It accounts for more than a quarter billion dollars in property damage annually in the United States. Lightning is responsible for more deaths and property loss than tornadoes and hurricanes combined, and of these violent forces of nature, lightning is the only one where protection can be economically provided.



**Figure 1.1 Lightning Flash Density for US 2007 to 2016**  
NLDN®, Vaisala

1.3 Requirements

DOE Orders and Standards Requirements Flow Chart



**1.3.1 10 CFR 851;**

**§ 851.27, Reference Sources.**

**1.3.2 DOE Order 420.1C, Facility Safety**

**1.3.3 DOE Guide 420.1-1 Nonreactor Nuclear Safety Design Guide For Use With DOE O 420.1C, Facility Safety**

**1.3.4 DOE G-420.1-3, Implementation Guide for DOE Fire Protection and Emergency Services Programs for Use with DOE O 420.1C**

**1.3.5 DOE-STD-1020-2012, DOE Standard, Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities**

**1.3.6 DOE-STD-1066, DOE Standard, Fire Protection**

**1.3.7 National Fire Protection Association (NFPA) 780, Standard for the Installation of Lightning Protection Systems**

**1.3.8 Underwriter's Laboratory (UL), Marking and Application Guide for Lightning Protection**

**1.3.9 UL 96, Lightning Protection Components**

**1.3.10 UL 96A, Installation Requirements for Lightning Protection Systems**

**1.3.11 UL 1449, Surge Protective Devices**

**1.3.12 Lightning Protection Institute (LPI), LPI-175, Standard of Practice for the Design, Installation, and Inspection of Lightning Protection Systems**

**1.3.13 LPI-177, Inspection Guide for Certified Systems**

**1.3.14 DOE-STD-1212-2012, DOE Standard, Explosives Safety**

## **CHAPTER 2**

### **LIGHTNING HAZARDS AND PROTECTION**

#### **2.1 Lightning Hazards.**

Lightning hazard to facilities and personnel can take many forms:

2.1.1. Electrical current produced by a voltage gradient resulting from a lightning flash to a facility can initiate physical damage, fires, equipment damage or injury to personnel.

2.1.2. Surface flashover or arcing of generated electrical current between conductive surfaces not in equilibrium can initiate damage directly by the heat, sparks, and molten metal generated by the arc.

2.1.3 Sideflash is an electrical spark caused by differences of potential that occurs between conductive metal bodies or between conductive metal bodies and a component of the Lightning Protection System (LPS) or earth electrode system during a lightning flash. Sideflash presents direct and indirect hazards to facilities, hazardous environments and personnel both internal and external to the facility. The direct hazard is the electrical energy transferred from the structure or its LPS to building components or personnel. Indirect hazards are the heat and the electromagnetic fields generated by the electrical energy which can cause concrete to spall or combustible materials to ignite. Electromagnetic fields could induce electrical currents on or in the building or equipment.

2.1.4. Generated arcing can cause damage or fires in electrical fixtures and equipment.

2.1.5. Lightning could initiate a fire involving combustible materials inside the facility.

2.1.6. Spalling of concrete or other surface materials generated by the heat of the current flowing through the structural components of the facility can physically damage equipment in the facility. Such spalling may also present an injury risk to personnel.

2.1.7. Lightning can affect support systems such as communication, CATV, fire protection, HVAC, and security systems.

2.1.8 Lightning can reach a structure not only by direct strike, but also indirectly by coupling to conductors or conductive utility services that penetrate the structure.

2.1.9 Lightning discharges will produce electromagnetic pulses that can be coupled onto conductors servicing the structure. These induced surges can be adequate to cause dangerous over-voltages, resulting in fires or damage to critical electrical and electronic hardware. Surge protection devices protect facilities against induced surges on power, communication, data and process control lines, and any other electrically conductive objects entering or exiting the facilities

#### **2.2 Protection.**

2.2.1 When lightning follows higher impedance paths, damage may be caused by heat and mechanical forces generated during the discharge process. Most metals, being good electrical conductors, are relatively unaffected by either heat or mechanical forces if they are of sufficient size to carry the expected magnitude of current. The metal path should be continuous and form a two-way path from each strike termination device horizontally and/or

downward to connections with ground electrodes. Use a nonferrous metal, such as copper or aluminum, as the conductor will ensure the integrity of the lightning conductor for an extended period of time.

2.2.2 Protection from lightning-induced hazards can best be achieved by a properly designed and installed LPS meeting the requirements of NFPA 780. An LPS consists of, as a minimum, strike termination devices (air terminals), low impedance paths to ground, and an earth electrode system. Additionally, the systems shall include bonding of all conductive penetrations and equipment, surge protection and sideflash protection. An LPS shall be designed and installed in accordance with the requirements of the latest edition of NFPA 780, except as modified within this document.

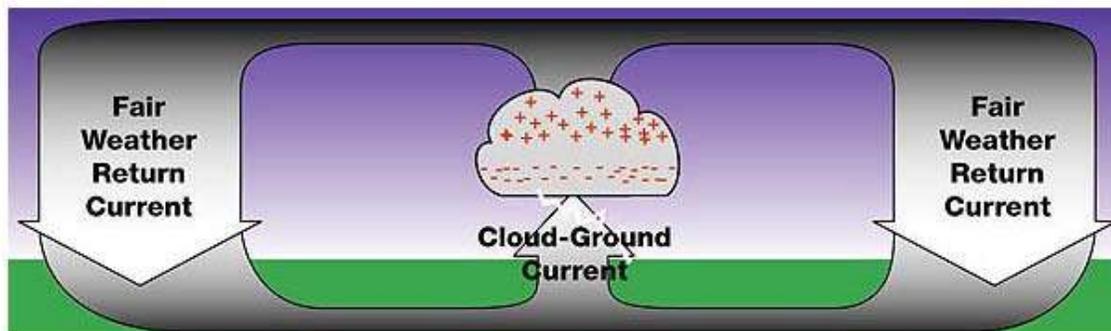
2.2.3 The Authority Having Jurisdiction (AHJ) or his designee shall approve any design variations from those specified.

## CHAPTER 3 CHARACTERISTICS OF LIGHTNING

### 3.1 General

3.1.1. Planet earth is similar to a huge battery continuously losing electrons to the atmosphere. These electrons could be lost in less than an hour unless the supply is continually replenished. It is widely agreed among physicists and scientists that the net result of thunderstorms occurring thousands of times daily around the earth is a return of electrons to earth, restoring normal magnitude of electrons at or near the surface of the earth. The rate of electron loss from earth, called the "air-earth ionic current," has been calculated to be nine microamperes for every square mile of earth's surface. Thunderstorms return electrons to earth by imposing an opposite electron potential gradient of approximately ten kilovolts per meter within a thundercloud. This feedback creates a potential difference of from ten to 100 mega volts in a single discharge between the center of a cloud and earth. These lightning discharges carry currents varying from ten to 345 kilo amperes to earth at an average rate of 100 times per second with a duration of less than one-half second per flash. Each flash consists of up to 40 separate strokes. Each stroke of lightning releases about 250 kilowatt hours of energy, enough to operate a 100-watt light bulb continuously for more than three months at the rated voltage of the bulb.

3.1.2. Figure 3.1 is a schematic of how charge balance is maintained on earth. Atmospheric electricity compares to a massive photographic flash. An electrical charge builds, a switch is closed, and electrons surge through the atmosphere, ionizing it and producing light energy. The ionized atmosphere completes the circuit.



Source: NASA/MSFC.

**Figure 3.1 Fair Weather "Circuit" Depicting Normal Potential**

3.1.3. The lightning phenomenon is defined as a transient electrical discharge with high electrical current over distances of kilometers that occurs when enough charge builds up in the atmosphere to produce electric fields that exceed the "breakdown field." Normally, lightning is associated with thunderstorms, but it can also be associated with dust storms, very large fires, and volcanoes.

3.1.4 Thunder storm clouds and the earth can act in unison to mimic a huge natural capacitor. The process of evaporation and formation of ice particles in tall cumulonimbus clouds caused water droplets, ice particles and dust to collide with each other. These collisions cause electrons to be knocked off the particles creating a charge separation within the clouds. Negative electrical charges accumulate at the base of the clouds. The base of the cloud thus acts like the negative plate of a capacitor. These charges induce positive charges to accumulate in the ground, comparable to the positive plate of a capacitor. The air between the clouds and the ground becomes the dielectric of this natural capacitor. The electrostatic field between the clouds and the ground produces ions and free electrons in the air. Eventually the difference in potential between the clouds and ground becomes so great that the air dielectric begins to break down. The ions and free electrons provide the necessary path for the leader propagation between cloud and ground, resulting in a lightning flash.

3.1.5 Scientists recognize four basic types of lightning discharges as follows;

3.1.5.1. Intra-cloud flashes (within clouds).

3.1.5.2. Inter-cloud flashes (between clouds).

3.1.5.3. Cloud-to-air flashes (between cloud and ionosphere).

3.1.5.4. Cloud-to-ground flashes (between cloud and ground):

3.1.5.4.1. Negative cloud-to-ground flashes.

3.1.5.4.2. Positive cloud-to-ground flashes.

3.1.6. Lightning discharges do not always bring electrons to earth, because positive ground-to-cloud flashes consist of low power energy transmissions from earth to small negative charge pockets in a thundercloud. Though charges may be of a different potential, magnitudes of discharge voltages and currents are approximately the same from cloud to earth, and all occur within the same discharge timeframes. Just before a lightning flash, the ground within a radius of several miles below the cloud becomes deficient in electrons. Many free electrons on the ground are repelled by the multitude of electrons in the cloud base. This results in the ground beneath the cloud base becoming more positively charged.

3.1.7. During cloud movement, the positively charged region below moves like its shadow. As the cloud charge builds, the pressure causes a chain reaction of ionized air. Ionization is the process of separating air molecules into positive and negative charges. This air, normally a good electrical insulator, becomes a good conductor and allows the cloud electrons to pierce the faulted insulation and descend this newly created ionized air path between cloud and earth. The lightning flash starts when a quantity of electrons from the cloud heads toward earth in a succession of steps, pulsing forward with an additional step every 50 microseconds, creating a faintly luminous trail called an initial or stepped leader. As the leader nears the ground, its effects create an ionized streamer that rises from earth to meet the advancing leader. When the two join, the ionized air path between cloud and earth is completed, and the leader blazes a faint trail to earth. Immediately a deluge of electrons pour from this lightning discharge channel, creating the brilliant main or return stroke that produces most of the light energy we see. The motions of the leader and the main or return stroke appear to

move in opposite directions, but lightning is not an alternating current since the transferred electrical recharge current moves back to earth.

## 3.2 Current in a Lightning Flash

3.2.1. Rather than describe the magnitude of an “average” lightning stroke, it is easier to give ranges for the various parameters. The important part of a lightning flash with regard to the resulting damage is the return stroke. The current in this return stroke ranges from about 2,000 amperes to about 400,000 amperes. Its distribution of values is a “log-normal” distribution, where:

3.2.1.1. one percent of strokes exceed 400,000 amperes.

3.2.1.2. ten percent of strokes exceed 80,000 amperes.

3.2.1.3. fifty percent of strokes exceed 28,000 amperes.

3.2.1.4. ninety percent of strokes exceed 8,000 amperes.

3.2.1.5. ninety nine percent of strokes exceed 3,000 amperes.

3.2.2. The current in most ground flashes emanates from negatively charged cells in the thundercloud and the resulting flash current is a negative flow. Occasionally, positive strokes occur. Regardless of the polarity, the current flow is unidirectional for each segment of potential degradation. Typical rise time and decay time for a negative flash are less than 10 milliseconds (ms) and 100 ms, respectively. Rise time for a positive flash is greater. Flashes are typically comprised of multiple strokes that, individually, conform to the description for a single stroke, but may range from 50 to 100 ms apart.

3.2.3. For the purposes of LPS design, the following values of peak lightning current ( $I_{max}$ ) and rate of rise of lightning current ( $dI/dt$ ) are considered the most severe:

3.2.3.1.  $I_{max} = 200 \text{ kA}$

3.2.3.2.  $(dI/dt)_{max} = 400 \text{ kA}/\mu\text{s}$

## 3.3 Voltage.

3.3.1 Before the flash, the potential of the charge cell may be roughly estimated by assuming the charge ( $Q$ ) in the cell at 100 coulombs (C) and the radius of an equivalent spherical cell to be 1 km. The capacitance ( $C$ ) of the cell is about  $10^{-7}$  Farad ( $3.6 \times 10^{-3} \text{C}$ ) and, from  $Q = CV$ , the potential,  $V$ , is estimated to be  $10^9$  volts (V). Based on these estimations, cloud potential may be more than 100 MV. Although the return stroke is the most important pulse of a lightning stroke, it is necessary to know something of the process that precedes it in order to understand why tall structures are more vulnerable.

3.3.2 The lightning stroke is preceded by a downward leader that makes a step-by-step descent of some tens of feet at a time from the cloud. When the last step brings the tip of the leader sufficiently close to earth, an upward leader leaves the earth to join the tip of the downward leader, establishing a conductive channel for the main current to flow. The initiation of this upward leader depends on a critical magnetic field being exceeded at the earth emission point and, therefore, is a function of the charge deposited by the down-coming

leader and any enhancement of the field caused by the geometry of the earth, structures, and vegetation. The length of the upward leader will be longer for greater charges, so high current flashes are more likely to start from tall structures/features for which the field enhancement is comparatively high.

### 3.4 Effects of a Lightning Strike on an LPS

3.4.1. **Electrical Effects;** As current is discharged through the resistance of the earth electrode of the LPS, it produces a resistive voltage drop that may momentarily raise the potential of the protection system to a high value relative to true earth. It may also produce around the earth electrode a high potential gradient dangerous to people and animals. In the same general manner, the inductance of the protection system must be considered because of the steep leading edge of a typical lightning pulse. The resulting voltage drop is the arithmetic sum of the resistive and inductive voltage components.

3.4.2. **Sidelflash;** Because of the short rise time and significant magnitude of current resulting from a lightning flash, the LPS can be considered to be at a uniform potential momentarily. Other metal objects in or on the building, that are not bonded to the LPS conductors, will have a lower electrical potential than the LPS components. This high potential difference during current flow poses a risk of electrical flashover from any part of the LPS to any adjacent metal located on or inside the structure. This flashover is called sidelflash, and may be a source for current discharge between LPS components and structural elements such as pipes, wiring, or structural metal resulting in risk to the occupants, equipment, and the fabric of the structure. This sidelflash can be dangerous whether it occurs inside or outside of the facility.

3.4.3. **Thermal Effects;** For purposes of lightning protection, the thermal effect of a lightning discharge is confined to the temperature rise of the conductor through which the current passes. Although the magnitude of current is high, its duration is short and the thermal effect on the protection system is usually negligible. However, this ignores the fusing or welding effects on damaged conductors or those that were inadequate on initial installation. In general, the cross-sectional area of an LPS conductor is chosen primarily to satisfy the mechanical strength requirements and sufficient to limit the rise in temperature to 1.8 °F [1 °C] during the entire discharge. For example, with a copper conductor of 1.97-square inch (in<sup>2</sup>) [50-square millimeter (mm<sup>2</sup>)] cross section, a severe stroke of 100 kA with duration of 100 ms dissipates less than 400 joules per meter of conductor, resulting in a temperature rise of about 1.8 °F [1 °C]. Likewise, an equivalent steel conductor will have a temperature rise of about 18 °F [10 °C].

3.4.4. **Mechanical Effects;** Whether a high current magnitude is discharged along parallel conductors within close proximity or along a single conductor with sharp bends, considerable mechanical forces are produced, making secure mechanical fittings essential. A second mechanical effect exerted by a lightning flash is caused by the sudden rise of 30,000 Kelvin (53,540 °F; 29,727 °C) in the air temperature, resulting in an explosive expansion of the adjacent air in the channel along which the charge is propagated. Because conductivity of the metal is replaced by that of the arc path, energy increases about one hundred-fold. A peak power of about 100 megawatts per meter can be reached in the return stroke and the shock wave close to this stroke can dislodge components of the structure or LPS.

## CHAPTER 4 DESIGN BASIS

### 4.1 General Criteria

4.1.1 Lightning protection system design consists of the use of strike termination means, low impedance paths to ground, and earth electrode systems, coupled with bonding of all conductive penetrations into the protected area, surge suppression, and sideflash protection. Except as modified in this document, LPS shall be designed in accordance with NFPA 780. The AHJ or their designee shall approve design variations (variances, exceptions, etc.) from those specified in NFPA 780 or this document. Figure 4.1 illustrates a typical industrial LPS and its components.

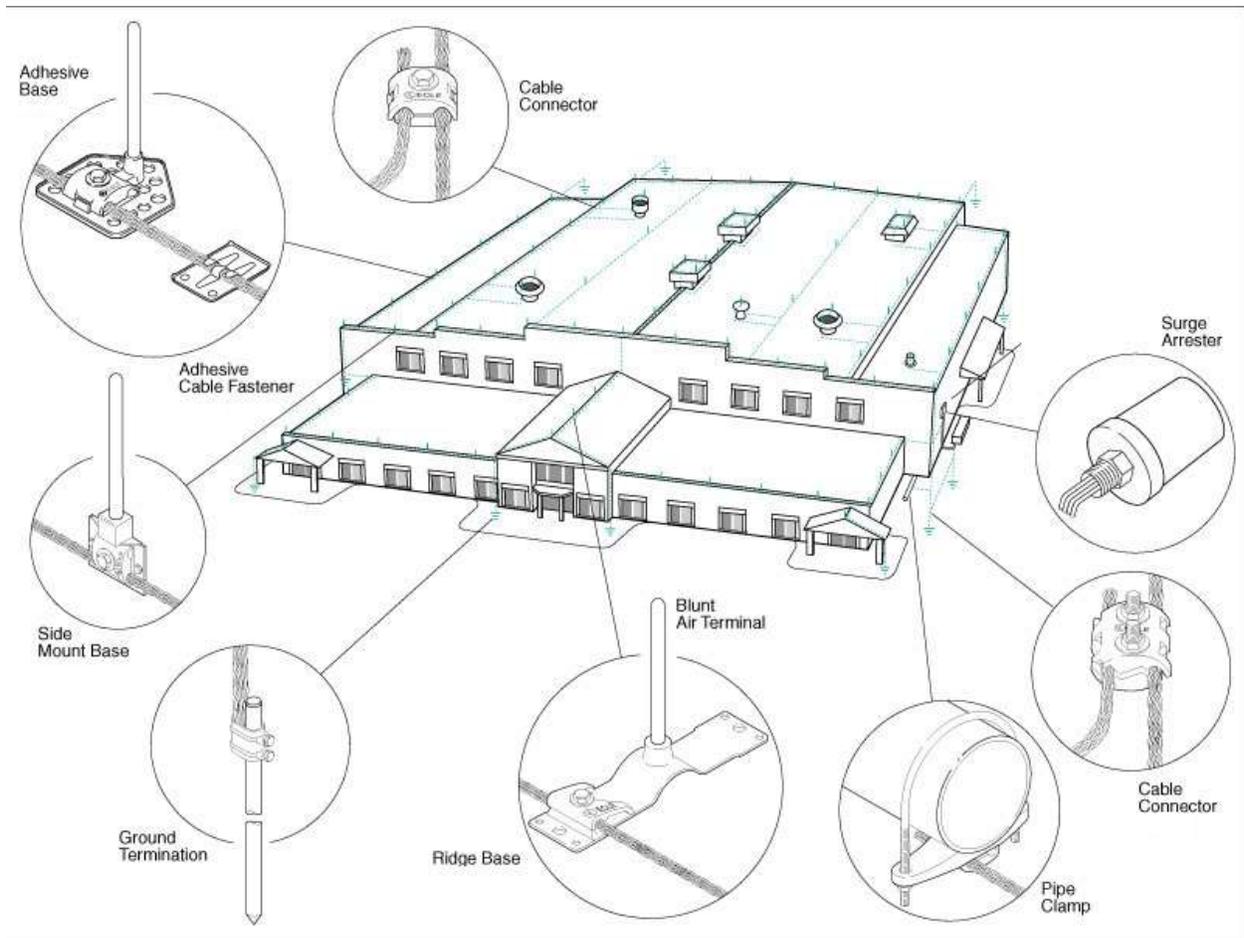


Figure 4.1

## 4.2 Risk Assessment/Need for a LPS

4.2.1 Lightning risk assessments should be performed, in accordance with Annex L of NFPA 780, for DOE structures and facilities. Annex L provides two types of assessments; a simplified or detailed assessment. The choice of whether the simplified or detailed assessment shall be based on the complexity, value, and occupancy of the facility. In many cases the simplified assessment is all that will be required. Facilities containing nuclear or hazardous materials or processes should be evaluated by performing a detailed risk assessment. Mission critical facilities should also be evaluated by performing a detailed risk assessment. Per NFPA 780 Annex L, the following information needs to be acquired and addressed during any risk assessment.

### 4.2.2. **Building use and processes**

4.2.2.1 General Office and Administrative

4.2.2.2 Warehousing and maintenance

4.2.2.3 Nuclear materials

4.2.2.4 Hazardous Materials

4.2.2.5 Mission Critical

### 4.2.3 **Number of personnel in the facility**

4.2.3.1 Occupancy numbers and time of day

4.2.3.2 Percentage of time personnel exposed

4.2.3.3 Loss of life potential

4.2.4 **Flash Density Data** – Generic from 780 or specific to site

### 4.2.5 **Utilities**

4.2.5.1 Electric

4.2.5.2 Communication Systems

4.2.5.3 Water

4.2.5.4 Gases

### 4.2.6 **Surge Suppression**

### 4.2.7 **Environment**

4.2.7.1 Location

4.2.7.2 Surrounding buildings

4.2.7.3 Building interconnections

4.2.7.4 Terrain

4.2.8 **Risk Assessment Spreadsheet** – Courtesy of Brookhaven National Laboratory, The Spreadsheet is posted on the EFCOG Electrical Safety Task Group Website (password protected).

### 4.3 Design Requirements

4.3.1 This section summarizes the minimum requirements for design of LPS for DOE facilities. Only LPS described in this chapter shall be used. Use of non-conventional LPS, such as streamer emission and charge dissipation systems shall not be allowed.

4.3.2 Lightning protection system design consists of the use of strike termination means, low impedance paths to ground, and earth electrode systems, coupled with bonding of all conductive penetrations into the protected area, surge suppression, and sideflash protection. Except as modified in this document, LPS shall be designed in accordance with NFPA 780.

4.3.3 It is recommended that installations be designed and installed by qualified, trained, personnel. The Lightning Protection Institute (LPI) training requirements for installers requires a series of tests consisting of exams to reach the level of Journeyman Installer, Master Installer certification, and Master Installer/Designer. UL training for installers requires a UL University instructor-led course or a private in-house training session.

#### 4.3.4 Lightning Protection Subsystems

4.3.4.1 An approved LPS consists of the following subsystems:

4.3.4.1.1 A strike termination device to intercept the direct attachment of a lightning flash and connects it to a path to ground. A strike termination device may include metal masts, air terminals, overhead wires (catenary) or permanent metal parts of a building.

4.3.4.1.2 Roof and down-conductors to interconnect the strike termination devices and form two paths from each strike termination device to the earth electrode system (e.g., heavy metallic cables, metallic building structural members).

4.3.4.1.3 An earth electrode system to transfer lightning current to the earth. The earth electrode system is connected to the down conductor and is in direct contact with the earth.

4.3.4.1.4 Surge protection devices (SPD) to limit harmful energy due to lightning entering a structure via power conductive communication lines and initiating any damage, personnel injury, or fire. A SPD attenuates, suppresses or diverts lightning induced electrical energy to the earth electrode system.

#### 4.3.5 Lightning Protection Systems Types

4.3.5.1 An Integral Air Terminal System is one that has strike termination devices mounted on the structure to be protected. These strike termination devices are connected to the earth electrode system via down conductors. Metallic structural members can serve as parts of the LPS. Air terminals should be designed and installed per the requirements on NFPA 780, Chapters 4 through 7.

4.3.5.2 A Mast System consists of one or more poles with a strike termination device connected to an earth electrode system by down conductors, per the requirements of NFPA 780, Chapters 4 and 7.

4.3.5.3 A Catenary System consists of wires (cables) stretched between the tops of two or more masts per the requirements of NFPA 780, Chapters 4 and 7.

#### 4.3.6 **Components of Strike Termination System**

4.3.6.1 An Air Terminal is the component of an LPS used to intercept lightning strikes. Air terminals include vertical spikes attached to the structure, overhead wires (as used with catenary systems) or grids. Air Terminals shall be UL Listed. Air terminal installation shall comply with NFPA 780.

4.3.6.2 Conductors provide low impedance paths from air terminals to the earth electrode system. Conductors shall comply with the requirements of NFPA 780, except, nuclear facility conductors and components shall meet Minimum Class II Material Requirements.

#### 4.3.7 **Down Conductors**

4.3.7.1 The number of down-conductors shall comply with NFPA 780

#### 4.3.8 **Grounding**

4.3.8.1 A grounding electrode system provides a single point of zero ground reference and a single point for system interconnection.

4.3.8.2 Lightning protection systems require an earth electrode (ground) system to dissipate the electrical energy of a lightning strike to the earth.

4.3.8.3 The earth electrode systems may consist of single ground electrodes at each down-conductor, multiple ground electrodes, concrete-encased electrodes, ground ring electrodes, radials, plates, or any combination of the above.

4.3.8.4 The resistance of lightning grounding systems should not exceed 25 ohms unless approved by the AHJ. A low resistance is preferred.

#### 4.3.9 **Bonding**

4.3.9.1 Bonding of metallic bodies and lightning protection ground systems is required to ensure that voltage potentials produced by lightning currents are near-equal throughout the structure and no potential differences exist that would be sufficient to produce a sideflash inside or on the surface of the protected structure. Requirements for bonding shall comply with NFPA 780.

4.3.9.2 Methods of bonding include mechanical, compression and thermal connections.

4.3.9.3 Bond all metal bodies within six feet of lightning protection components. If NFPA 780 bonding calculations allow a greater distance then use these distances.

4.3.9.3 Other metal masses that are integrated into the structure of the building (e.g., ventilators, steel doors, metal doorframes, steel reinforcing bars, sprinkler systems, utilities, communications systems, etc.) shall be bonded to the nearest structural member or LPS component that is integrally bonded to the earth electrode system.

4.3.9.4 Lightning protection system bonds should be as short and as direct as reasonably achievable.

4.3.9.5 Do not paint or coat LPS bonds and conductors.

4.3.9.6 Bond resistance should be less than one ohm unless approved by the AHJ.

#### 4.3.10 **Surge Suppression for Incoming Conductors**

4.3.10.1 Surge protection devices shall be provided in accordance with NFPA 780 as part of all power, communication, security, data, and process control conductors that enter or exit a facility.

4.3.10.2 Install SPDs on the supply side of the main service disconnect.

4.3.10.3 Surge protection shall be located between the respective conductor and the structure ground as close as possible to the point where the conductor penetrates the LPS zone of protection or the structure.

#### 4.3.11 **Sideflash (Arcing) Protection**

4.3.11.1 To prevent unintentional damage or injury by either the direct or the indirect effects of sideflash, protection should be provided for equipment and personnel unless analysis of operations shows no potential. Sideflashes can occur and cause damage to equipment of personnel both inside of and outside of the protected structure.

4.3.11.2 Separating components and equipment from the LPS or conductive penetrations of the structures, provides protection against consequences of sideflash.

4.3.11.3 NFPA 780 shall be used to determine sideflash protection for all structures with LPS.

#### 4.3.12 **Maintenance Considerations**

4.3.12.1 All LPS designed and installed on DOE facilities shall consider future accessibility for testing, maintenance, and inspection (TM&I). Maintenance and testing personnel will need to be able to see and touch the LPS component during TM&I activities.

4.3.12.2 All lightning protection components shall be visible so that future continuity testing of the components is kept to a minimum. Concealed components require periodic continuity testing to ensure they do not degrade over time. Visible components can eliminate this testing requirement.

## **CHAPTER 5**

### **TESTING, MAINTENANCE AND INSPECTION**

#### **5.1 Inspection Overview**

5.1.1 The LPS should be certified and or inspected by a competent and qualified individual, acceptable to the AHJ after initial installation. These inspections can be done either by:

5.1.1.1 Lightning Protection Institute (LPI) or Underwriter's Laboratory (UL) who issue an LPI Master Installation Certificate or a UL Master Label.

5.1.1.2 A LPI or UL trained and certified inspector employed or contracted by the site contractor.

5.1.1.3 Other independent organization approved by the AHJ

5.1.2 LPI - Inspection Program will provide on-site lightning protection system inspection services, follow-up inspection reports and issue certification for systems that comply with the following national safety standards:

5.1.2.1 UL 96A, Installation Requirements for Lightning Protection Systems

5.1.2.2 NFPA 780, Standard for the Installation of Lightning Protection Systems

5.1.2.3 LPI 175 Standard of Practice for the Design, Installation and Inspection of Lightning Protection Systems

5.1.2.4 LPI-177 Inspection Guide for Certified systems

5.1.3 UL's Lightning Protection Inspection Certificate Service offers independent, third party inspection of lightning protection systems, and verifies that these systems comply with the below national standards.

5.1.3.1 UL 96A, Installation Requirements for Lightning Protection Systems

5.1.3.2 NFPA 780, Standard for the Installation of Lightning Protection Systems

#### **5.2 Inspection Criteria**

5.2.1 The minimum inspection requirements shall be as outlined in Annex D of NFPA 780. Visual inspections should be performed to verify the following:

5.2.1.1 The system is in good repair.

5.2.1.2 There are no loose connections that might result in high-resistance connections.

5.2.1.3 No part of the system has been weakened by corrosions, vibration, or an obvious lightning strike.

5.2.1.4 All down conductors and grounding electrodes are intact (non-severed).

5.2.1.5 All conductors and system components are fastened securely to their mounting surfaces and are protected against accidental mechanical displacement.

5.2.1.6 There have been no additions or alterations to the protected structure that would require additional protection against lightning strikes or surges.

5.2.1.7 There is no indication of damage to surge protection devices.

## 5.2.2 **Recommended TM&I Frequencies**

5.2.2.1 An annual visual inspection should be performed on all visible LPS components per the requirements of NFPA 780 Annex D.

5.2.2.2 A visual inspection should be performed after a known or suspected lightning strike or other natural phenomena that could have damaged the LPS..

5.2.2.3 The annual visual inspection should be scheduled to precede the normal lightning high frequency period for the site, if practical.

5.2.2.4 A complete inspection of the LPS should be performed on 36 to 60 month frequency as practical for the site. The frequency shall be approved by the AHJ.

5.2.2.4.1 This inspection shall include the visual inspection as well as a ground resistance test performed on all, or a specified number, of the ground electrode connections, as approved by the AHJ.

5.2.2.4.2 This inspection shall include continuity testing of any components and conductors that are not located so that they can be visually inspected.

5.2.2.4.3 Some facilities may have frequency requirement contained in their Safety Basis Documents (TSR/DSA). These requirements shall take precedence over the frequencies contained in this and all other governing documents.

5.2.2.4.4 Extensions may be approved by the AHJ.

5.2.3 TM&I activities should be conducted per the requirements of AHJ approved procedures or work instructions. Appendix A provides a sample TM&I Work Instruction.

## 5.3 **Acceptance Criteria**

5.3.1 **General Criteria** – The LPS shall be maintained equal to its original installed condition. Deficient conditions identified by the TM&I inspections shall be corrected so that the system will function as intended to protect the structure, installed equipment and processes, and personnel.

5.3.2 **Initial Inspection** – After installation the LPS shall be inspected to ensure the system complies with the design drawings, specifications and NFPA 780 requirements as approved by the AHJ.

5.3.3 When conducting required follow up inspections on building LPS, maintenance inspectors shall utilize the following categories/classifications for reporting any identified LPS deficiencies.

**5.3.3.1 Level 1 (Non-Functional): Personnel and Sensitive Operations protection,** Deficiencies that significantly compromise the ability of the LPS to effectively protect facility occupants, special nuclear material or hazardous contents from a lightning related event. Examples may include but are not limited to;

5.3.3.1.1 Missing, improperly spaced, or fallen air terminals (usually two or more adjacent air terminals).

5.3.3.1.2 Disconnected, broken, or damaged conductors or down leads.

5.3.3.1.3 Disconnected, broken, or damaged connections between the LPS and the associated ground electrode system.

5.3.3.1.4 Broken or missing bonding connections (25% or greater).

5.3.3.1.5 Damage to or failure of surge protection devices (2 or more for the facility).

**5.3.3.1.7 A Level 1 deficiency shall be repaired within one week.**

**5.3.3.2 Level 2 (Impaired but Functional): Equipment Protection,** Deficiencies that leave rooftop mounted equipment and high value asset equipment within the building subject to damage from a lightning related event. Examples may include but are not limited to;

5.3.3.2.1 Existing rooftop mounted equipment that is not bonded.

5.3.3.2.2 SPDs not installed (electrical, communications data, etc.).

5.3.3.2.3 Building components subject to sideflash that are not properly bonded (door & window frames, roof flashings, structural supports, bollards, ladders etc.).

5.3.3.2.4 New rooftop equipment not bonded to LPS.

**5.3.3.2.6 A Level 2 deficiency shall be repaired within 30 day or as acceptable to the AHJ.**

**5.3.3.3 Level 3: Component Protection and Testing,** Existing equipment and metal structures that are constructed of materials that are less than 3/16" in thickness and are not properly bonded with required conductors and/or terminals. Ground resistance testing that is not completed due to the inability to isolate the system or inability to meet the distance requirements of NFPA-780 Annex-E. Examples may include but are not limited to;

5.3.3.3.1 Exhaust fan housings, ventilation stacks, other metal components less than 3/16" thick which require separate bonding and air terminals.

5.3.3.3.2 Improper height or support of air terminals.

Energy Facilities Contractor's Group (EFCOG)

5.3.3.3.3 Equipment with less than two paths to ground.

5.3.3.3.4 Conductor bend radius less than 8".

5.3.3.3.5 Conductors supported at lengths greater than 3ft.

**5.3.3.3.7 A Level 3 deficiency shall be repaired as soon as practical and acceptable to the AHJ.**

5.3.4 Consult with the LPS Subject Matter Experts and the AHJ to ensure these priority classifications are acceptable for individual sites.

## Chapter 6 Personnel Safety

### 6.1 General

6.1.1 Lightning is the second-leading weather killer in the United States. According the National Oceanic & Atmospheric Administrations' (NOAA) National Weather Service (NWS), lightning strikes kill an average of 73 people and injure another 300 persons each year in the United States.

6.1.2 Most of these tragedies could be avoided with proper planning and simple precautions. Many victims say they were caught outside and could not get to a safe location. Other victims waited too long before seeking shelter. By heading to a safe place about five to ten minutes earlier, they could have avoided being struck by lightning. Some victims say they went back outside too early. Staying inside the safe location just a few more minutes may have saved them from this encounter. Other victims were talking on a corded telephone or using electrical equipment or in contact with plumbing system. Just avoiding physical contact with conductive components could prevent injury from the effects of a lightning strike.

6.1.3 High winds, rainfall, and a darkening cloud cover are the warning signs for possible cloud-to-ground lightning strikes. While many lightning casualties happen at the beginning of an approaching storm, more than 50 percent of lightning deaths occur after the thunderstorm has passed. The lightning threat diminishes after the last sound of thunder, but may persist for more than 30 minutes. When thunderstorms are in the area, but not overhead, the lightning threat still exists when skies are clear.

6.1.4 While nothing offers absolute safety from lightning, some actions can greatly reduce risks to workers. If a storm is approaching, avoid being in, or near, high places, open fields, isolated trees, unprotected gazebos, rain or picnic shelters, communications towers, flagpoles, light poles, metal fences, convertible vehicles, golf carts and water. If you can see lightning or hear thunder, the risk is already present. Louder or more frequent thunder means lightning activity is approaching, increasing the risk for lightning injury or death. If the time delay between seeing the lightning and hearing the thunder is less than 30 seconds, you are in danger.

6.1.5 No place is absolutely safe from a lightning threat, however, some places are safer than others. Large enclosed structures are safer than smaller, or open, structures. When inside during a thunderstorm, avoid using a corded telephone, taking a shower, washing your hands, doing dishes, or having contact with conductive surfaces, including metal doors, window frames, wiring and plumbing. Generally, enclosed metal vehicles, with the windows rolled up, provide good shelter from lightning.

### 6.2 Planning for Personnel Warning

6.2.1 At sites where conditions may exist and subject workers to risk of lightning strikes, an action plan, policy or procedures should be considered to address personal safety during lightning activity. The following elements should be considered in these plans or procedures:

- 6.2.2 Monitoring Systems
- 6.2.3 When work activities should be suspended and workers notified
- 6.2.4 Employee responsibilities and education on lightning safety guidelines
- 6.2.5 Safe evacuation locations
- 6.2.6 Reassess the hazard and when to resume work
- 6.2.7 Emergency procedures and telephone numbers in case a person is struck by lightning

### **6.3 General Guidance for Outdoor Workers**

6.3.1 Personnel who work outdoors in open spaces, on or near tall objects, with explosives or with conductive materials such as metal, generally have a greater risk to lightning exposure. For example, heavy equipment operators, power utility workers, telecommunication workers and other field labor workers are at greater risk than others. Even though no lightning safety guidelines will ensure 100% safety for a worker, the following steps will help minimize risk of a lightning casualty or strike to an individual.

6.3.1.1 Know the weather forecast beforehand and discuss in the daily pre-job briefing. Understand and comply with a site warning system if one is used.

6.3.1.2 Stay attentive to the skies for clues that thunderstorms may be developing, especially for increasing, thickening, and darkening clouds. Seek proper shelter as appropriate. Use the 30-30 rule to know when to seek proper shelter. When you see lightning, count the time until you hear thunder. If time is 30 seconds or less, seek shelter. Wait 30 minutes or more after hearing the last thunder before leaving shelter.

6.3.1.3 The best shelter is generally a large fully enclosed substantially constructed building that contains electrical wiring and plumbing in the walls. Once inside, stay away from the conducting paths to the outside. Generally buildings that have exposed openings are not considered safe (picnic shelters, canopies, metal sheds, etc.)

6.3.1.4 If you can't get to a building, a vehicle with a solid metal or hard topped roof and metal sides is a second choice. Safe vehicles include hard-topped cars, minivans, buses, trucks, etc. Unsafe vehicles include convertibles, golf carts, riding mowers, open cab construction equipment and boats. Avoid contact with any conducting paths going outside and keep the windows closed.

6.3.2 If you can't get to proper shelter or a vehicle, avoid locations that put at an increased risk to lightning strike. The following are examples:

- 6.3.2.1 Higher elevations
- 6.3.2.2 Wide open area such as fields and areas and parking lots
- 6.3.2.3 Tall isolated objects such as trees, towers, and poles

6.3.2.4 Water

6.3.2.5 Near or in contact with metal fences or other metal structures that can conduct electricity, including metal scaffolding and equipment

6.3.2.6 Large equipment such as bulldozers, cranes, backhoes, track loaders and tractors

6.3.2.7 Tops of buildings

6.3.3 If caught in an exposed area with no shelter available, seek depressed areas or dense woods (but not isolated trees). Crouch as low as possible and kneel on ground while maintaining feet together. Keep as low as possible but do not place hands on ground so that risk of step potential hazard is minimized. If near a tree or other high structure, move away while shuffling feet keeping constant contact with the ground.

## **6.4 General Guidance for Safe Shelters and Indoors**

6.4.1 Lightning can enter a building or shelter through a direct strike, electrical wires or pipes that enter the structure or through ground. Once in a structure, the lightning can travel through the electrical, phone, plumbing, and radio/television reception systems. Lightning can also travel through any metal wires or reinforcement bars in concrete walls or flooring. Some additional guidelines to reduce risk of lightning strike or injury to employees located in safe shelters or indoors are:

6.4.1.1 Avoid using a cord type telephone. Cordless and cell type telephones are safe to use.

6.4.1.2 Avoid taking a shower, washing hands, doing dishes or any contact with water.

6.4.1.3 Avoid having contact with a conductive surface including metal doors, window frames, electrical wiring and plumbing

6.4.1.4 Stay away from doors and windows.

6.4.1.5 Avoid using computers or other equipment that is connected to the electrical system.

6.4.1.6 Stay inside until 30 minutes after you hear the last clap of thunder or until an announcement is given

## **6.5 Guidance for Organized Outdoor Events**

6.5.1 An action plan should be discussed for large organized outdoor events that may be subject to risk of lightning. The event coordinator should designate a responsible person(s) to monitor the weather to initiate the evacuation process when required.

6.5.2 Portable weather radios will provide a good source of up-to-date weather information. The portable battery powered tone-alert NOAA Weather Radio will allow you to monitor any short-term forecasts for changing weather conditions. The tone-alert feature can automatically alert you when the NWS issues a severe thunderstorm watch or warning.

6.5.3 Safe sites should be identified beforehand along with a means to route people to those locations. Buses may serve as an excellent shelter.

6.5.4 Consider including lightning warning and safety information in programs and flyers.

## **6.6 First Aid for Lightning Victims**

6.6.1 Most lightning victims survive their encounter with lightning, if timely medical treatment is administered. It is safe to touch victims and provide medical treatment since individuals that are struck do not carry a charge as some have been led to believe. Call 911 immediately if an individual is struck. If the victim has no pulse, begin cardiac compressions or use an automated external defibrillator (AED if available) until medical personnel can arrive.

6.6.2 If you are still in an active thunderstorm with risk to yourself, consider moving the victim and yourself to a safer location

## REFERENCES

### **Department of Energy (DOE)**

10CFR851, Worker Safety and Health Program

DOE Order 420.1C, Facility Safety

DOE G 420.1-1, Non Reactor Nuclear Safety Design Guide for Use with DOE O 420.1C

DOE G 420.1-3, Implementation Guide for DOE Fire Protection and Emergency Service Programs for Use with DOE O 420.1C

DOE-STD-1020, DOE Standard, Natural Phenomena Hazards Analysis and Design Criteria for DOE Facilities

DOE-STD-1066, DOE Standard, Fire Protection

### **Department of Defense (DOD)**

DDESB – TP22, Lightning Protection for Explosives Facilities, Department of Defense Explosives Safety Board

### **Lightning Protection Institute (LPI)**

LPI 175, Standard of Practice for the DESIGN – INSTALLATION – INSPECTION, of Lightning Protection Systems

LPI-177, Inspection Guide for Certified Systems

### **National Fire Protection Association (NFPA)**

NFPA 70<sup>®</sup>, National Electrical Code<sup>®</sup>

NFPA 780, Standard for the Installation of Lightning Protection Systems, including Annex D, E, G, L, and M

### **Underwriter's Laboratory (UL)**

UL, Marking and Application Guide for Lightning Protection

UL 96, Lightning Protection components

UL 96A, Installation Requirements for Lightning Protection Systems

UL 1449, Surge Protective Devices

### **National Oceanic & Atmospheric Administration (NOAA)**

National Weather Service (NWS), Lightning Safety Website,  
<http://www.lightningsafety.noaa.gov/links.htm>

### **Vaisala**

National Lightning Detection Network (NLDN)

## Appendix B

### Recommended Work Steps for Inspection of Facility Lightning Protection System

#### 1.0 Prerequisites

Obtain the appropriate drawings showing the lightning protection components and installation for use during inspection. (This may be engineering installation drawings, facility prepared sketches, and/or engineering analyses indicating the components found on an existing facility that does not have engineering drawings indicating the installed components).

Obtain safety equipment and tools required to complete the inspection. This should include small wrenches to tighten loose connections, fall protection equipment as required for roof top work, lifts and etc.

Obtain reference materials as necessary.

Review previous inspection records and any findings and corrective actions as necessary to ensure that deficiencies have been corrected.

Calibrated test instruments as required for ground resistance and/or continuity testing.

Individual inspections steps may be performed concurrently.

#### 2.0 Annual Inspection Criteria

##### 2.1 Visually inspect that the System is in Good Repair;

- *Air terminals are in the vertical position*
- *Verify no broken conductors*
- *Ensure all LPS components are present*
- *Visually inspect bonding jumpers to sanitary water lines, fire protection risers, and ground electrode system*
- *Verify components on roof stacks and other components*

##### 2.2 Visually inspect for loose connection or high resistance joints

- *Air terminal bases*
- *Bonding jumpers & connections*
- *Cross connected cables connectors*
- *Tighten loose connection, splices, and bolts as necessary*

##### 2.3 Visually inspect for components and joints weakened by corrosion or vibration

- *Air terminal bases*
- *Any bi-metallic connections*

## Energy Facilities Contractor's Group (EFCOG)

- *Cable connections and cables*
- *Verify firm attachment to roof and other surfaces – 36-in maximum spacing on fasteners*
- *Verify attachment to roof stacks and components – 36-in maximum spacing on fasteners*
- *Tighten loose connection, splices, and bolts as necessary*

2.4 Visually inspect to ensure that all down conductors and grounding electrodes are intact

- *Verify down conductors are firmly attached to building walls or steel – 36-in maximum spacing on fasteners*
- *Verify no broken or frayed conductors*
- *Inspect guards on down conductors to ensure integrity – 6-ft minimum above ground surface*
- *If visible inspect ground electrode connections*
- *Tighten loose connection, splices, and bolts as necessary*

2.5 Visually inspect all conductors and components to ensure that they are securely fastened to their mounting surface

- *Verify Air terminals are firmly connected their bases*
- *Verify roof and structure attachments are adequate – 36-in maximum spacing on fasteners*
- *Tighten loose connection, splices, and bolts*

2.6 Visually inspect that there are no additions or alterations to the structure that would require additional protection

- *Compare to system drawings and/or component listing*

2.7 Visually inspect surge protection devices for indication of damage or overvoltage to devices

- *Inspect for damage to the devices*
- *Verify indicator lights are on and in correct sequence*

2.8 Visually inspect and compare to referenced drawings to ensure that the system complies with NFPA 780 requirements

### **3.0 Testing Criteria**

3.1 Test to verify continuity of those components of the system that are concealed (built in) and are not available for visual inspection

- *Perform continuity testing on a representative sample of concealed building LPS components*

Energy Facilities Contractor's Group (EFCOG)

3.2 Perform a ground resistance test of the grounding electrode system and any individual electrodes that are accessible or visible to test

- *Perform fall of potential ground (three point) test at each test point*
- *Use visible down conductors at building exterior as necessary*
- *Use of a clamp on resistance meter shall be approved by the AHJ prior to use.*

3.3 Perform continuity testing to determine that suitable equipotential bonding has been established for any new services (utility, communication, fire protection, power, CCTV, etc.) or construction that has been added to the structure since the last inspection