Section 1: System

1.1 Types. Lightning protection system areprimary, secondary or a combination of the primary and secondary.

1.1.1 Primary. Design primary protection to prevent damage from direct lightning strikes by diverting any charges from structures through a low resistance path to earth.

1.1.2 Secondary. Design secondary protection to prevent metal parts of buildings, building contents, or other types of structures from accumulating electrical charges that can cause sparking or flashover. Sparking or flashover is likely to occur when metal objects are proximate. In the event of a lightning discharge, the potential of independently grounded metal objects can change with respect to nearby objects generating flashover between the objects.

1.1.3 Combination. The installation of a primary and a secondary protection system for the same structure is not always required. A secondary static ground system providing an interconnection of metallic masses within a building or on piers and wharves may also be required with a primary lightning protection system. When a structure is equipped with both primary and secondary systems, interconnect all grounds.

1.2 Primary system. Design protection based on (30.5 m) lightning strike arc. Design either primary or secondary type and determine mast locations or grounded aerial conductors and their heights. Mast location or grounded aerial conductors and their heights influence the type of masts along with mast foundation requirements and the location of the ground counterpoise. Primary protection shall consist of lightning masts or grounded aerial conductors as described in paras. 1.2.1 and 1.2.2.

1.2.1 Lightning masts. Lightning masts (freestanding air terminals) placed around a facility and connected to a buried ground counterpoise. (See figures 1 and 2)

1.2.2 Grounded Aerial Conductors. Overhead conductors spanned above a facility and connected to a buried ground counterpoise.

1.3 Secondary systems. A secondary system generally consists of a buried ground counterpoise to which all metal parts, including reinforcing steel of the building or other structures are connected. An equipment ground bus may be utilized for the grounding of the building contents. The ground bus shall not form a loop. Connect ground bus to ground counterpoise.

1.3.1 Air Terminals. Points (Lightning rods) mounted on the salient parts of facilities and connected to the ground counterpoise may be used for protection for certain specific application in a secondary system.

Section 2: system components

2.1 Masts. Lightning masts shall be tapered metal, self-supporting type, (single section design or multisession design) with slip joints, as dictated by total height of mast. The cross section shall be circular or polygonal, symmetrical about the longitudinal axis, and uniform in configuration throughout the entire length. Wood masts may be used only when heights and structural strength permit and shall be electrical pole line embedded type, topped with a lightning rod or metal cap and with two bare copper ground wires not less than No.1(50 mm^2), run down each side of the pole to the ground system. The ground wires shall have protective molding extending from grade level to a point at least (3.05 m) above grade.

2.1.1 Material. Metal material shall be corrosion-resistant steel, no corrosion-resistant steel with hot-dipped galvanized finish, or aluminum for single section or multiple section masts with anchor bolt mounting. No combination of materials shall be used that form an electrolytic couple which in the presence of moisture, causes accelerated corrosion.

2.1.2 Top Point: Mast top shall be fitted with a copper or bronze air terminal or metal cap to take the lightning stroke. The point shall be included in the determined overall height of the mast.

2.1.3 Height and Location. Refer to appendix A for determination of mast height and for location as related to structure being protected. Masts of heights up to (12.2 m) shall be single section design. Mast (12.2 m to 21.34 m) in height should be single-section design if delivery to the site is practical. Design for masts in excess of (45 m) receives special consideration.

2.1.4 Zone of Protection. A lightning mast system establishes a zone-of-protection. The-zone-of-protection is described by an arc having a radius not greater than (30.5 m). To prevent side flashes, each mast shall be separated from the structure by not less than one-half of the height of the assumed salient plane, but never less than (2 m). The maximum distance from the structure shall be (7.6 m).

2.1.5 Joint design. Slip-joint design shall meet the following requirements:

a- Assure overall structural integrity of the mast.

b- Include field assembly requirement to assure a snug fit, so that joints of the mast will not loosen when subjected to vibrational modes caused by wind or other means after erection.

c- Be compatible with field erection requirement to assure ease of installation at the site.

d- Have good metal-to-metal contact, so that electrical conductivity will be equal to or better than parent metal used.

2.1.6 Joint Test. After assembly, each joint shall be tested at the site and shall be measured by a digital ohmmeter with a 0.01-ohm resolution and an accuracy of 5 percent of the reading, plus one digit. Tests shall consist of comparative measurements across slip joints, with equal spacing of meter probes at least 4 ft. (1.22 m) apart. An acceptable joint is one yielding a measurement equal to or less than a similar measurement of the parent metal in a given section of the mast, with the same spacing of the meter probes. The lowest meter range providing an indication in the scale region of greatest accuracy should be used. If the meter reads zero or infinity, an incorrect scale has been chosen or the meter is broken.

2.1.7 Metal Mast Foundation. Foundation for setting metal masts shall be in accordance with the following:

a- Steel or aluminum, mounted by anchor bolts set in a concrete foundation poured in place. Following manufacturer's recommendation for foundation design and type and for setting of anchor bolts.

b- Steel mounted by means of a stub set directly into a concrete foundation. Corrosion-resistant steel masts may be set directly into earth where soil conditions permit.

2.2 Grounded Aerial Conductors. Overhead conductors shall be spanned between masts and connected to a ground counterpoise to suit the type of installations. (Refer to Appendix A.)

2.3 Earthed Energy Dissipation Systems

2.3.1 Electrodes. Made electrodes, as defined in the NEC, shall consist of ground rods not less than ¾ in. (19 mm) diameter and 10 ft. (3.05 m) long. Ground rods shall be copper clad steel or solid copper. Connections to ground rods shall be made by bolted clamp type devices.

2.3.2 Ground Counterpoise. Each ground counterpoise shall consist of a (50 mm^2) bare copper cable completely surrounding the facility, with its ends connected together to form a closed loop. The size of any strand of the cable shall be not less than (1.5 mm^2). The counterpoise shall be buried at least 30 in. (762 mm) below grade, external to the structure and away from structural foundations or footings. Each counterpoise shall be fixed by driven ground rods. Connection at each ground rod shall be made with a bolted clamp type device to facilitate disconnection of the counterpoise from the ground rod for periodic testing.

2.3.3 Radials. Radials systems shall consist of (50 mm^2) bare copper cables arranged in a star pattern with structure at the center. The size of any strand shall be not less than (1.5 mm^2). The radials shall be buried at least 30 in. (762 mm) below grade, external to the structure. Each radial shall be fixed by ground rods. Connection at each ground rod shall be made with a bolted device to facilitate disconnection of the radials from the ground rods for periodic testing. Quantity and length of radials shall be as required to provide the required ground resistance. Refer to IEEE 142, Recommendation Practice for Grounding, Industrial and Commercial Power Systems, for resistance calculations.

2.3.4 Plates. The use of plate electrodes is discouraged due to the high cost of achieving proper grounding effects with this system.

Section 3: Installation

3.1 General Lighting protection system shall be provided in accordance with this Manual.

3.2 Design calculation. Design calculation shall consider earth resistance and shall be based upon the soil resistivity for the specific possible. Computer programs available and should be used whenever possible. Project design criteria shall include names of approved computer programs for use in design.

3.2.1 Earth resistance. Maximum ground resistance for any lighting protection system should not exceed 10 ohms. In high resistance soils or rock formation, it may be necessary to provide ground counterpoises for artificial grounds or to sink ground wells. After installation, each system shall be tested by the single, direct reading instrument method. Where characteristics are unknown, trial grounds should be installed and periodically tested during the course of at least 1 year to include seasonal variations.

3.2.2 Soil Resistivity. Project criteria will set forth the specific soil resistivity values to be used for grounding system design.

3.4 Ordnance Facilities. Ordnance facilities shall be protected in accordance with the following criteria: DOD-STD-6055.9; NAVSEA OP, Vol. I; NFPA 78; and Appendix A.

3.4.1 Storage and Handling Facilities above Ground. Provide a primary protection system consisting of lighting masts or overhead conductors spaced around the facility. Connect the masts and all metalwork in the vicinity, such as railroad tracks, metal sheaths of underground cables, and metal piping and conduits below ground that do not extend into the building for other structure being protected, to the primary ground counterpoise. All railroad tracks that extend into the building or structure shall also be grounded at a minimum of 10 ft (3.05 m) from the building or structure.

3.4.2 Earth- Covered Magazines. Provide a secondary protection system. Where metal ventilator provides a salient point above the structure, mount a pointed lightning rod on the ventilator and connect it to the secondary ground counterpoise. A pointed lightning rod should also be mounted on the concrete portal wall and connected to the secondary ground counterpoise. Bond together reinforcing steel by wrapping it with wire and connecting it to the secondary ground counterpoise.

3.4.3 Cranes on Piers and Wharves. Provide a primary protection system consisting of overhead conductors spanned between structural supports and connected to ground rods or to metal plates submersed in water.

3.4.4 Marshaling Yards (Truck and Railroad). Provide a primary protection system consisting of overhead conductors spanned between structural supports and connected to a primary ground counterpoise. Ground all metal parts and reinforcing steel of above grade structures to the ground counterpoise. The reinforcing steel of precast concrete slabs should be grounded, but where inaccessible within the slabs, it is permissible to omit such grounding. Ground railroad tracks 10 ft. (3.05 m) or more outside of barriers at entrances and exits to the yard and where they cross counterpoise.

3.4.5 Railroad Sidings. Provide a primary protection system consisting of overhead conductors spanned between structural supports and connected to ground rods. Ground all metal parts and reinforcing steel of aboveground structure to driven ground rods. Ground all railroad tracks to ground rods located 10 ft. (3.05 m) or more outside of the entrance to barrier.

3.4.6 Electric Service. Electric and communication services to explosives operating buildings and magazines shall be run underground in metallic conduit for the last 50 ft. (15 m). Service to buildings not containing explosives may be overhead. The line side of the main protective device shall be provided with suitable surge arresters. Surge arresters shall be located at the service transition to underground conduit outside the 50 ft. (15 m) limit. A separate ground shall be provided at the secondary electric service entrance. This ground shall be bonded to the facility ground counterpoise. The electric supply to an explosive area shall be arranged so that it can be cut off by switching devices located at one or more control points outside of and immediately adjacent to the explosives areas.

3.4.7 Exterior Overhead Pipelines. Bond overhead pipes which enter a building, storage facility, or area to all metal objects that are within side flash clearance of the pipes where they are in a zone of lightning protection. Pipe segments shall be electrically continuous.

3.4.8 Fences. Fences shall be grounded on each side of every gate, at points 150 ft. (45 m) on each side of high-tension line crossing, and at 150 ft. (45 m) intervals along the fence where high-tension lines (as defined by ANSI C2) are directly overhead and run parallel to the fence. Fences shall be grounded every 1,000 ft. to 1,500 ft. (300 – 450 m) of length when fences are in isolated places and at lesser distances depending upon proximity of fence to public roads, highways, and buildings. The ground shall be made with copper cable. Where plastic coated fabric is used, the post shall be bolted, and each strand of the fence shall be brazed to the metallic bare conductors. The conductors shall then be grounded.

3.5 Generating Plants. Commercial type, Metal-oxide, surge arresters shall be provided on all overhead feeders adjacent to plant as described in paras. 3.5.1 and 3.5.2

3.5.1 Surge Protection. Surge protection shall be provided between the aerial surge arresters and generator or on a bus for several generators. Where a generator is connected to an overhead line through a transformer, provide a station type surge arrester on the high voltage side of the transformer.

3.5.2 Grounding. Provide protection for smokestacks as described in para3.8 and ground all steel columns, trusses, and equipment frames at their lowest points to a low resistance station grounding system.

3.6 Outdoor substations or Switching Stations. All overhead feeders shall be provided with surge rod system. The ground rod system shall be connected below grade to the station ground mat. Refer to IEEE 80, Guide for safety in substation grounding, and IEEE 81, Guide for measuring earth resistivity, ground impedance, and earth surface potentials of a ground system. Additional protection shall be as described in paras3.6.1 through 3.6.3.

3.6.1 Air Terminals. On distribution metal station structures, provide lightning rods at each corner of the stations, extending rods above the structure and the electric conductors. Connect the structure and all equipment frames, transformers, tanks, and bases to a low resistance grounding system.

3.6.2 Grounding Aerial Conductors. In areas where lightning storms are prevalent, install overhead ground conductors above the transmission and distribution system conductors to form a ground wire network over distribution stations. Extend the overhead ground wires out over transmission lines for a minimum of ½ mile (0.8 Km). aerial ground wires shall be grounded at the station and at each pole.

3.6.3 Grounding. Provide a ground system of No.2 (70 mm^2) copper cable, welded to the columns and equipment frames and connected to a ground system. Provide a ground mat afor station supplying distribution voltages and a counterpoise for s substations supplying distributions voltages and a counterpoise for substations supplying utilization voltages. A ground mad shall consist of a system of bare conductors located on or below grade throughout the stations and connected to a counterpoise to provide protection from dangerous touch voltages.

3.7 Transmission and Distribution Lines. Overhead aerial lines shall be provided with lightning protection coordinated with NFGS-16302 and in accordance with standard utility practice at the project location. Acceptable shielding results when a perpendicular line from grade to the ground wire and when a line from the ground wire to the conductor protected to not result in an angle greater than 30°. Overhead ground wires may be steel, copper, aluminum, or copper clad steel, with sizes dependent upon mechanical requirements but not smaller than No.1 (35 mm^2) copper-equivalent. Ground the overhead ground wires at each pole. Where an overhead electric transmission and distribution line transitions to underground, the underground cable shall be provided with lightning protection.

3.7.1 Distribution Line Clearances. The towers or poles support distribution lines operating at less than 69 KV, and unmanned electric substation operating at less than 69 KV, shall not be closer to ordnance facilities than traffic route distances as defined in DOD-STD-6055.9.

3.7.2 Transmission Line Clearances. For transmission lines operating at 69 KV and above, and for electric substations operating at 69 KV and above which are part of system serving a substation off base area, both the towers or poles supporting the lines and the stations shall not be closer to ordnance facilities than inhabited building distances, as defined in DOD-STD-6055.9. When failure of the lines and stations will not cause serious hardships, both towers and poles supporting the lines and the stations may be located at public traffic route distances.

3.7.3 Clearance Calculations. Provide clearance distance calculations shall be based on air blast over pressure only. Fragment distances will not be used.

3.8 Flagpoles and chimneys. Provide grounding at the bases of metal chimneys or flagpoles at the lowest points in accordance with NFPA 78. Provide protection for other chimneys and flagpoles in accordance with NFPA 78.

3.9 Towers and Antennas. Provide grounding at the bases of metallic tower or at the lowest points in accordance with NFPA 78. At least two columns should be connected to an adequate ground by No.2(70 mm^2) copper cable. Provide the same grounding for metallic watch/surveillance tower structures. Structure adjacent to metallic towers and within their zone of protection do not require primary protection, but all metal frames, ventilators, doors, and window frames shall be bonded together and adequately grounded. Provide antenna lead-ins with spark gap protection connected to ground adjacent to supporting structure of antennas.

3.10 Aircraft and aircraft hangars. Provide aircraft and aircraft hangars in accordance with NFPA 78. Grounding receptacles shall be located in accordance with DM-21.1, Airfield Geometric Design, and DM-21.9, Skid Resistant Runway Surface.

3.11 Ordinary Buildings: Provide protection in accordance with NFPA 78. Health care facilities are included under ordinary buildings, except protection for flammable liquids and gases shall apply as appropriate. Where air terminals are located on flat roofs, either near mechanical equipment or in areas traversed by maintenance personal, special consideration must be given to preventing injury from tripping over terminal points, such as installing longer or elevated air terminals.

3.12 Obstruction Lights. Provide air terminals 1 ft. (0.3048 m) above the top of the obstruction lights. Provide surge connected to the lighting circuit conductors and bonded to the lightning protection system.

Appendix-A
Primary Lightning protection for Ordnance handling facilities

1- Scope. The following design method will provide adequate primary lightning protection for ordnance handling buildings with vertical masts, or overhead aerial wiring, in the vicinity of the building to be protected. This associated structures or complexes.

2- General. Experiment have indicated that under certain assumed test conditions, avertical conductor will generally divert to itself direct lightning strikes which might otherwise fall within a cone shape or edge shape space zone-of-protection space in which the apex is the top of the vertical mas, or the overhead horizontal ground wiring of the wedge. In this case, the basis approximately two times the height of the mast or the overhead horizontal ground cable.

2.1 Lightning protection system. The lightning protection system employed wherein is based on the zone-of-protection as determined by clearance arcs and a 100 ft (30.5 m) lightning striking distance. All masts and overhead ground wiring that is used for the protection of a structure must be adequately grounded. If the structure being protected is of metal, grounding must also be bonded to the structure. The ground resistance should not be over 10 ohms. A sufficient number of masts or overhead ground wires must be used so that the entire structure is covered by their zone-of-protection.

3. Application of criteria. The following criteria apply to primary lightning protection:

   a- Basic requirements are an adequate design for lightning protection and economical cost of the system provided.
   b- All three dimensions, the length, the width, and the height, of a structure to be protected by a primary lightning protection system are of major importance in determining the height, number, and location of the masts or the overhead aerial wiring which will be used to protect the structure.
   c- The spacing of the masts along the length of the structure shall be a minimum of 1-1/2 times the height for the masts and a maximum of 200 ft. (61 m).
   d- The distance "(c)" of the masts form the structure shall be one-half the height of the assumed salient plane (s/2) but never less than 6 ft (1.8 m) or more than 25 ft. (7.6 m). In cases where a minor readjustment may be necessary to accommodate road clearance, an exception shall not grossly exceed the limits.
   e- The height of the masts is determined by the equation:
      Equation: $D = \sqrt{([L + 2c)/N\text{-}2]^2 + [(w + 2c + B)/2]^2)}$
      Equation: $M = s + 0.293 \sqrt{(2d)^2 + P}$

Where "M" is the height of the masts, "s" is the height of the assumed salient plane, "D" is the mast spacing on the diagonal axis as determined by equation

(1), with c= 40 ft. (12 cm). "p" is given an empirical value(see Appendix A) according to the value of "D" as calculated from equation (1).

The height of the masts as determined by the formulae is based on the condition that the structure to be protected is located between two parallel rows of masts. To determine the height of the masts, use equation (1), and using c= 40 ft. (12 cm), calculate for D, and then determine M by using the curves of appendix A, chart No. 1.

- f- The protection of a structure by self-standing vertical masts dictates that the distance from the center line of the structure or complex to the masts on the normal or the diagonal axis must not be more that 100 ft. (30.5 m). When this condition cannot be met, the protection for the structure or complex will be by overhead ground wiring. To determine the final distance, D1, along the diagonal axis, use Equation (1) substituting D1 for D, with C values between 6 ft. (1.8 m) minimum to 25 ft. (7.6 m) maximum. D1, shall not exceed 100 ft. (30.5 m)
- g- When overhead ground wiring are used for protection, support the overhead ground wiring on masts located at the vicinity of the protected structure at distance from the structure established as 6 ft (1.8 m) minimum to 25 ft (7.6 m) maximum. The lowest point of mid-span sag in the overhead ground wiring above the salient plane of the protected structure is to be no less than 10 ft. (3.05 m) increase the distance of cable which is run parallel to the structure by 1 ft. (0.3 m) for each 10ft (3.05 m) of horizontal cable greater than 50 ft. (15 m). Determine mid-span sag of the overhead ground wire from the curve of Appendix A.

4- Graphic examples. In appendix A, example 1: L, W and S are known, c is given the value of 40, B=18 ft. (Explained in Appendix A, A-1 Definitions of terms), and N is equal to 6. In equation (1) substitute these values and D is found to equal 98.5 ft. In appendix A, A-1, refer to the curves at point 98.5 ft (30 m) on the horizontal scale, then extend vertically to the 50 ft. slant line, and carry horizontally to the vertical scale, again using equation (1) and substituting actual distance c = 6 ft. (1.8 m) minimum to 25 ft. (7.6 m) maximum, this will show a mast height of 95.5 (29 m).
In accordance with Para. 3, Appendix A, determine actual D1 distance from the center-line of the building or complex to row of masts on the diagonal axis.

After the height and location of the masts have been determined, proceed as follows:

- a- Draw a plan of the building to scale. Locate the masts at distances which are determined by the method shown in Appendix A, Example 1.
- b- Draw an elevation of the building to scale. Locate the masts at distances which are determined by the method shown in Appendix

A, A-3. Draw a 100 ft striking distance radius from the apex of the masts to the center-line of the building or complex as shown. Draw two arcs (the normal axis and the diagonal axis clearance arcs) as shown in Appendix A, from the point of intersection with the center-line of the building. These arcs must clear the salient plane.

c- Draw a lengthwise scale elevation of the building. Locate the masts as shown in Appendix A, A-5 (refer to para. 4b, Appendix A). No part of the protected building should lie outside the zone-of-protection. Appendix A provides examples which illustrate application of this principle.

5- Facilities other than structures. The following criteria apply for facilities other than structures.

a- This type of facility can be protected by using overhead ground cable spanned between two metal towers or poles which are effectively grounded and meet criteria in para. 3, Appendix A.

b- In this system, the overhead cable will intercept lightning strikes and the resulted electrical current will be safely carried to ground via the cable and supporting towers or poles.

c- The design method establishes the height of the horizontal ground cable at mid-span to provide the required zone-of-protection for a specific facility.

d- The mid-span sag of the overhead cable must be included when the height of the supporting towers or poles is determined (See Appendix A).

e- Selection of cable is based on mechanical strength rather than electrical considerations. The overhead ground cable should be stranded, non-corrosive, copper coated steel wire. Minimum size shall be 3/8 in. (9.5 mm) high strength (7 No. 8 strands).

f- The construction of the towers and their structural members or the class of poles should be based on considerations of mechanical and wind loading stresses.

g- Appendix A illustrate lightning protective by overhead ground cables for railroad and truck marshaling yards, railroad siding and detail of overhead ground wire supporting poles and counterpoise. Pier and wharves should be protected by meeting requirements stated in paras. 1 and 3, Appendix A.

h- To check the adequacy of the zone-of-protection when the height of supporting towers or poles is determined, draw sketches to scale as shown in Appendix A. The effective height of the overhead ground cable shall be maintained between the low point of the sag and the protected facility.

Electrical Engineer
Roshna Rasheed Abdullah