CHAPTER 2
LIGHTNING PROTECTION

2-1. Discussion

a. Lightning phenomena. The 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 thunderstorms occurring thousands of times daily around the earth return electrons to earth to maintain 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 9 microampere for every square mile of earth's surface. Thunderstorms supply electrons back to earth by an opposite electron potential gradient of perhaps 10 kilovolts per meter within a thundercloud. This feedback forms a potential difference of from 10 to 100 megavolts in a single discharge between the center of a cloud and earth. These lightning discharges carry currents varying from 10 to 345 kiloamperes to earth at an average rate of 100 times per second with duration of less than ½ second per flash. Each flash consists of up to 40 separate strokes, Each stroke of lightning lasting for this brief instant 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 lamp. Lightning discharges do not always bring electrons to earth, because so-called positive ground-to-cloud strokes consist of low power energy transmissions from earth to small negative charge pockets in a thunder cloud. However, magnitudes of discharge voltages and currents are approximately the same from cloud to earth, and all occur within the same discharge timeframes. Just before the lightning flash, the ground within a radius of several miles below the cloud becomes deficient in electrons. Repelled by the army of electrons in the cloud base, many of the free electrons on the ground are pushed away. The result is that the ground beneath the cloud base becomes more positively charged. As the cloud moves, the positive charge region below moves like its shadow. As the cloud charge balloons, the pressure becomes so great that a chain reaction of ionized air occurs. Ionization is the process of separating air molecules into positive ions and negative electrons. This air which is 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 the initial or stepped leader. As the leader nears the ground, its effects create an ionized streamer which rises 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 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.

b. Nonconventional systems. Nonconventional and unacceptable systems include the so-called dissipation array, and those using radioactive lightning rods, Radioactive lightning rods have been proven less effective than passive air terminals in storm situations. These systems have not been recognized by NFPA or UL. Use of these systems will not be permitted unless specifically approved by the appropriate using agency. Dissipation arrays consist of two types:

(1) A high tower with top-mounted dissipation suppressor, and radial guy wire array. This type is used on isolated high towers, antenna structures and offshore facilities.

(2) A series of high towers located beyond a given area to be protected and supported by a number of sharp pointed strands of barbed wire for the protection array.

c. Code applicability. NFPA No. 78 is intended to apply to the protection of ordinary buildings, special occupancies, stacks, and facilities housing flammable liquids and gases. The lightning protection code will be utilized where lightning damage to buildings and structures would cause large economic loss or would prevent activities essential to the Department of Defense. NFPA No, 78 does not relate to the protection of explosives manufacturing or storage facilities. Protection for these facilities will be in accordance with paragraph 2–9. Since NFPA No. 78 does not prescribe a comprehensive coverage pattern for each type of facility required by the military departments of the government, additional guidance is given in this chapter. Temporary DOD storage facilities and structure housing operations not regularly conducted at a fixed location and other facilities specifically ex-

empted by the responsible using agency are not governed by the lightning protection code.

d. Effects of lightning discharges.

(1) General. When any building or structure is located within a radius of several hundred feet from the point where a lightning discharge will enter the surface of the earth, the lightning discharge current becomes so high that any building or structure within this radius becomes vulnerable to immediate damage.

(2) Nature of damage. Damage may range from minor defacement to the building to serious foundation upheaval, fire and personnel casualties. Damage control can be effective dependent on extent of fireproofing and lightning protection incorporated into the project design. Although lightning strokes generate static discharges in the form of radio noise, it is generally accepted that these cause only an instant of interference to manmade electronic systems. Increased heating effects are also a factor since a lightning bolt increases the temperature of the lightning channel to about 15,000 degrees C. This sudden increase in temperature and pressure causes such an abrupt expansion of air that any hazard type of atmosphere which comes within the ionized air path of the lightning bolt becomes explosive. The explosive nature of the air expansion of bolt channels can cause physical disruption of structures located near the lightning stroke. Lightning discharges below the earth surface sometimes fuse sand into fulgurates which appear like glass tubes. Trees of 40 feet or more in height are especially vulnerable targets for attraction of lightning discharges, and are susceptible to being totally destroyed.

e. Effective resistance to ground.

(1) The lightning protection system will be designed to provide an electrical path to ground from any point in the system, and that point will be of considerably lower resistance than that otherwise available by use of the unprotected facility.

(2) Low resistance to ground is desirable for any lightning protection system but not essential. This is in conformance with NFPA No. 78 and MI L–HDBK–419. Where low resistance to ground is mandatory, grounding electrode patterns as described herein and MIL-HDBK-419 will furnish ample length of electrical path in contact with earth to dissipate each lightning discharge without damage to the protected facility.

2–2. Limitations in use of lightning protection

a. General. Lightning protection will be installed as part of the initial construction project, particularly in view of long replacement time and high cost of structures. Installation cost of lightning protection systems during project construction is small when compared to the cost of the installation as a whole. Economic and operational considerations will be made in determining the need for lightning protection system, unless otherwise directed by the using agency. Unless lightning frequency at the project site averages five or less thunderstorms per year, as indicated in figure 2-1, lightning protection will be provided for buildings and structures as follows:

(1) Buildings of four floors having elevator or stairwell penthouses or other similar projections above roof.

(2) Buildings of five floors or more with or without projections above roof.

(3) Structures such as steel towers, aluminum and reinforced concrete towers, and flagpoles without inherent grounding, and smoke-stacks and steeples of 50-foot elevation or more above lowest point of contact with finished grade.

b. Other applications. Special consideration will be given in determining need for lightning protection as follows:

(1) Whether building is manned, and there is inherent hazard to personnel.

(2) Whether building contains explosive or hazardous areas or rooms, weapons systems technical equipment, or security communication equipment.

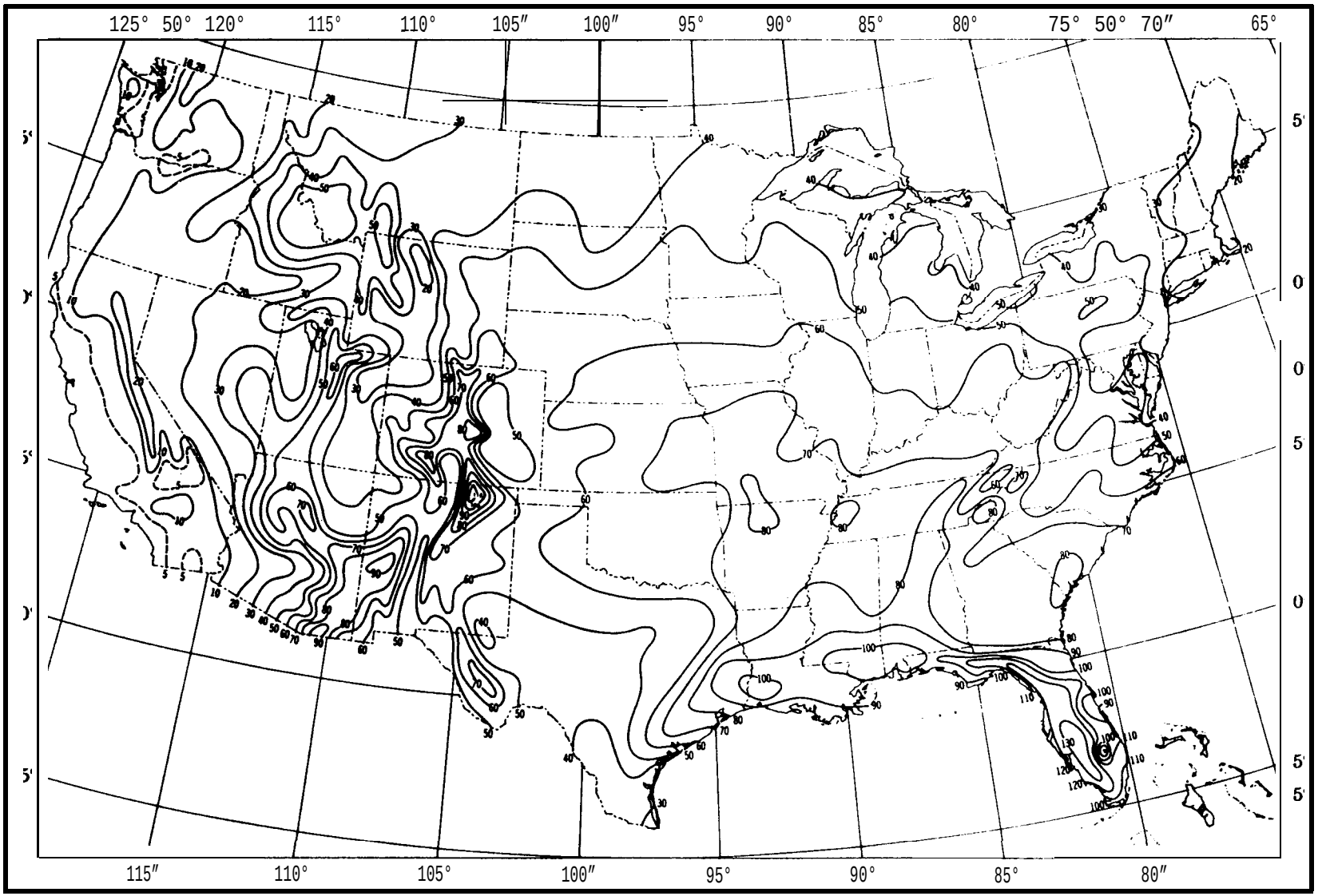
(3) If an unprotected building is destroyed by lightning, the length of outage which can be tolerated until replacement is made. This includes the restoration of high priority facilities such as water supply, weapons systems, police and security intelligence communications, strategic communication system operating components.

(4) Replacement of building contents and value thereof.

2–3. Air terminals. The purpose of air terminals is to intercept lightning discharges above facilities. Air terminals will be in accordance with UL 96, and 96A, NFPA No. 78 or MIL–HDB-419. Where building roof is not metal and building construction includes steel framing, air terminal connection assemblies will conform generally to figure 2-2.

2-4. Grounding

a. General. Grounding generally will conform to NFPA No. 78, except as required by this manual or by the using agency. Guidance for grounding for purposes, such as electromagnetic pulse (EMP), electromagnetic interference shielding, NASA and HQDCA electronic facility grounding, are subjects of other engineering manuals which govern grounding requirements. Those grounding systems will also serve as grounding of the lightning protection system. Where separate systems are installed such systems will be bonded below grade to any other independently installed exterior grounding system such as for electro-



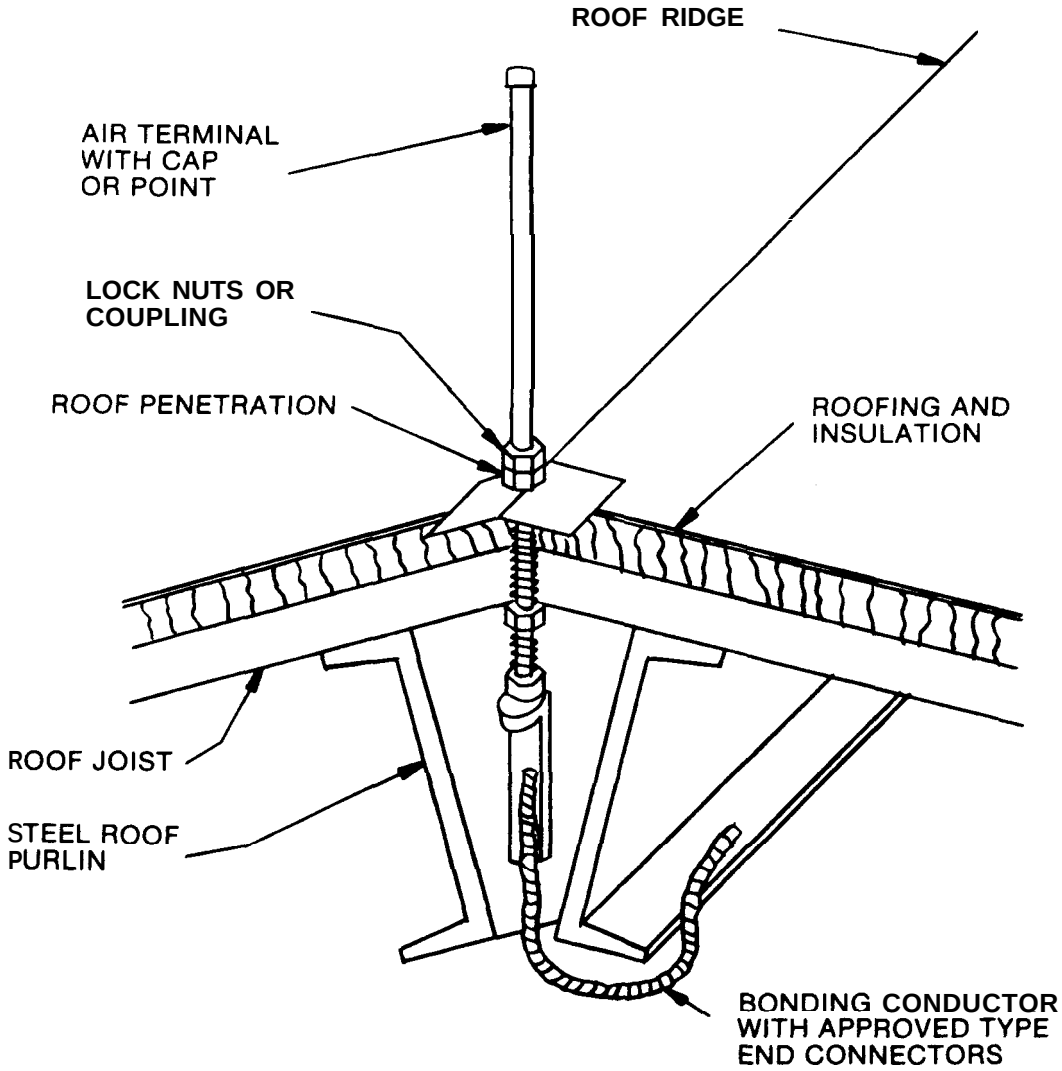
National Oceanographic and Atmospheric Administration

Figure 2-1. Mean number of thunderstorms--annual

magnetic shielding not suitable for complete lightning protection system. However, exterior protection grounding system will be bonded to static electricity exterior grounding system.

b. Ground rods. Ground rods will be not less than 10 feet in length, nor less than ¾-inch diameter pipe or equivalent solid rod. Ground rods will be located clear of paved surfaces, walkways, and roadways. Rods will be driven so that tops are at least six inches below finished grade, and three to eight feet beyond perimeter of building foundation. Where ground rods are used with a counterpoise, tops will be driven to same elevation as counterpoise below finished grade. Exact location of rods must give preference to use of moist earth. Contact with chemically injurious waste water or other corrosive soils wiIl be avoided. Where avoidance of chemically injurious or corrosive soils is impracticable, use of stainless steel rods and magnesium-anode protection will be considered. Driving stud bolts will be used for driving, and couplings will be used for sectional rods. Where buried metal pipes enter a building, the nearest ground rod will be connected thereto.

c. Earth electrode subsystem. Each earth electrode subsystem or counterpoise will consist of one or more closed loops or grid arrangement of No. 1/0 AWG bare copper conductors installed around facility perimeter not less than 2 feet below earth surface. Larger conductors should be used when installed in highly corrosive soils. A second loop, if used, should not be less than 10 feet beyond the first and inner loop. At least 2 ground rods should be provided at each corner of each counterpoise loop where earth-seeking current tend to concentrate. Counterpoise



US Army Corps of Engineers

Figure 2-2. Typical air terminal assembly using steel, framing as protective system conductor

will extend not less than 3 feet nor more than 8 feet beyond the perimeter of building walls or footings. Conductor ends, connections to down conductors, tops of ground rods, and crossovers will reconnected for electrical continuity. Figure 2-3 illustrates a below grade weapons system facility counterpoise. Pattern will be as required in this manual or as required by using service.

d. Radials. A radial system of grounding consists of one or more No. 1/0 AWG copper conductors not less than 12 feet long, extending away from each ground rod or grounding connection. The use of multiple radials is an effective form of grounding, offering substantially lower reactance to the high frequency of lightning current wave fronts than do single straight conductors. Installation of grounding radials will take advantage of crags and cracks in surface rock formations in obtaining maximum available earth cover. Connections of radials to down conductors will be made so as to insure electrical continuity.

2-5. Nonreinforced concrete or wood frame buildings. Lightning protection will be provided on outside of exterior surfaces without reliance upon components of building for conductors. Fasteners for conductors will be other than aluminum on concrete, and will be selected for attachment to building concrete or wood.

2–6. Reinforced concrete buildings. Reinforcement steel may be used for down conductors in conformance with NFPA No. 78 and if approved by the using agency. Joints should be made in no fewer than every fifth reinforcement rod and at corners of building. Joints will be made electrically conductive and will be connected top and bottom for connections to roof conductors and to grounding electrodes, respectively. Grounding pigtails from bottoms of reinforcement fabric will be connected to exterior grounding system at same or lower elevation as that where pigtails leave walls and footings.

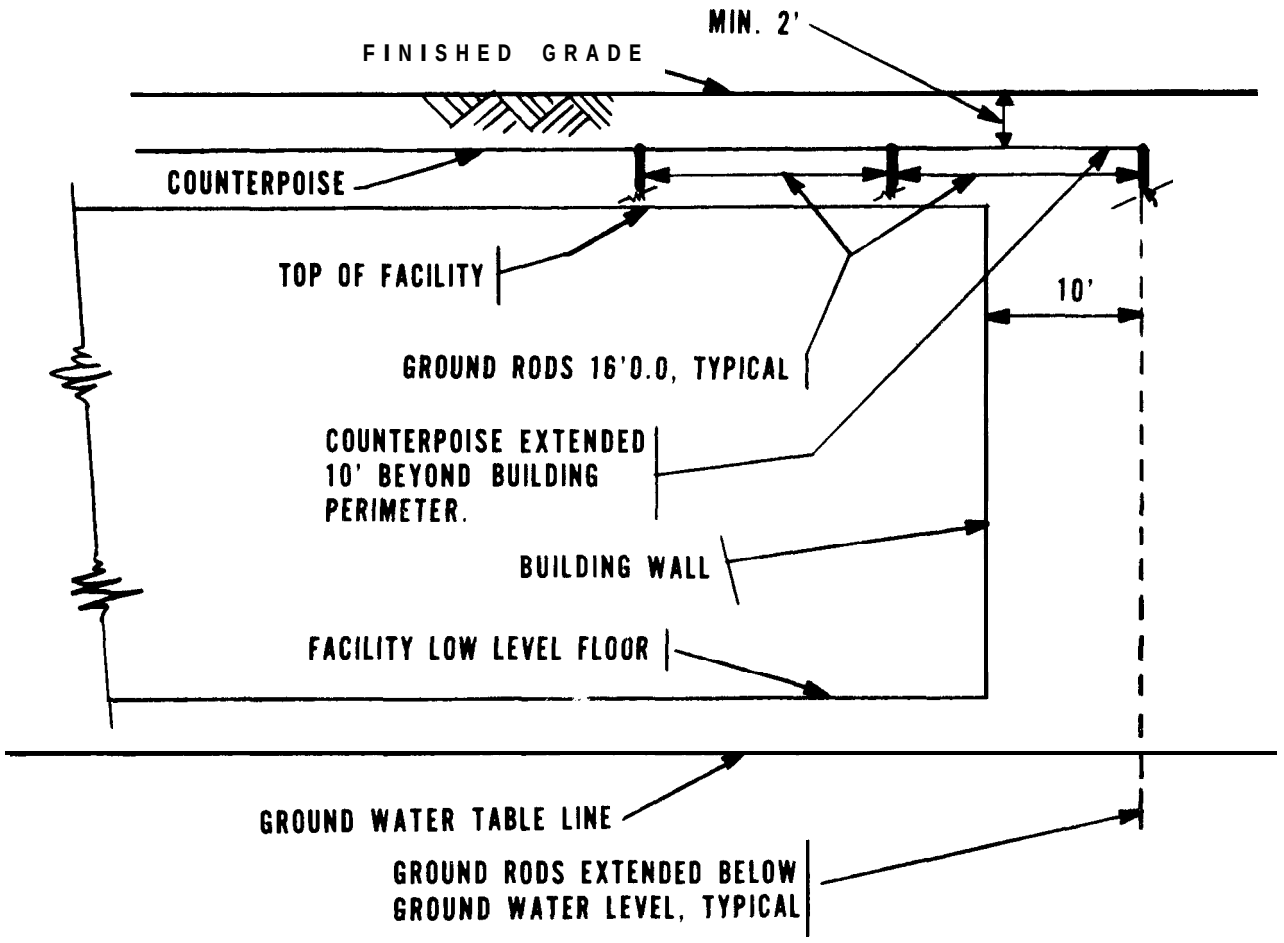


Figure 2–3. Below grade weapons system facility counterpoise, cross section elevation

2-7. Steel frame building with nonconducting roof and sides. Air terminals will be provided and installed in conformance with figure 2-2 and paragraph 2-3. Not less than one steel column will be grounded at each corner of building.

2–8. Metal clad building with steel framing. Steel columns of metal clad buildings will be bonded top and bottom to metal siding. Except for facilities used for storage of propellant type weapons and unless the using service guidelines or requirements differ, air terminals may be omitted from building containing no hazardous areas.

2–9. Building containing hazardous areas. Metal containers of hazardous materials will not be located within 10 feet of lightning protection system. Any metals within hazardous atmospheres having connections to other metals within 10 feet of lightning protection system will be bonded to the nearest lightning protection system down conductor. Metal doors and windows within hazardous areas will be included in such grounding, and doors will be bonded to metal framing by flexible braid-type copper conductors, and connected to lightning protection system.

2–10. Classified communications building. Lightning protection and grounding of communications facilities will comply with MIL-STD-188-124 and MI L–HDBK-419.

2–1 1. Aircraft control-navigation aids.

a. General. These facilities are considered of such importance that aircraft pilots must be assured of reliability, particular when landing during any lightning storm, and when pilot's visibility is severely limited. Counterpoise grid g-rounding system will be provided for each building.

b. Instrument landing system (ILS), tactical air navigation (TACAN) and ground control approach (GCA), facilities. One-floor frame buildings housing equipment for ILS and TACAN facilities and other similar type structures will be protected as described in paragraph 2-5; however no fewer than two air terminals will be provided on each facility. Transmitter and receiver buildings for GCA facilities will be protected as described in paragraph 2-6.

c. Control towers. Protection will be provided independently of antennas and other superstructure. These terminals will be interconnected around top perimeter of control tower for connections to down conductors.

2–12. Igloos. Protection for corrugated steel arch earth-mounted igloos, also called "magazines", will be provided as required by the using agency. Metallic conduits containing electrical conductors will be bonded to steel arch, and all will be grounded in conformance with paragraph 24.

2–13. Fences. Metal fences that are electrically continuous with metal posts extending at least 2 feet into the g-round normally require no additional grounding. Other fences should be made electrically continuous and grounded on each side of every gate. Fences should all be grounded every 1,000 to 1500 feet when located in isolated areas; and every 500 to 750 feet when located within 100 feet of public roads, highways and buildings. All metal fences will be grounded at or near points crossed by overhead powerlines in excess of 600 volts and also at distances of 150 feet on each side of the line crossing.

2–14. Railroads. Rails that are not electrically continuous and that extend within 100 feet of facilities used for storage, manufacturing, processing or handling explosives, explosive ingredients. explosive gases, or flammable liquids will be bonded together with flexible copper cables or straps and grounded. Switches will be bonded to rails. Where overhead power lines in excess of 600 volts crosses railroads, the rails will be made electrically continuous and grounded at a distance of 150 feet on each side of overhead lines. Where tracks are located within 25 feet of structures with a grounding system, the tracks will be grounded to the structural grounding system. This is to effectively discharge potentials generated by static electricity and lightning before such discharges are permitted to accumulate or otherwise cause an air gap spark to ignite loose hazardous materials. Isolation points should be provided in the tracks outside of hazardous areas to avoid stray currents from being conducted into the bonded or grounded area.

2–15. Weapon system electronic facilities aboveground

a. General. This guidance pertains to designs for the protection of radars, antennas, electronic equipment vans, launchers, missile controls, and guided missile batteries when permanently installed. Any lightning stroke may damage or destroy such electronic weapon facilities by blast effect or by creating surges in connecting wiring. A direct stroke could ignite magnesium portions of van walls, cabinets, consoles, and radar antenna castings. When lightning occurs with rain, moisture encourages burning of magnesium and splattering of molten metal. Protection for weapon support buildings is as required by construction types discussed in previous paragraphs.

b. Protection pattern. Patterns will comply with NFPA No. 78. When structure is a van type, pole will be located opposite middle of van's longest side, and not less than 6 inches from concrete base of van

to pole. One pole may serve two van units having long sides parallel and located not more than 12 feet apart. Protection equipment will be located and arranged in a manner that will not obstruct the operation of any radar electronic acquisition or tracking beam.

c. Protection system. Down conductors of not less than No. 2 AWG bare copper on pole will be provided from lightning rod to ground rods located not less than 6 feet from van and not less than 6 inches from edge of hardstand. Spiral type grounds under poles (butt grounds) are acceptable. Pole guys will be electrically conductive to ground, and guy anchor will be interconnected to pole ground rod below grade. Each ground rod at pole will be interconnected below hardstand to ground rod of' van grounding system. Where vans are clustered, van ground rods will be interconnected in compliance with MIL-HDBK-419.

2–16. Weapon system electronic facilities below ground

a. Protection included with other protection systems. When external grounding system design is included for electromagnetic pulse (EMP) protection, electromagnetic interference shielding or other protection system, separate lightning protection will not be required.

b. Protection not included in other protection systems. When external grounding system design does not include EMP protection, electromagnetic interference shielding or other protection system, lightning protection counterpoise will be provided including connections to metallic objects below grade, such as the following:

(1) Electrical conduit.
(2) Mechanical piping.
(3) Metal tanks.
(4) Manhole grounds.
(5) Missile cells or equivalent.
(6) Internal grounding system of control buildings and power plants.
(7) Metal ducts for fans.
(8) Tunnels.

The main counterpoise will be installed above each buried weapon system building, at least 2 feet below finished grade, and will extend beyond the building perimeter not less than 3 nor more than 8 feet. Main counterpoise will be connected to ground rods located as in figure 2–3, and driven to a point at least 6 inches below normal ground water table level, where earth is available for driving. See also above for building reinforcement system grounding. Metal equipment extending above ground will be grounded to protection system counterpoise.

2–17. Electrically-controlled target training system

a. General. Reliability of continuous operational availability of electricallty-cont rolled target systems for rifle squad tactical ranges is of such importance to infantry training in the scheduling of firing periods and to morale of' large numbers of troops that provisions of lightning protection is warranted. Lightning protection for rifle range support facilities need not be provided.

b. Control tower. Complete protection system will be provided. The system should have at least two air terminals installed on roof.

c. Target control system. Where a control relay is separately provided at each target mechanism box assembly station of such rifle ranges, lightning protection counterpoise or grid will not be required for protection of down range target area. Where such control relays are not provided, grounding counterpoise or grid will be provided above wiring in trenches below grade to all targets from control tower.

2–18. Petroleum oil lubricants (POL) facilities

a. Storage tanks. Generally, protection for storage tanks will depend on their inherent contact with earth. Where steel storage tanks are constructed on foundations of concrete or masonry, grounding will be provided in accordance with grounding schedule show-n in table 2–1, regardless of tank height. Where steel tanks are constructed in direct contact all around the perimeter with not less than 18 inches of earth, grounding will not be required. See AFM 85-16 for additional requirements pertaining to Air Force facilities.

Table 2-1. Fuel Storage Tank Grounding Schedule

Tank Circumference—Feet	Ground Connections Minimum Number
200 And Less	2
201 Through 300	3
301 Through 400	4
401 Through 500	5
501 Through 600	6
601 Through 800	7
801 And More	8

b. Pump house. Protection for POL pump house will be provided complete as required for the applicable type of building construction.

c. Fill stands. Protection for fill stands will conform to NFPA No. 78.