A.4.13.2.4 Minimal benefit is gained from the second ground rod if placed closer than the sum of the driven depth of both rods.

N **A.4.13.3.2** Field experience has demonstrated that a copper conductor could experience accelerated corrosion at the point where the copper conductor exits the concrete. Concrete and soil composition could have a direct impact on the amount of corrosion, if any. Investigation of existing installations at the proposed site or chemical analysis of the concrete and soil composition would provide a basis to determine if additional corrosion protection is warranted. Each installation should be evaluated to determine the need for any additional corrosion protection. Tinned copper conductors or installation of a nonmetallic sleeve over the conductor where the conductor exits the concrete are two methods that could mitigate corrosion. The nonmetallic sleeve should extend 6 in. (150 mm) on each side of the transition from concrete to soil. See Sections 4.2 and 4.3 for additional requirements.

A.4.13.5 Augmentation of the grounding system specified in 4.13.5 and 4.13.8.2 by the use of one or more radial conductors is recommended. Radial conductors should be sized in accordance with the requirements for main conductors and installed in accordance with 4.13.8.1.

A.4.13.6 The 2 ft^2 (0.18 m^2) surface area requirement can be accomplished by using a 1 ft^2 (0.09 m^2) plate with both sides in contact with the earth.

A.4.13.8.1 For those instances in which it is necessary to install the grounding conductor directly on bedrock, it is recommended that main conductor solid strips be utilized. If there are locations along the length of the radial conductor in which there is sufficient soil available for the installation of an earth electrode, the installation of an additional earth electrode is encouraged. When a ground ring electrode is used in an application with insufficient soil cover, radial(s) should be considered to supplement the ground ring electrode to direct the lightning away from the protected area for all locations where property boundaries allow their addition.

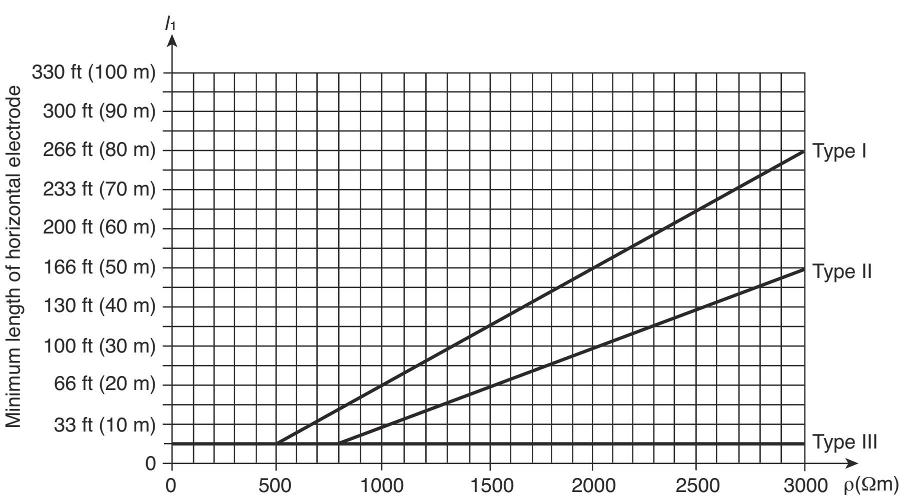
A.4.13.8.1.2 For applications involving shallow or no topsoil, the overall earth resistivity could be high, leading to a correspondingly high grounding system resistance. In such applications, the use of radials extending from the structure is encouraged. Where high earth resistivity is encountered, a greater radial length than that specified in 4.13.5 is recommended. It is also recommended that the length of radials used in these applications meet the criteria for Type II lightning protection systems (as defined in IEC 62305-3, *Protection Against Lightning — Part 3: Physical Damage to Structures and Life Hazard*) as shown in Figure A.4.13.8.1.2.

A.4.13.8.3.1 It is preferable that grounding electrodes be located no closer than 24 in. (600 mm) from foundation walls to minimize the probability of damage to the foundation, although this is not always practicable for all applications. For reference, IEC 62305-3, *Protection Against Lightning — Part 3: Physical Damage to Structures and Life Hazard*, requires that ring earth electrodes be buried at a depth of at least 18 in. (450 mm) and a distance of approximately 3 ft (1 m) around external walls. Note: The metric equivalent values given in this paragraph are the values cited in the IEC standard.

N **A.4.14.1** The interconnection of incoming services to the lightning protection system should be performed as near the service entry as reasonable and not meander greatly through the structure before its interconnection. For larger structures with services entering the structure at different locations, multiple equipotential ground bus bars (EGB) should be considered. In these cases, the interconnection of the multiple EGBs is best accomplished through interconnection with a ground ring electrode.

A.4.14.2 A ground ring electrode conforming to 4.13.4 will be the most efficient method to meet the ground loop conductor requirement.

Δ **A.4.14.3** Definitions in *NFPA 70 (NEC)* and in this standard for *bonded (bonding)*, *grounded*, *grounding*, and *grounding electrode* are similar. The actual sections in the *NEC* and in this standard that



Note: Minimum length of horizontal electrode denotes the combined total length of all conductors that each electrode comprises.

FIGURE A.4.13.8.1.2 Minimum Length of Each Grounding Electrode Based on Earth Resistivity. ***(Source: IEC 62305-3, Edition 2, Figure 3.)***

define what constitutes these various items point to differences in application, equipment, and requirements.

Section 250.50 of the *NEC* requires that all electrodes present at each building or structure be bonded together to form the grounding electrode system, which coordinates with the requirements of Section 4.14. The differences occur in 250.52 of the *NEC*, which describes grounding electrode devices not shown in Section 4.13. Grounding electrode devices described in 250.52 of the *NEC* but not referenced in this document include the following:

(1) 250.52(A)(1): 10 ft (3 m) of metallic underground water pipe extending from the structure in contact with earth.
(2) 250.52(A)(2): The metal frame of the structure in contact with earth.
(3) 250.52(A)(3)(2): The concrete-encased electrode described as #4 AWG would need to be a main-size conductor per 4.13.3.2.
(4) 250.52(A)(4): The ground ring electrode not smaller than 2 AWG is acceptable for Class I but would not be acceptable for Class II *(see Table 4.1.1.1.2)*.
(5) 250.52(A)(5): Pipe electrodes described in item (a) are not included. Rod electrodes described in item (b) as zinc-coated steel are not covered *(see 4.13.2.5)*.
(6) 250.52(A)(6): Other listed electrodes would need to comply with the various paragraphs of Section 4.13.
(7) 250.52(A)(7): Plate electrodes would need to comply with 4.13.6.
(8) 250.52(A)(8): "Other local metal underground systems or structures" are not referenced as grounding electrodes in this standard.

The lightning protection system designer must be familiar with these differences to be able to coordinate interconnection with other building grounding electrodes or the structural grounding electrode system as required by 4.14.3.

Where separate but adjacent buildings or facilities are interconnected directly (not through a utility) by electric, CATV, CCTV, data, or communications wiring, the grounding systems of those buildings should be directly interconnected to each other with a main-size conductor. The need for this interconnection can be eliminated by the use of fiber optic cable, shielded wire, wire run in grounded metallic conduit, or redundant surge protection [SPDs installed at the entrance(s) and exit(s) of both buildings or facilities].

A.4.14.5 Section 250.64(F) of the *NEC* identifies locations where grounding electrode conductors and bonding jumpers might be located for common system grounding or bonding. Section 250.104 of the *NEC* details the interconnection of metallic piping, the structural frame, and all separately derived grounding systems. Subsection 4.14.5 requires one connection to other building grounded systems.

Much like a ground bus bar, the common grounding point for the lightning protection system to other building grounded systems could be distinguishable as located in the first 5 ft (1.52 m) of water pipe, but it could include the entire water pipe system. A common connection point on the structural metallic frame could be apparent, or it could be the extent of the building framework. There is no qualifier (size of pipe or structural metal) in the *NEC*, which is different from this standard. NFPA 780 qualifies the structural metallic frame as a current-carrying part of the system if it meets or exceeds the $\frac{3}{16}$ in. (4.8 mm) thickness requirement *(see 4.19.1)*.

Where installation of the electrical grounding system is made in full compliance with the *NEC*, it would be necessary to connect to the lightning protection ground system only once to comply with 4.14.5. The location must be identified by the method used in the *NEC*. In cases where the building structural metallic frame is a part of the lightning protection system or is bonded as required by 4.9.13, it would generally be expected that no additional bonding runs at grade level between systems would be required.

The lightning protection system designer could consider simplification of the system interconnection requirement by specifying one connection to the metallic water pipe system, but in certain cases the use of plastic pipe sections makes this not a part of the building grounding system. In other instances, the building structural frame cannot be exposed for connection of derived systems, so this could not be the method for interconnection of grounded systems, or there might be no metallic frame. The designer could also specify connection of the lightning protection ground system to the electrical grounding electrode, but in the case of buildings served by feeders of branch circuits *[see 250.104(A)(3) in the NEC]*, there may or may not be a grounding electrode at a separate building.

Knowledge of the requirements or acceptable allowances in the *NEC* is necessary to determine common bonding of the lightning protection system to other building grounded systems at a single point. If the installed building grounded systems are not in compliance with current *NEC* requirements, common ground bonding must include the interconnection of all building-grounded systems to the lightning protection grounding system. If there is no problem with multiple bonds between various systems or loops, then multiple connections from the lightning protection system will simply improve the overall grounding system quality for the structure.

N **A.4.14.6.1(2)** A method to determine whether grounded media and buried metallic conductors are inherently bonded through construction is to perform a bonding test using test equipment suitable for the purpose. The measured bonding resistance for inherently bonded conductors should typically be in the range of tens of milliohms but should not exceed 200 milliohms.

A.4.14.6.1(6) There could be installations where multiple sections of piping and associated junctions exist between the gas meter/regulator and the entrance of the line to the structure. Such junctions can create increased impedances at frequencies that are associated with overvoltages. Where there is internal piping that could be susceptible to overvoltages, care should be taken to ensure that the interconnection of the lightning protection grounding system is made to pipe sections that will not increase the impedance between the pipe and the grounding section. This could be accomplished by connection to the last section of the pipe entering the structure. This interconnection could be made either external or internal to the structure.

Where lightning protection is installed on a structure containing corrugated stainless steel tubing (CSST), the CSST should be bonded to the lightning protection system in more than one location to lower the probability of arcing. The CSST should be bonded as close to the gas service entrance as possible, at any appliance supplied by the CSST, and at any manifold present in the gas piping system. In addition, the length of any bonding conductor between the CSST gas piping system and the lightning protection grounding system should be as short as possible.

Shorter bonding lengths limit the voltage drop between CSST and other metal components, lowering the probability of the development of an electric arc. Shorter bonding lengths conduct a larger amount of current to ground and reduce voltage differences between the CSST and other metallic components. A bonding length of 25 ft (7.6 m) or less is likely to be effective in preventing arcing due to induced currents.

Bonding clamps should not be installed directly on the CSST or its jacket. The means of bonding the CSST should be installed in accordance with the CSST manufacturer's instructions.

Maintaining a separation between metal bodies (except appliances and bonding connections) and CSST piping could also mitigate arcing. A separation distance of 6 in. (150 mm) or more is recommended.

Δ **A.4.14.6.2** Isolating spark gaps can be used to provide the required bond in those cases where galvanic corrosion is a concern or where a direct bond is not allowed by local code. The use of isolating spark gaps is not recommended for those applications where significant follow current can be expected. It is recommended that isolating spark gaps used in this application be installed in accordance with the manufacturer's instructions and be rated for the environment in which they are to be installed (e.g., hazardous classified location, direct burial, as applicable). The devices used in the applications should be rated at a maximum discharge current no less than 100 kA, 8/20 μs [2.5 kV spark overvoltage (U_p)], have an isolating resistance no less than 10^8 ohms, and have a maximum dc spark overvoltage of 500 V.

A.4.15.2 In the case of flat or gently sloping roofs, the roof conductors required by 4.9.7 can be used for achieving roof-level potential equalization. In the case of pitched roofs, the interconnection should be a loop placed at the eave level.

A.4.16 See Annex C for a technical discussion of lightning protection potential-equalization bonding and isolation.

In addition to the bonding of metal bodies, surge suppression should be provided to protect power, communication, and data lines from dangerous overvoltages and sparks caused by lightning strikes.

A.4.16.4 An ungrounded metallic body, such as a metal window frame in a nonconducting medium, that is located close to a lightning conductor and to a grounded metal body will influence bonding requirements only if the total of the distances between the lightning conductor and the ungrounded metal body and between the ungrounded metal body and the grounded metal body is equal to or less than the calculated bonding distance.

A.4.17 Metallic antenna masts or supports should not be used as strike termination devices. Thin metallic supports could be damaged and damage to the antenna lead-in conductors will most likely occur. Antenna should be placed in a zone of protection and isolated from the lightning protection system. Communications conductors should not be located near lightning conductors. *(See 4.20.6 for communications surge protection requirements.)*

A.4.19.3.4 Protecting the base metal with a conductive, corrosion-inhibiting coating, coating the entire bond with a corrosion-inhibiting coating, or other equivalent methods can be utilized.

A.4.20.1 Surge protection alone is not intended to prevent or limit physical damage from a direct lightning strike to a facility or structure. Rather, it is intended to defend against indirect lightning effects imposed upon the electrical services to a structure as part of a coordinated lightning protection system installed in accordance with the requirements of this standard.

Surge currents and their corresponding overvoltage transients can be coupled onto electrical utility feeders in a number of ways. These mechanisms include magnetic or capacitive coupling of a nearby strike or the more dramatic but much less frequent conductive coupling of a direct cloud-to-ground discharge. These overvoltage transients pose a significant threat to modern electrical and electronic equipment.

A.4.20.2 An SPD responds to surges by lowering its internal impedance so as to divert surge current to limit the voltage to its protective level — the measured limiting voltage. After the occurrence of surges, the SPD recovers to a high-impedance-state line-to-ground and extinguishes current-to-ground through the device when line voltage returns to normal. The SPD achieves these functions under normal service conditions, which are specified by the frequency of the system, voltage, load current, altitude (i.e., air pressure), humidity, and ambient air temperature.

A.4.20.2.2 Antennas are considered a part of conductive signal, data, and communication services.

Δ **A.4.20.2.4** Permanent failure of electrical and electronic systems can result from conducted and induced surges transmitted to an apparatus via connecting wiring, as well as the effects of radiated electromagnetic fields impinging directly onto the apparatus itself. Protection at primary panels and subpanels (coordinated SPD system) is recommended to reduce such effects.

To reduce the probability of failure of mission-critical equipment or equipment that is critical to life safety, surge protection should also be considered on branch distribution panels powering this equipment. IEC 62305-4, *Protection Against Lightning — Part 4: Electrical and Electronic Systems Within Structures*, recommends that the length of system wiring between the point at which the SPD is installed and that of the equipment being protected be no greater than 30 ft (10 m). Induced voltages can be reintroduced onto long lengths of system wiring, which will add to the protection level (U_p) of the SPD. If this level exceeds the withstand level (U_w) of the equipment being protected, the protection afforded by the SPD might not be adequate. In such a case, the installer should locate an SPD closer to the point of utilization of the equipment. This same philosophy extends to protection of service panels.

Depending on the presence of other protective measures (e.g., shielding), SPDs should be considered on branch distribution panels as close as 30 ft (10 m) or more from the primary service entrance panel where the electrical equipment fed by the panel is susceptible to overvoltages. Inductive coupling of electrical and magnetic fields can result in surges sufficient to cause damage to susceptible electrical equipment.

A.4.20.2.5 Most services to facilities will require discrete surge suppression devices installed to protect against damaging surges. Occasionally, services will be located in an area or a manner where the threat from lightning-induced surges and overvoltage transients might be negligible. For example, the requirements in 4.20.2.3 *(also see A.4.20.6.1)* exempt services less than 100 ft (30 m) in length that are run in grounded metal conduit between buildings requiring surge protection. Other examples where SPDs might not be required to be installed at each service entrance are those applications where fiber optic transmission lines (with no conducting members) are used. The standard recognizes that there can be acceptable exceptions and consequently allows for such exceptions to the requirements for surge suppression on electrical utility, data, and other signal lines, provided a competent engineering authority has determined that the threat is negligible or that the system is protected in a manner equivalent to surge suppression.

Allowance in this standard for the exemption of surge suppression at specific locations is not intended as a means to provide a broad exemption simply because surge suppression might be considered inconvenient to install. Rather, this allowance recognizes that all possible circumstances and configurations, particularly those in specialized industries, cannot be covered by this standard.

Determinations made by an engineering authority for exempting installation of SPDs should focus on the likelihood of lightning activity in the region, the level of damage that might be incurred, and the potential loss of human life or essential services due to inadequate overvoltage protection.

Four methods of analysis are commonly used for this determination, although other equivalent analysis can be used. The four methods are the following:

(1) A *risk assessment* could be performed in accordance with IEC 62305-2, *Protection Against Lightning—Part 2: Risk Management*, and surge protection requirements could be waived if justified by the assessment.
(2) The *lightning flash density/risk analysis* is an analysis to determine the frequency of lightning activity in the geographic area of the facility. As a rule of thumb, if the flash density exceeds one flash per square kilometer per year, surge suppression or other physical protection should be considered. Lightning energy can indirectly couple to services at ranges greater than 0.6 mi (1 km) to create potentially damaging overvoltages.
(3) *Plant/facility statistical or maintenance records* can also be used for risk analysis. If these records can demonstrate the lack of damage on a service due to surges, they can be used to justify low risk of surge damage to a particular system or facility.
(4) The *lightning electromagnetic environment analysis* starts with a threat electromagnetic field from a nearby lightning strike and computes the magnitude and rise-time characteristics of transients coupled into services feeding a structure or facility. Based on the computed threat, SPDs can be sized appropriately or omitted, as warranted. This analysis is typically performed for critical communications facilities and in military applications. Electromagnetic environments for such an analysis can be found in MIL-STD-464C, *Interface Standard Electromagnetic Environmental Effects Requirements for Systems*, and IEC 62305-4, *Protection Against Lightning—Part 4: Electrical and Electronic Systems Within Structures.*

In all cases, the criticality of continued operation, potential life hazard to persons and essential services, and the consequence of facility damage or shutdown should be factors in the analysis. If a hazardous condition results from a surge causing temporary shutdown without permanent damage (e.g., through the disabling of a computer or communication system), then the requirements for surge suppression as articulated by Section 4.20 should not be exempted.

A.4.20.3.1 SPDs are typically sized significantly larger than the expected challenge level. At service entries, it is generally agreed that a nominal discharge current (I_n) of 20 kA will provide adequate protection. However, larger ratings that protect against less probable but more powerful lightning events will usually provide a better capability to handle multiple strikes and will usually provide a longer service life.

Rating the SPD's I_n higher than the minimums in this document is recommended in areas with frequent lightning.

Where installed, SPDs at branch panels or subpanels should have an I_n rating of 10 kA 8/20 µs or greater per phase.

Where installed, supplementary protection (also called *point of utilization*) SPDs should have an I_n rating of 5 kA 8/20 µs or greater per phase.

Δ **A.4.20.4** The measured limiting voltages of the SPD should be selected to limit damage to the service or equipment protected.

Devices rated in accordance with ANSI/UL 1449, *Standard for Safety for Surge Protective Devices*, reflect that the voltage rating test in this edition utilizes a 3 kA peak current instead of the 500 A current level previously used in the SVR test of the 2nd edition of ANSI/UL 1449, *Standard for Safety for Transient Voltage Surge Suppressors.*

A.4.20.5 Surges can be induced upon any line entering a structure.

Where installed, branch panels over 100 ft (30 m) from the service entrance should have L–G or L–N and N–G modes of protection. Additionally, L–L protection is also permitted — although this is usually achieved by the L–N modes across two phases.

The following modes of protection are possible to minimize voltage differences between the individual conductors:

(1) Line-to-line (L–L) protection places the SPD between the current-carrying conductors in a power system.
(2) Line-to-neutral (L–N) protection places the SPD between the current-carrying conductors and the grounded conductor (neutral) in a power system.
(3) Line-to-ground (L–G) protection places the SPD between the current-carrying conductors and the grounding conductor (ground) in a power system.
(4) Neutral-to-ground (N–G) protection places an SPD between the grounded conductor (neutral) and the grounding conductor (ground) in a power system. This mode of protection is not required at the service entrance (primary service panel board) if the neutral-to-ground bond is implemented at this location or within proximity of this point of installation. Thus, in general, an SPD with only L–L and L–N modes of protection might be required at the service entrance.

(5) *Common mode* is a term used for a mode of protecting telecommunications, data lines, and so forth. This mode places the SPD between the signal conductor and ground. It is analogous to L–G mode in power systems.
(6) *Differential mode* is a term used for a mode of protecting telecommunications, data lines, and so forth. In this mode, an SPD is placed between the individual signal lines, analogous to the L–L mode of protection in power systems.

A.4.20.6.1 SPDs should be placed on both ends of external signal, data, and communication lines longer than 100 ft (30 m) that connect pieces of equipment or facilities, to protect against surges coupled into the wiring or caused by ground potential differences.

A.4.20.6.4.1 The purpose of the SPD is to equalize L–L, L–N, L–G, and N–G potentials. While a good ground is important, a good bond is imperative to minimize damage due to lightning and power contact or induction.

A.4.20.6.4.4 Differential mode protection should also be provided where practicable.

A.4.20.7.2 Longer, or looped, SPD line and ground conductors increase the impedance of the SPD ground circuit. Increasing the lead length serves to increase pass-through voltage at the point where the SPD is wired into service equipment or a branch panelboard. Consequently, it is essential to minimize lead length impedance in this circuit.

A.4.20.7.4 Some SPD units are provided with a failure indicator. This feature is recommended because it facilitates maintenance or test procedures. Where used, this indicator should be visible. Building maintenance should consider periodic inspection or testing of SPDs. *(See NFPA 70B.)*

A.4.20.8 The effectiveness of the SPD is based on the impedance of the path to ground. A lower impedance minimizes voltage differences of conductors attached to SPDs near the service entrance and reduces the chance of arcing or insulation breach. Consequently, it is essential to minimize impedance in this circuit.

A.5.8.1 The metal thickness could be less than the dimensions required in Chapter 4. On a nonmetal helipad, a flat metal plate should be permitted to serve as a strike termination device in the landing area if the landing area exceeds 50 ft (15 m) in both dimensions. The minimum exposed area of the plate should be 3 in.^{2} (1950 mm^2). The minimum thickness of the plate should be $\frac{3}{16}$ in. (4.8 mm). The plate should be installed flush with the helipad surface and exposed to the air. The plate should be connected to the roof lightning protection system with a two-way horizontal or downward path. Conductors connecting the plate to the lightning protection system should be installed flush with or below the helipad surface. Refer to 4.18.3.2 for the bonding requirements.

A.5.8.6 The connection does not provide lightning protection for the parked aircraft. Consideration should be given to relocate the helicopter to a safer location.

A.5.9.4.2 Refer to G.1.1.3 for guidance on installation criteria.

A.6.9 A ground grid located within 50 ft (15 m) of the foundation of a stack and constructed of wires meeting the requirements of this standard for main conductors is a permitted grounding electrode. If the stack is located within 50 ft (15 m) of the grid in all directions, the grid can also serve as the bottom loop conductor required by 6.4.2.

A.7.1 In the structures covered in Chapter 7, a spark that would otherwise cause little or no damage could ignite the flammable contents and result in a fire or explosion. The requirements of this chapter should be considered the minimum acceptable and the authority having jurisdiction (AHJ) could find it necessary to supplement these requirements to address specific risks. It is also up to the AHJ as to when any upgrades to existing lightning protection systems are to be accomplished. Flammable vapors can emanate from a flammable liquid [flash point below 100°F (37.8°C)] or a combustible liquid [flash point at or above 100°F (37.8°C)] when the temperature of the liquid is at or above its flash point. Provided the temperature of the liquid remains below the flash point, combustible liquids stored at atmospheric pressure will not normally release significant vapors; since their flash point is defined to be at or above 100°F (37.8°C).

N **A.7.1.2** This chapter shall not apply to the protection of nonmetallic tanks containing flammable vapors, flammable gases, or liquids that give off flammable vapors. *(See Annex N.)*

A.7.1.3 It is recommended that consideration be given to upgrading the lightning protection systems to the current requirements not only during new construction but also for reconstructed tanks and any external floating roof tank that undergoes a major roof repair or that has its entire seal system replaced.

A.7.2.1 Hazardous (classified) locations are defined by Chapter 5 of *NFPA 70*.

A.7.3.3.2 Sparks or damaging impact at the striking point could also be experienced. This should be taken into consideration in the determination of air-termination device locations. For example, U.S. Army Ammunition and Explosives Safety Standard DA-PAM 385-64 requires that air terminals on structures containing explosive materials that are located at vents emitting explosives vapors under natural draft be at least 5 ft (1.52 m) higher than the vent. For vents where explosive gases are emitted under forced draft, the air terminals are required to be at least 15 ft (4.5 m) above the vent.

A.7.3.4.3 Where it is not practicable to install down conductors external to the hazardous locations, the following should be considered:

(1) The down conductor passing through the hazardous location should be continuous (i.e., without splices).
(2) Where the minimum autoignition temperature of the hazardous environment is less than or equal to 160°F (70°C), the down conductor should be installed in a nonmetallic enclosure suitable for the hazardous area.

A.7.3.7 A 20 ft (6 m) diameter or larger vertical cylindrical tank resting on earth or concrete or 50 ft (15 m) diameter or larger vertical cylindrical tank resting on bituminous pavement can be substituted for the ground ring electrode.

N **A.7.3.7.3(1)** It is possible to ground metal tanks by utilizing buried pipe in direct contact with earth. The shorter the distance from the tank to the point of entry to earth, the greater the efficacy of the ground. For a pipe or piping system to be considered a grounding electrode, it should be electrically continuous and buried in direct contact with the earth for at least 10 ft (3 m). Generally, the more pipe that is in contact with earth, the more effective it will be in serving as a grounding electrode. Multiple grounding electrodes are better for grounding metal tanks. If only one ground entry point is available, additional buried length of pipe should be considered. See 4.13.5 for requirements for length of radials.

A.7.4.1.2 The lightning risk assessment provided in Annex L does not currently incorporate the concept of defining multiple lightning protection zones (LPZs) in a structure.

A.7.4.3.1 For fixed roof tanks (metallic cone or dome) and internal floating roof tanks, there is a possibility of flammable vapors being present at atmospheric vents. If present, flammable vapors can be ignited by a lightning flash. Bonding techniques to prevent discharge between the floating roof and the shell are addressed in API 650, *Welded Steel Tanks for Oil Storage*, Appendix H. Tanks handling low–vapor pressure materials or in-service tanks with properly maintained floating roofs with tight-fitting seals are not likely to have flammable vapors at atmospheric vents unless they are being refilled from empty. In these cases, no further lightning protection is required.

A.7.4.3.2.1 Sliding contacts between the tank floating roof and tank shell are used to conduct the short and intermediate components of lightning-stroke current.

A.7.4.3.2.1.2 Refer to API RP 545, *Recommended Practice for Lightning Protection of Aboveground Storage Tanks for Flammable or Combustible Liquids*. Shunts are used for conduction of fast- and intermediate-duration components of lightning-stroke current.

A.7.4.3.2.1.2(7) API RP 545, *Recommended Practice for Lightning Protection of Aboveground Storage Tanks for Flammable or Combustible Liquids*, recommends a minimum service life of 30 years.

A.7.4.3.2.2 Fixed contacts, such as bypass conductors, are used for conduction of the intermediate- and long-duration component of lightning-stroke current.

A.7.4.3.2.2.7 API RP 545, *Recommended Practice for Lightning Protection of Aboveground Storage Tanks for Flammable or Combustible Liquids*, recommends a minimum service life of 30 years.

A.8.1.1 The risk assessment process found in Annex L can be used for facilities, provided that it is adequately documented.

A.8.1.3(1) Data by López and Holle, "Lightning Casualties and Damages in the United States from 1959 to 1994," suggest that a minimum warning distance of at least 6 mi to 8 mi (9.6 km to 12.8 km) is required to ensure that there is no significant damage from a lightning strike.

A.8.1.3(3) Annex L provides guidance for performing a facility risk assessment.

A.8.3.2 The best method to protect extremely sensitive operations from all sources of electromagnetic radiation is to enclose the operations or facility inside a metallic, "Faraday-like" cage. A metallic, Faraday-like cage is an enclosure that comprises a continuous grid of conductors, such that the voltage between any two points inside the enclosure is zero when the cage is immersed in an electrostatic field. A metallic cage or Faraday shield lightning protection system is one in which the protected volume is enclosed by a heavy metal screen (i.e., similar to a birdcage) or continuous metallic structure with all metallic penetrations bonded. The lightning current flows on the exterior of the structure, not through the interior. A Faraday-like shield, which is not an ideal Faraday cage, is formed by a continuous conductive matrix that is properly bonded and grounded.

A freestanding structure that is determined by the AHJ to be a metallic cage or Faraday-like shield might not require either grounding systems or strike termination devices. Use of a strike termination system on these structures provides a preferred attachment point for lightning and could prevent structural damage, such as concrete spall, from direct lightning attachment.

The intent of this type of structure is to prevent the penetration of lightning current and related electromagnetic field into the object to be protected and prevent dangerous thermal and electrodynamic effects of current as well as dangerous sparking and overvoltages for electrical and electronic systems. Effective lightning protection is similarly provided by metallic structures such as those formed by the steel arch or the reinforcing steel in the walls and floors of earth-covered magazines (also referred to as bunkers, huts, or igloos) if the steel reinforcement is bonded together and it meets the bonding resistance of 8.10.7.1.

A.8.3.3 The isolation of the down conductors from the structure will reduce the magnetic field strength in the structure and the probability of a sideflash from a down conductor.

A.8.3.3.2 It is recognized that some partial lightning current will flow on a mast guy.

A.8.3.5 The spacing dimensions of strike termination devices based upon the 100 ft (30 m) rolling sphere method (RSM), with terminals 12 in. (300 mm) tall, are 25 ft (7.6 m) at the center of the roof, 20 ft (6.1 m) at the roof perimeter, and 24 in. (600 mm) set back from the outer end of roof ridges. For terminals 24 in. (600 mm) tall, the dimensions increase to 35 ft (12 m) at the center of the roof, 20 ft (6.1 m) at the roof perimeter, and 24 in. (600 mm) set back from the outer end of roof ridges.

A.8.5.4 Welding includes exothermic welding.

A.8.5.5.1 All internal metallic door frames (and metallic doors through bonding to the frames) should be considered for bonding to the ground ring electrode.

A.8.5.7 Hazardous arcing can occur between rail cars and structural members, bollards, metallic barricades, etc., where the rail cars are stored or unloaded inside a structure. Bonding of the track to the structure or its grounding system at the entry point to the structure can maximize the safe separation distance between explosive-ladened rail cars and grounded structural components.

A.8.7.2 The purpose of the lightning protection system requirements expressed in 8.7.2 is to protect the explosives positioned on these structures from being ignited by direct lightning strikes. Open-air explosives staging areas on a wharf will generally require lightning protection from a mast or catenary system. A ship alongside an explosives-handling wharf is capable of providing a zone of protection for a section of the explosives-handling wharf and could be considered to provide a zone of protection for an explosives staging area.

A.8.7.2.4 The conductors between the deck-level potential equalization network and grounding electrodes should be provided at or near the location of lightning protection masts or catenary cables where practicable.

A.8.7.2.5.3 The grounding electrodes should be submerged below the 100-year drought water level.

A.8.7.4 ISO containers are sometimes used for temporary storage of various explosives materials, such as small arms in ammo boxes, various weapons system configurations in shipping containers, commercial explosives, fireworks, and so forth. Because the metal frame of a properly maintained ISO container does not meet the metal thickness requirement for strike termination devices, there could be burn-through for some strikes. The metal frame will provide some shielding from lightning electromagnetic effects, and the surface area contact of the superstructure on the local earth will provide some impedance to earth. These provide protection against the effects of lightning for some configurations and sensitivity of contents, but not all. In some cases, it might be necessary to provide strike termination devices, additional bonding, and grounding of the ISO container. Whether the ISO container is to be supplemented by lightning protection is a decision for the AHJ to make, based on a risk assessment of the sensitivity of the container's contents.

A.8.9 The effectiveness of any lightning protection system depends on its installation, its maintenance, and the testing methods used. Therefore, all installed lightning protection systems should be properly maintained. Proper records of maintenance and inspections should be maintained on each facility to ensure adequate safety. These records are part of the lightning protection requirements and should be maintained.

A.8.10.7 The instrument used in earth resistance testing should be capable of measuring 0 ohms to 50 ohms, ±10 percent. The instrument used to measure bonding resistance should be capable of measuring 0 ohms to 10 ohms, ±10 percent.

A.8.10.7.8 Assistance in determining a qualified person can be found in *NFPA 70E.*

A.9.1 Modern turbine blades are typically constructed of composite materials such as carbon or glass-reinforced plastic. Some parts and discrete components such as mounting flanges, balancing weights, hinges, bearings, wires, electrical wiring, and springs are made of metal. Lightning strikes blades that have metallic and nonmetallic components. The technical challenge in designing lightning protection of wind turbine blades is to conduct the lightning current safely from the strike attachment point to the hub in such a way that the formation of a lightning arc inside the blade is avoided. This can be achieved by diverting the lightning current from the strike attachment point along the surface to the blade root, using metallic conductors either fixed to the blade surface or inside the blade.

Typically for blades up to 60 ft (18 m) long, receptors at the tip of the blade are adequate. However, it might be necessary for longer blades to have more than one receptor to obtain the desired interception efficiency. Protection of the blades is provided by the blade manufacturer and is typically an integral part of the blade.

Any wiring for sensors placed on or inside blades should be protected via bonding to the down conduction system. Wiring should be either shielded cables or placed in metal tubes. The cable shield or metal tube should be placed as close as possible to the down conductor and bonded to it.

A.9.1.2 This protection is addressed by specific manufacturer product approval standards.

A.9.2.6 A tubular metal tower, as predominantly used for large wind turbines, usually fulfils the dimensions required for down conductors stated in NFPA 780 and IEC 62305-3, *Protection Against Lightning — Part 3: Physical Damage to Structures and Life Hazard*, and can be considered an effective electromagnetic shield.

A.9.4.1 Consideration should be given to design requirements for power generation facility grounding, including sizing of conductors for fault currents and requirements for touch and step potential.

A.9.4.2 Additional vertical or horizontal grounding electrodes could be used in combination with the ground ring electrode.

A.10.1.2 A lightning protection system does not afford protection if any part of the watercraft contacts a power line or other voltage source while in water or on shore. A lightning protection system lowers but does not eliminate risk to watercraft and its occupants.

A.10.2.2.4 Carbon fiber fittings, including masts, should be isolated electrically from the lightning conductor system. Since carbon fiber is a conductor, sideflash risk is increased in the vicinity of carbon fiber composite (CFC) structures, especially near the water. The use of CFC reinforcement in areas such as chainplates is to be avoided.

A.10.3.1 The techniques described in Chapter 10 should also be applied to watercraft for the placement of strike termination devices and determining the zone of protection.

A.10.3.2.1 Where a standing person is not covered by the zone of protection, a warning to this effect should be included in the owner's manual.

For retrofit applications and those applications where a sufficient zone of protection cannot be provided, the zone of protection of the lightning protection system should be identified and provided to the user of the watercraft.

A.10.4.1.1 See Table 9.12.5(a) of NFPA 302 for minimum strand sizes for watercraft conductors. Main conductors of greater cross-sectional area as discussed in Section 4.9 provide a greater degree of safety.

A.10.4.1.3 If a metal with the area given by the equations in 10.4.1.3 is subject to the lightning heating (action integral) required to raise the temperature of a copper conductor with an area of 0.033 in.^{2} (21 mm^2) from a nominal temperature of 77°F (298 K) to the melting point of copper, then its temperature would be raised to the melting point of the metal. Values for silicon bronze and stainless steel are given in Table A.10.4.1.3(a) and Table A.10.4.1.3(b).

Δ **Table A.10.4.1.3(a) Areas for Main Conductor Not Containing Electrical Wiring (inch-pound units)**

Metal	C_p (Btu/lb$_m$ °F)	D (lb$_m$/in.^{2})	ρ (Ω in.)	MP (°F)	Area (in.^{2})
Silicon bronze	0.086	0.32	9.95×10^{-6}	1981	0.13
Stainless steel	0.122	0.29	3.74×10^{-5}	2781	0.19

Δ **Table A.10.4.1.3(b) Areas for Main Conductor Not Containing Electrical Wiring (metric units)**

Metal	C_p (J/kg^{-1} K^{-1})	D (kg/m^{-3})	ρ (Ω m)	MP (K)	Area (mm^2)
Silicon bronze	360	8800	2.55×10^{-7}	1356	85
Stainless steel	510	7930	9.6×10^{-7}	1800	125

A.10.4.1.4 The area of a conductor of uniform cross-section that has the same resistance as a copper conductor of area A_{Cu} is given by the following equation:

[A.10.4.1.4]

$$A = \frac{\rho}{\rho_{Cu}} A_{Cu}$$

where:

A = cross-sectional area
ρ = resistivity of alternative metal (Ω m)
ρ_{Cu} = resistivity of copper (1.7×10^{-8} Ω m)
A_{Cu} = 21 mm^2 for a main conductor

Using the parameters in Table A.10.4.1.3(a) and Table A.10.4.1.3(b), the areas are 0.49 in.^{2} (315 mm^2) for silicon bronze and 1.8 in.^{2} (1200 mm^2) for stainless steel.

A.10.4.1.6 Routing lightning conductors near the outer surface of the hull lowers the risk of internal sideflashes forming between the lightning conductors and other conducting fittings and of external sideflashes forming between conducting fittings and the water. Routing lightning conductors externally is also more consistent with the layout recommended for buildings wherein air terminals, down conductors, and grounding electrodes are located on the outside of the building. However, in the case of internal conducting fittings being very close to the water, such as a keel-stepped mast, a grounding electrode should be provided as close as is practicable to the portion of the fitting that is closest to the water.

A.10.4.1.7 All lightning conductors should be routed as far as possible from the water, and especially the waterline, to minimize the risk of an external sideflash forming between the lightning conductor and the water. Similarly, conducting fittings, electronic equipment, and electrical wiring should be located as far as possible from the water.

A.10.4.2.3 Using the parameters in Table A.10.4.1.3(a) and Table A.10.4.1.3(b), the required areas are 0.052 in.^{2} (33 mm^2) for silicon bronze and 0.075 in.^{2} (48 mm^2) for stainless steel.

A.10.4.2.4 Using the same equation as in A.10.4.1.4, with 0.013 in.^{2} (A_{Cu} = 8.3 mm^2) as the area for a copper bonding conductor, the required areas are 0.19 in.^{2} (125 mm^2) for silicon bronze and 0.73 in.^{2} (470 mm^2) for stainless steel.

A.10.4.2.7 Large metallic masses include metal cabinets that enclose electronic equipment, tanks, handrails, lifeline stanchions, engines, generators, steering cables, steering wheels or tillers, engine controls, metallic arches, and bow and stern pulpits.

A.10.4.3.1 The function of the loop conductor is to conduct the lightning current around the outside of the watercraft while minimizing the risk of a sideflash to the water, or to metallic structures and personnel in the vessel. In the absence of conducting fittings or occupied areas it is preferable to place the loop conductor as high as possible above the waterline to minimize the risk of a sideflash between the loop conductor and the water. However, this risk is less for a horizontal conductor than for a conductor, such as a chain plate, that is more vertically oriented. If conducting fittings or crewed areas exist near the loop conductor it is preferable to place the loop conductor between the vulnerable location and the water.

N **A.10.4.3.2** Typical applications are sailboat masts and amidships towers. A mast in a sailboat could require a masthead air terminal or the tip of a metal mast could act as an air terminal. If the mast material is aluminum and its cross-sectional area exceeds the requirements in 10.4.1.2, then the mast itself is permitted to act as an air terminal and main conductor. For other mast materials, such as carbon fiber composite (CFC) and wood, a separate conductor is required for the main conductor.

Connections to the loop conductor should be made via two main conductors, typically one to port and one to starboard. In determination of the path in each case, conductor bends *(see 4.9.5)*, and total conductor length should be minimized and "U" or "V" pockets *(see 4.9.4)* avoided wherever possible. Conductor paths that are long and tortuous result in larger voltages being induced between the ends of the conductor.

For watercraft with multiple masts or towers, the main conductor for each should be connected to the loop conductor by two main conductors in a similar fashion.

A.10.4.4.1 A main conductor is designed to conduct all of the lightning current. Close to the water, and especially inside the hull below the waterline, the optimum direction for a main conductor is perpendicular to the hull directly inboard of the grounding electrode in contact with the water. A bonding conductor is intended to conduct the relatively small currents required to equalize potentials between conducting fittings and the lightning protection system. The optimum orientation for bonding conductors is parallel to the water surface and the best location is as far from the water surface as is practicable.

A.10.4.5.2 Requirements for connector fittings are given in Section 4.12. Where practicable, these requirements should be followed for connections in a watercraft lightning protection system. Conductor connections should be of the bolted, welded, high-compression, or crimp type. The bolt securing the connector can be utilized as either a main or bonding conductor subject to the requirements regarding cross-sectional area defined in Section 10.4.

A.10.4.6.2 The area of a conductor of uniform cross-section that has the same resistance per unit length as a main conductor is given by the equation in A.10.4.1.4. For connecting a main conductor, the areas are 0.49 in.^{2} (315 mm^2) for silicon bronze and 1.8 in.^{2} (1200 mm^2) for stainless steel. For connecting a bonding conductor, the required areas are 0.19 in.^{2} (125 mm^2) for silicon bronze and 0.73 in.^{2} (470 mm^2) for stainless steel.

Equating resistances for a copper conductor of area A_{Cu}, resistivity ρ_{Cu}, and length L_{Cu} and a metal connector of area A, resistivity ρ, and length L gives a maximum allowable length for the metal connector as follows:

[A.10.4.6.2]

$$L = L_{Cu} \frac{A}{A_{Cu}} \frac{\rho_{Cu}}{\rho}$$

where:
L = length of metal connector
L_{Cu} = length of copper conductor
A = area of metal connector
A_{Cu} = area of copper conductor
ρ_{Cu} = resistivity of copper conductor
ρ = resistivity of metal connector

The length is the same for both main and bonding conductors and is 6.5 in. (165 mm) for silicon bronze and 2.5 in. (63.5 mm) for stainless steel when L_{Cu} = 24 in. (600 mm).

A.10.5.2.1 In order to allow for main conductors to be routed externally to vulnerable areas (as described in 10.4.1.6) and to reduce the risk of external sideflashes from the lightning conductors, grounding electrodes should be located as close to the waterline as is practicable. Where an onboard fitting is below the waterline and close to the water, an additional supplemental grounding electrode is advisable in the vicinity of the fitting.

A.10.5.2.3 Seacocks are particularly susceptible to damage and leaking after a strike and should be inspected after all suspected strikes.

A.10.5.4.1 A supplemental grounding electrode can be painted or covered with a thin coating [<0.04 in. (<1 mm)] but should not be encapsulated in fiberglass.

A.10.5.5 An air gap or SPD (such as a gas discharge tube) might be desirable to reduce corrosion in the presence of leakage currents in the water and could reduce galvanic corrosion. However, using an air gap to isolate an immersed conductor from the water can increase the risk of a ground fault current bypassing any ground fault protection device. Hence, a hazardous current can be inadvertently introduced into the water. For this reason, measures should be taken to ensure that loose electrical connections cannot contact any part of the isolated grounding electrode. A spark gap should not be used where there is the possibility of ignitible vapors or personal hazards.

A.11.1.1 Chapter 11 pertains to lightning protection of airfield lighting systems. These systems are installed underground in both paved (i.e., full-strength pavement and shoulder pavement) and unpaved areas. The protected components include in-pavement fixtures, elevated fixtures, airfield signs, underground power, communications systems, control and signal circuits, and components of runway, taxiway, and apron lighting systems. These systems are installed on the portions of an airport that encompass the approach, departure, landing, takeoff, taxiing, and parking areas for aircraft and include runways, taxiways, and other parts of an airport used for taxiing, takeoff, and landing of aircraft; loading ramps; and parking areas exclusive of building-mounted helipads, approach light structures, and antennas. This chapter could also apply to other areas with airfield lighting systems.

There are two generally accepted methods for providing lightning protection for airfield lighting circuits: equipotential and isolation. The equipotential method, which is described in 11.4.2.6.1, is shown in Figure A.11.1.1(a). The isolation method, which is described in 11.4.2.6.2, is shown in Figure A.11.1.1(b). The two methods should not be employed on a single circuit. The designer should select the installation method based upon sound engineering practices and the success of the selected method in previous installations.

A.11.1.2 Aboveground items, such as elevated support structures, can be protected in accordance with Chapter 4.

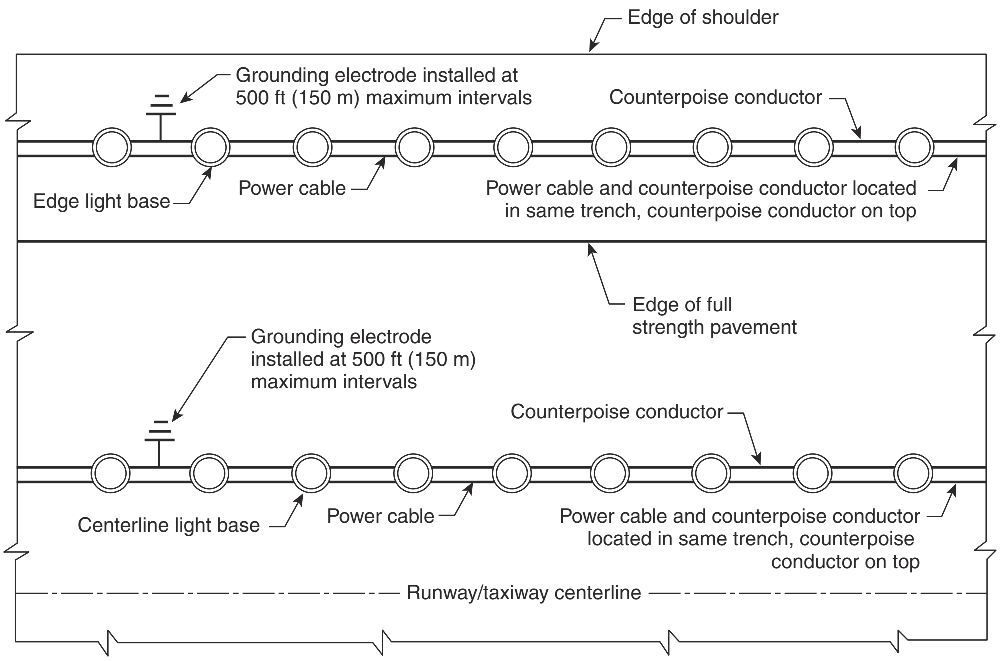
A.11.2.1 A typical airfield lighting series (current-driven) circuit is powered by a constant current regulator (CCR) or equivalent power supply. Current is the same at all points in the series circuit. The output voltage is directly proportional to the load and output current step. The CCR output (primary circuit) is normally ungrounded. The internal overcurrent protection of the CCR or an equivalent power supply monitors the actual output current. Series airfield lighting circuit overcurrent protection does not rely on a low impedance return path or ground connection for proper operation.

The installation of an equipotential airfield lighting counterpoise system on a series circuit also provides equipotential bonding between all elements of the airfield lighting system. The airfield lighting counterpoise system maintains all interconnected components at earth potential and protects personnel from possible contact with energized metallic light bases, mounting stakes, or fixtures.

The principles used to protect airfield lighting systems from lightning are also applicable to the protection of parallel (voltage-powered) circuits, control circuits, communications, and signal circuits.

The parallel (voltage-powered) circuit is similar to the typical alternating current system used in homes and in industry. Voltage is nominally the same at all points in the parallel

 Shaded text = Revisions. Δ = Text deletions and figure/table revisions. • = Section deletions. *N* = New material.



Notes:
1. The counterpoise conductors are shown parallel to the raceways or cables being protected for graphic simplicity. The counterpoise conductors are actually installed above and centered over the raceways or cables to be protected in accordance with 11.4.2.6.1. (*See Figure 11.4.2.6.1.*)
2. Grounding electrodes can be any of those described in 11.4.5.2. Ground rods are typically used for this application.

FIGURE A.11.1.1(a) Equipotential Method.

circuit. The parallel circuit current varies according to the load.

Parallel circuits must be installed in accordance with *NFPA 70*. The required equipment grounding conductor must be sized in accordance with Article 250 of *NFPA 70*. Equipment grounding conductors for parallel circuits should be routed within the same raceway or cable with the parallel circuit conductors or in close proximity to direct buried conductors and cables to reduce the overall circuit impedance, allowing expedited operation of the overcurrent device.

The equipment grounding conductor must be bonded to each metallic airfield lighting component and the airfield lighting vault building ground system in accordance with *NFPA 70*. All metallic airfield lighting components must be bonded to the equipment grounding conductor.

The lightning protection system for a parallel (voltage-powered) airfield lighting circuit should be installed in the same manner as a lightning protection system for a series (current-driven) airfield lighting circuit.

• **A.11.2.4** A lightning protection system for airfield lighting circuits could still be required for the conditions described in 11.2.4 to comply with funding agency requirements. The AHJ could also require compliance with this standard for conditions described in 11.2.4.

A.11.3.2 The function of an airfield lighting counterpoise system is to provide a preferred, low-impedance path for lightning energy to earth.

A.11.4.1.1 The copper counterpoise conductor size should be determined by the Engineer of Record based upon sound engineering practices. A 2 AWG bare, solid copper counterpoise conductor is recommended.

The following factors should be evaluated when considering a larger size counterpoise conductor:

(1) The airport's ability to maintain airport operations after an airfield lighting circuit or system failure
(2) Accessibility of the copper counterpoise conductor for testing or repair (e.g., if the counterpoise conductor is installed in or under pavement)
(3) Availability of qualified persons to perform airfield lighting system repairs
(4) Life cycle cost of the larger size counterpoise conductor, including consideration of counterpoise conductor replacement prior to the end of an expected 20-year life
(5) Results of a lightning risk assessment performed in accordance with Annex L
(6) Past performance of the airfield lighting counterpoise system at the airport or geographic area

The AHJ can determine and approve the size of the copper counterpoise conductor.

A.11.4.1.2 Corrosion, oxidation, chemical reaction, and electrolysis can all be considered adverse effects on a bare copper counterpoise conductor. Most metals are subject to some form of corrosion, oxidation, chemical reaction, or electrolysis. Where the history of grounding systems (buried conductors, buried metallic objects) in the area is not known, a soil resistivity and soil pH profile in conjunction with the consultation of a materials/corrosion specialist could be necessary to properly