U.S. Army Training and Doctrine Command

Guide for Lightning Protective Measures for Personnel

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1.0 Introduction

This document is intended to provide information to installations for the development of defenses against lightning for the protection of personnel.   It provides a concise discussion of lightning phenomena, hazards, personal defenses and engineering defenses.

In Army operations, lives are lost and many injuries are incurred each year by lightning. Analysis of these mishaps indicate that some simple steps, based on knowledge of lightning and the associated hazards, may have prevented some of these accidents.

1.1 The "Typical" Lightning Accident

Although there is probably no such thing as a "typical" accident, most Army lightning mishaps have several things in common. These are:

-Troops are in unimproved shelters, usually in tentage, or in the open.
-Troops are working with antenna/mast equipment.
-Troops are using field phones.
-Troops are not informed about lightning hazards and consequently took no action.
-Troops had no prior warning of approaching lightning other than audible and visual warnings.
-Troops are most often affected by indirect lightning current, rather than being directly struck by lightning.

The most severe mishaps occur while troops were in the field, sleeping in tents. Lightning then strikes nearby, to a tree or even to the tent pole and the resulting current from the strike affects soldiers nearby. Fatalities from indirect lightning events have occurred at ranges of 40 to 60 feet from the point of the lightning strike.

1.2 Lessons Learned

From the review of the accidents, we have learned that there are three essential elements of personnel protection from lightning.

1 – Knowledge; What to do if lightning threatens, development of a plan to protect troops. Knowledge of first aid procedures for electrical shock is also important.

2 – Warning; Advance warning of approaching lightning.

3 – Shelter; Where to take shelter from lightning. Consider that many structures that provide shelter from the elements will not protect from lightning effects and actually increase risk.

In this guide, we address all three of these elements and provide guidance for implementation.

2.0 Discussion of Lightning Phenomena and Hazards

2.1 Introduction to Lightning Hazards

To better understand how to protect personnel and facilities from lightning we will briefly discuss lightning characteristics, the lightning attachment process and lightning hazards.

2.1.1 Lightning Parameters

A lightning strike is essentially a high amplitude direct-current pulse with a well-defined waveform. While there are several types of lightning, the type that concerns us is **cloud to ground** lightning. Understanding of the waveform of cloud to ground lightning is useful to the designer in formulating a protection system. Precisely how lightning is generated and how it is propagated to earth does not impact design greatly, therefore it is not within the scope of this report. The lightning pulse is divided into four parts, components A to D. Figure 1 illustrates a lightning waveform. Component A is the high-current pulse. It is a direct current transient that has been recorded to reach up to 260,000 amperes and last for a duration of up to 200 microseconds. Typical rate of current rise with respect to time is 3×10^{10} A/s, but could reach 2×10^{11} A/s. On the average, it will reach 20,000 amperes for a 50 microsecond duration. Strikes above 200,000 amperes are considered rare. Component B is a transition phase on the order of several thousand amperes. Component C is a continuing current of approximately 300-500 amperes that lasts up to .75 second. The last component, D, not shown, is a restrike surge that is typically half that of component A in a given strike. It has generally the same duration as component A. Typically 3 or 4 restrikes will occur in one lightning event but the maximum observed is 26 restrikes in **one** lightning event. Sources differ on the magnitude of 'D'; some state all restrikes are one-half the magnitude of the A component and some sources imply that the D component continually decreases by one-half (e.g., 1/2A, 1/4A, 1/8A, etc.).
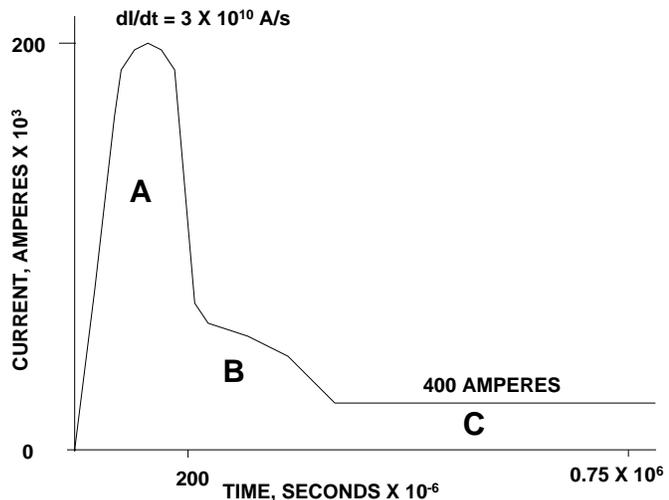

Figure 1 Representative lightning event.

2.1.2 Lightning Attachment Process

Let us examine how lightning interacts with the ground and how it attaches to objects on the ground. Most lightning that reaches the ground (over 90%) is negatively charged. It begins to intercept the ground by lowering a stepped leader - a precursor to the actual lightning discharge. This leader progresses in steps toward the ground and is comprised of electric charge. It

completes this process in a length of time measured in tens of milliseconds. Below the leader is a region of very high electric field. As the leader approaches the earth, the high electric field induces objects on the ground to emit leaders of opposite polarity charge. Since opposite charges attract, the path of the downward leader is influenced by an upward leader of opposite polarity. Upon connection, the actual current discharge associated with lightning begins as shown in figure 2.
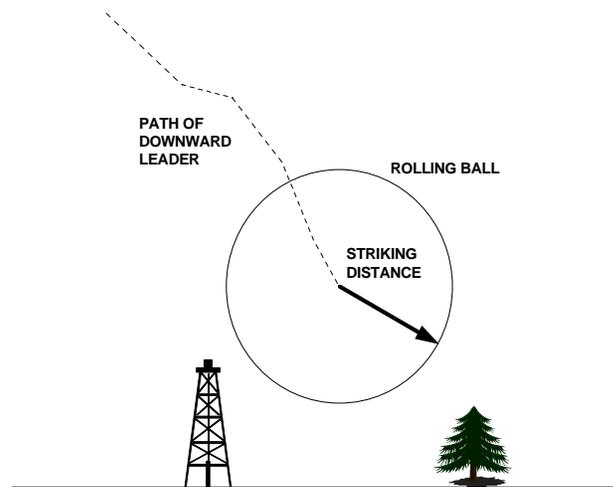
2.1.3 Rolling Sphere Model of Lightning

The final step in the lightning attachment process occurs at a point during the downward leader progression, when the leader "decides" toward which upward leader it will travel. As the downward leader approaches the objects on the ground, it is attracted to upward emitted leaders. A model of lightning propagation used today to represent this final step is the rolling sphere model as illustrated in figure 3. It's important to point out that this is largely an empirical model that models the observed behavior of lightning.
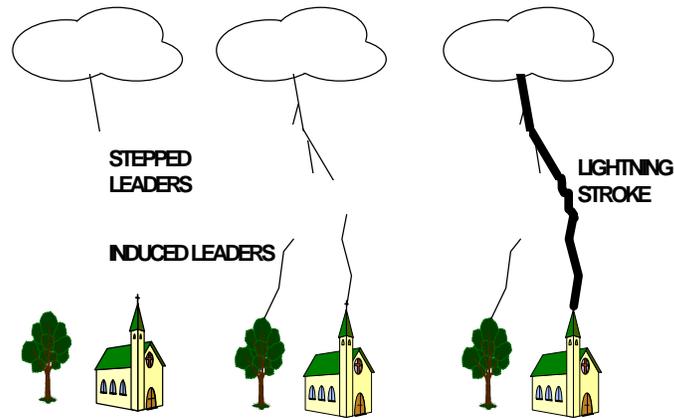
Figure 2 - Illustration of Lightning Attachment.

Once the downward leader is within a certain radius, known as the striking distance, the upward and downward leader attract and connect. The striking distance is defined in the NFPA 780 as the distance over which the final breakdown of the initial lightning stroke occurs. The sphere used in the model eventually intersects an object on the earth's surface. This object can be a tree, structure or person.   At that time, we expect that the tip of the leader located at the center progresses rapidly toward the object intersecting the sphere. Taller objects generally have an advantage since they are closer to the stepped leader and begin to emit their own leader sooner.   From this type of model, we derive the concept of attractive area, which is explained in the next section.

Figure 3 - **Rolling Sphere Model of Final Lightning Attachment Step.**

2.2 Assessment of Lightning Risk

To determine the probability of strike several variables are considered such as geographical location, time of year and structural configuration.

2.2.1 Probability of Strike

The first aspect of lightning risk is the probability of strike. The procedure used to assess a probability of strike is to calculate an "attractive area" for the object in question. The term "attractive area" is the common phrase used but is really not the best choice of words since lightning events initiate without influence from features close to the ground. The attractive area really represents a zone where there is a high probability of lightning striking the object in question in the event that lightning initiates overhead within that zone. Once the attractive area is known, it is compared with the flash density to find the expected number of lightning attachments to the object within a period of time. A coefficient is also sometimes used to account for other objects/structures nearby.

2.2.2 Determination of Lightning Attractive Area

A key variable in the assessment of lightning probability is the lightning attractive area, A_e. Strike frequency is proportional to the attractive area. The attractive area is determined by finding the area of the structure and adding a region equal to three times the structure height. Expressing this mathematically, we find the attractive area:

$$A_e = LW + 6H(L+W) + 9pH^2$$

Where: L= length [km], W= width [km], H= height [km]

In cases of a prominent singular structure or prominent part of the structure, then the attractive area reduces to:

$$A_e = 9pH^2$$

2.2.3 Geographical Factors

The next step in the probability determination is to find the product of the attractive area and the lightning flash density of a given particular geographical area and account for the local environment of the structure. Flash density is the expression of the number of lightning events in a given area per unit time. Typically, the flash density is expressed in flashes per square kilometer per year.

The map in figure 4 shows the expected annual flash density within CONUS.

To account for the local environment of the object, we use an environmental coefficient, given in the following table.

Table 1 – Determination of Environmental Coefficient, C_1	
Relative Structure Location	C_1
Structure located within a space containing Structures or trees of the same height or taller Within a distance of 3H.	0.25
Structure surrounded by smaller structures Within a distance of 3H	0.5
Isolated structure, no other structures located within a distance of 3H.	1.0
Isolated structure on a hilltop	2.0

Mean Annual Ground Flash Density
(flashes/km²)
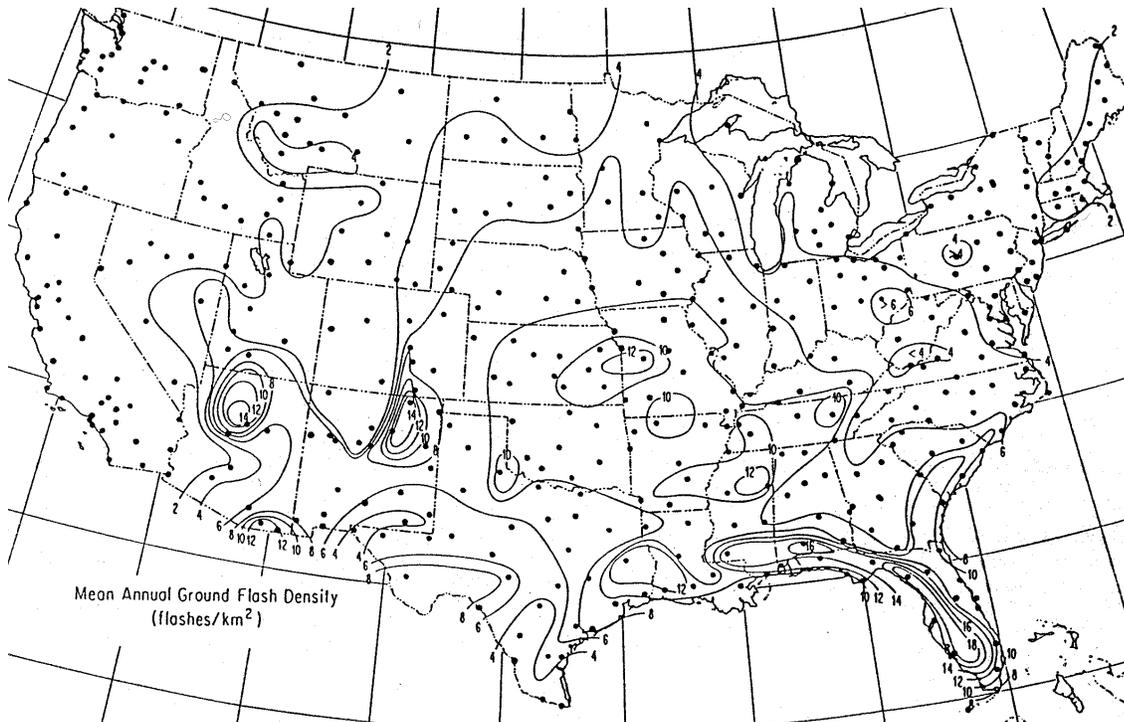
Figure 4 Mean CONUS Annual Lightning Flash Density

Finally the strike frequency to an object is given by the product of the attractive area, flash density and the environmental coefficient.

$$N = D_f A_e C_1$$

where: D_f = flash density [flashes/km^2 per year], A_e= attractive area [km^2], C_1 = environmental coefficient [no unit].

As an example, a structure of 3 by 10 meters, and 3 meters high, would have an attractive area, $A_e = 2.7 \times 10^{-4}$ km^2. If $D_f = 6$ flashes/km^2 per year if the structure were in a clearing, meaning use $C_1 = 1.0$, then the expected frequency of strike would be N= 1.6×10^{-4} or about 0.16 % per year. If the same structure was in a heavily wooded area, then $C_1 = 0.25$, decreasing the chance of strike to 0.04 % or if it were on a hilltop, increasing the chance of strike to 0.32 %.

Although these values seem small, if the total area of all structures on a post were added together and considered, we would find that several strikes are expected to structures on the post within a year's time. If we also consider that some given area of terrain is occupied by troops in the field for most of the year the same calculation is valid. Consider that if one square kilometer is occupied by troops in the field most of the year, we would expect about 6 strikes per year near troops. (No environmental factor is applied since troops in the open are more susceptible to lightning effects, as will be explained in the next section.)

2.3 Personnel Hazards

The danger from lightning is not confined to a direct lightning strike. Most lightning injuries (and almost all Army lightning injuries/fatalities) come from indirect effects of nearby lightning strike. The two prominent effects are step potential and flashover.

2.3.1 Step Potential Hazards

We can expect a significant voltage difference near the point where lightning current enters the earth. In figure 5 we model the current injected flowing outward through thin "shells" in the earth, each with an incremental resistance, which develops an incremental voltage, dV, over the surface of the earth. This is known as the **step potential**, named after the potential drop across human (or animal) feet in the space of a step. Step potential developed from lightning effects, or even large fault currents, can be lethal. Figure 6 illustrates the hazard from step potential. If current (I_{1-2}) on the order of tens of thousands of amperes (a typical lightning event) is injected on the left of the figure, the resulting potential (voltage) difference (V1-V2) over the illustrated step length can easily be tens of thousands of volts. Since there is a voltage difference between two points (feet) and the human body presents an impedance, a current can flow resulting in shock. The magnitude of the current (Ib) depends on the foot contact impedance (Rf) and the body impedance (Rb).
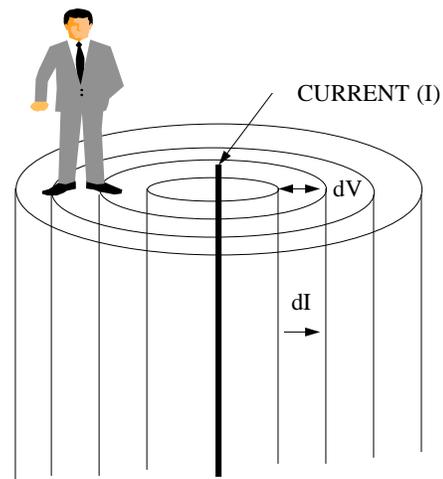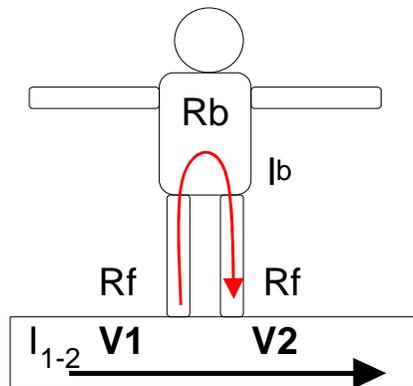

Figure 5 Step Potential.

Figure 6 Body current path induced by step potential.

The step potential hazard is manifest in situations where people perceive that they are safe. Many step potential accidents occur when people are gathered in a tent, under a tree, or other unprotected structure (like the huts on golf courses) that is hit by lightning. Even though there is no direct strike to personnel, injuries and fatalities from the resultant electrical shock can (and do) occur. Protection from step potential is an important design consideration for personnel protection.

2.3.2 Flashover Hazards

Flashover occurs when lightning attaches to something that has a relatively high impedance path to ground. A good example of such an event is lightning striking a tree.   The tree presents a path to ground, but the path has a high impedance compared to that of a properly installed, well grounded lightning protection system. If we model the lightning as a current (I) source and the object through which it is passing as a general impedance (Z) we see that a significant voltage can develop on the object. If this voltage exceeds the air breakdown value (approximately 10^6 volts/meter) the lightning current may jump from that object to another grounded object in the vicinity.

In figure 7, we illustrate the flashover effect. If lightning were to attach to a tree current would flow through the tree to ground.   This usually causes significant damage to the tree from the rapid heating and expansion of moisture within the tree. Note we are modeling the current flow as upward, since we have mentioned that most cloud to ground lightning is negatively charged. By Ohm's law, $V = IZ$, as current flows through the tree, a voltage is developed.   If this voltage exceeds the air breakdown value to a nearby object (or person), the lightning current will likely seek a path through the air to the nearby object or person. If a person is touching the tree to begin with then the breakdown value is governed by the skin impedance (which would be quite low in comparison) and the person

Physical System   Equivalent Circuit

Figure 7 Flashover hazard.

would find themselves as part of the circuit. A typical lightning strike might produce 20,000 amperes of current and a typical tree might have a 100-ohm impedance. In this case, the voltage developed would be 2 million volts, enough to flashover to objects 2 meters away. Many lightning injuries occur from the flashover hazard. Most common is from being in the vicinity of trees during lightning storms or near electrical conductors that are subject to lightning current. Common sources of this injury occur when a person is near a residential telephone line and it is energized by a distant lightning strike. Consideration of flashover hazards is also an important design issue for the protection of personnel.
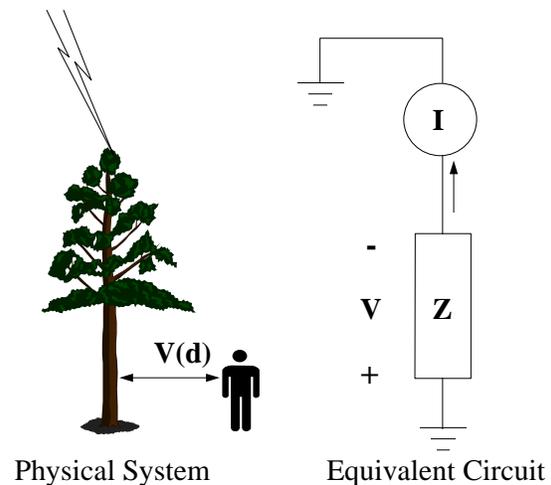
3.0 Lightning Detection, Warning and Safety Procedures

An essential part of minimizing risk due to lightning is detection and warning.

3.1 Lightning Detection

Several methods are available to detect lightning. In one form or another, these methods can be applied by soldiers at all levels to know when a lightning hazard is expected or imminent.

A major disadvantage of most detection systems is that they cannot predict the first strike of lightning. They can only tell what has already happened.   At the front of a fast-moving storm, risk of first strike may be significant. Tracking and early warning is a good feature available from many lightning detection systems. Let's discuss them in ascending complexity.

3.1.1 Visual/Audible Detection

This method involves little more than training troops to recall the "flash-to-bang" method to determine the distance of lightning strikes. Once a lightning flash is observed, the sound of the associated thunder takes 5 seconds to travel one mile. Using this rule of thumb, soldiers can easily detect and measure the distance to a lightning event. Unfortunately, maximum audible range of the thunder associated with lightning is approximately 6 miles, flash-to-bang time of 30 seconds. Detection of lightning at a range of 6 miles may not provide troops enough time to take protective measures or discontinue especially hazardous operations.

3.1.2 Weather Reports

Weather reports are available through various media; radio, television and internet. These reports, especially forecasts, are useful to know when to expect lightning hazards and consequently plan accordingly.

3.1.3 National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS) Radio

NOAA radio, available throughout the continental U.S. in the 162.4 – 162.55 MHz band, also broadcasts storm alerts affecting the nearby area. These radios provide some degree of early warning but are not specific to lightning.

3.1.4 National Lightning Detection Network (NLDN)

NLDN is a system of lightning sensors covering most of CONUS. Lightning warning services from NLDN are available through Global Atmospherics Inc. These services are available by subscription and are relatively inexpensive. (See www.lightningstorm.com for details.) Warnings can be issued by this service via pager.

3.1.5 Radiofrequency Detectors

Detectors are available that locate lightning by using a characteristic radio signature. While more expensive, these instruments can provide the direction and location of distant lightning, up 50 or 100 miles away. Detection at this range provides the ability to track the approaching storm and thus provide a great deal of early warning.

3.1.6 Electric Field Detectors

At some government installations, electric field detectors are employed. These devices are limited in capability, since they do not detect lightning directly. They do have the advantage of being able to detect the conditions necessary for a lightning strike and are very useful as a part f a comprehensive lightning warning system. Electric field detectors are very limited in range and many would be needed to cover an installation.   The expense and limited capability of these devices make them practical in only the most critical applications, such as bulk explosives handling or special weapons operations. A point detector is useful at critical sites, like bulk fuel handling or ammunition points.

3.2 Warning Procedures

The best detection methods are useless if the information is not disseminated. Standing Operating Procedures need to be in place at operations centers, range control or with the Staff Duty Officer (whomever is designated as the responsible party) for notification of the lightning hazard.

Most installations already have some form of notification procedure, telephonic or tactical radio, which can be easily adapted to lightning warnings. Features of notification should provide for positive real-time verification of message receipt and provide for backup or alternate means of notification. Recreational activities, such as the golf course, should also receive notification when lightning threatens.

3.3 Safety Criteria and Procedures

3.3.1 Personnel Protection Plan

In preparing personnel protection against lightning, planning is essential. Personnel must be aware of the hazards from step potential and flashover and must know what to do if an electrical storm threatens. Consequently, the following measures are recommended to protect personnel on-site.

3.3.1.1 Before Field Deployment

Check the weather forecast for the geographical area of deployment. A cursory risk assessment can be made on how probable lightning activity is. If lightning activity is reasonably probable plan for:

1) Monitoring of lightning activity. Designate a responsible person for monitoring.
2) A lightning shelter consisting of a permanent substantial structure or a shelter specifically designed for personnel protection against lightning.
3) Priority of work efforts in the event that outdoor activity is curtailed. Curtailment of low priority activities will minimize personnel exposure to lightning hazards.
4) Communication of the lightning hazard on-site. How will all personnel be notified?
5) Protected location for operational (mission essential) personnel.
6) Personnel awareness of the lightning hazard. Awareness can be promulgated through a handout for personnel or more formal training.

3.3.1.2 During Deployment – Activity Curtailment

If lightning activity threatens during the deployment, a number of incremental steps to minimize personnel exposure are necessary.

1) Criteria: Lightning at 30 miles.

Actions:
a) Notify personnel of increased lightning hazard.
b) Prepare to cease unnecessary outdoor activity.
c) Have nonessential personnel find shelter.

2) Criteria: Lightning at 15 miles. Or thunder heard by personnel, but no lightning flash observed.

Actions:
a) Secure outdoor equipment.
b) Cease outdoor activity other than securing equipment and critical tasks.
c) Personnel not occupied due to activity curtailment should move to designated lightning shelter.

3) Criteria: Lightning at 8 miles or lightning observed.
Actions:
a) Immediate cessation of outdoor activity. Abandon efforts to secure equipment if not completed.
b) All personnel take cover in designated shelter. If no other shelter is available, personnel can move to hardtop automobiles for shelter. Personnel on foot should find low risk locations and disperse if no other options are available.

Most periods of lightning activity move with a storm front and are often relatively brief. If sporadic lightning activity is present between 15 mile and 30 mile ranges, limited critical tasks may be undertaken outdoors but personnel must be informed of the hazard. Tasks that are especially hazardous during lightning storms, such as working with antenna masts or emplacing the grounding system, should not be performed at this time. In this circumstance, real time monitoring of lightning and fast personnel notification is crucial. Once lightning is observed within 8 miles, outdoor activity should again cease.

3.3.1.3 During Deployment – Activity Reinstatement

Reinstatement of activities are in the reverse order of the above. If possible, delay resumption of outdoor activities (especially grounding and antenna mast work) until lightning moves out of the 30 mile range. If absolutely required, allow only critical tasks once lightning moves out of the 15 mile range.

3.3.2 Lightning Risk Minimization Procedures

Upon notification to take cover from lightning or upon hearing thunder, personnel outdoors can take actions to minimize their exposure to lightning.

Personnel should:
-Move to a substantial building, a permanent structure, or a structure specifically designed as a lightning shelter. Small, unprotected shelters and huts (like golf or bus shelters) are not safe.
-Stay within metal vehicles.
-Move to a low-lying area.
-Minimize contact with electrical equipment and hard-wired phones during lightning activity, including tactical phones and associated equipment (wire, etc.)
-Secure electrically initiated munitions (blasting caps, TOW rounds, etc.) IAW TM instructions.

Personnel should not:
-Remain in an open area.
-Move near tall objects such as trees or poles. (Including antenna masts, see below.)
-Remain in water.
-Remain near metal fences, tracks, etc.
-Remain on hilltops or other high ground.
-Remain in tents.
-Work with signals or other electrical equipment. Antenna masts and similar equipment are dangerous to work with during lightning storms. Do not attempt to secure antenna equipment during lightning storms. Move personnel at least 50 feet away from antenna masts and poles during lightning storms.

If unable to take shelter, personnel should more to as low a spot as possible and crouch with feet closely together. Any objects that may produce a metallic upward projection, such as a radio or rifle, should be removed and placed horizontally on the ground nearby. Any weapon placed on the ground nearby should be cleared IAW local procedures before placing it on the ground. Groups of personnel in the open or in forested areas should disperse to minimize the possibility of multiple injuries from a single lightning strike.

4.0 Shelter Specifications

At some installations, shelters have been equipped with lightning protection for personnel. Special considerations are needed to protect personnel in these structures. Often, these considerations are not commonly known. Our objective here is to specify shelters that provide robust protection for personnel. An example of one type of shelter is provided below.

Example of a lightning protection shelter.

The specifications and instructions in this guide are not to be used for protection of large buildings or other structures. They are intended for application to relatively small personnel shelters. For larger, more complicated installations additional guidance (as detailed in the references) must be consulted.

4.1 Shelter Introduction

A Lightning Protection (LP) Shelter must protect against the following lightning effects:

a. Direct strike
b. Flashover
c. Step potential

3 primary subsystems are employed:

a. Strike Termination subsystem
b. Downconductor subsystem
c. Grounding subsystem

4.2 Strike Terminations

The intent of the strike termination is to intercept the lightning event and direct it into the lightning protection system, eventually for dissipation into ground.

Several methods of strike termination can be used.

1) Air terminals. These terminals consist of upward pointing copper rods affixed to the upper parts of the structure to be protected. Spacing and positioning of the air terminals, as described below, are critical parameters for lightning protection.

2) Metal parts. Metal parts of a structure can serve as strike terminations. (1/8" thick steel or 3/16" copper or aluminum.) Thinner metal parts have a more significant risk of burnthrough.

3) Overhead wire. An overhead conductor can be used to intercept lightning.   In this case, ¼" steel cable (or greater) is recommended.

4) Lightning protection masts: essentially a tall extension of the air terminal concept.
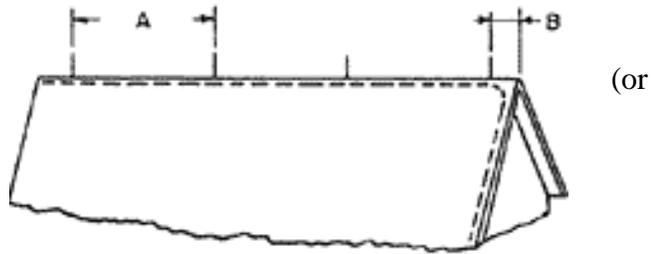
Pitched Roof:
A: 20 ft., maximum; B: 2 ft., maximum.

4.2.1 Placement of Strike Terminations

Strike terminations are placed at locations where they are likely to intercept the lightning strike.

4.2.1.1 Integral to the structure:

Strike terminations must be placed within 2 feet of ridge ends on pitched roofs and at the edges and corners of flat or gently sloping roofs. Air terminals must be spaced not more than 20 ft. apart.

Pitched Roofs: (Pitched roof defined as spans less than 40 ft., 1/8 pitch or spans greater than 40 ft., ¼ pitch.) Air terminals can be placed on the ridge only provided the height of the eaves does not exceed 50 ft. above grade.

Gently Sloping Roofs and Flat Roofs: (Defined as roofs with less pitch than pitched roofs.) Additional strike termination devices, not to exceed a 50 ft. interval, will be placed on the flat or gently sloping areas.
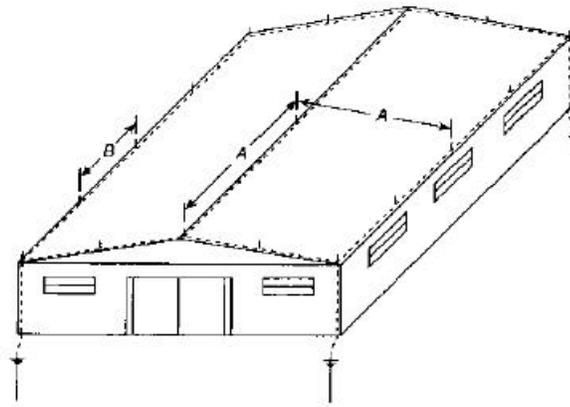
An air terminal installed on a structure must have 2 paths to ground via a main-sized downconductor (described in 4.3.1).

Flat/Gently Sloping roof:
A: 50 ft., maximum
B: 20 ft., maximum

4.2.1.2 Lightning Protection Masts

Masts with an air terminal affixed to the top can be used to protect structures. The mast (less than 50 ft. height) protects a conical area with the apex of the cone at the tip of the installed air terminal on top of the mast. The radius of the base of the protected conical area is equal to the mast height, to the tip of the air terminal[1]. Masts must be placed such that the structure is entirely contained within these cones. Although the structure may be within the protected area, ground currents remain a significant hazard in the event of a lightning strike.

4.2.1.3 Overhead wires:

Similar to lightning protection masts, an overhead wire can be placed over a structure. The strike termination in this case is the wire. The conductor must be placed so that it is 8 ft. or higher than the top of the structure to be protected.
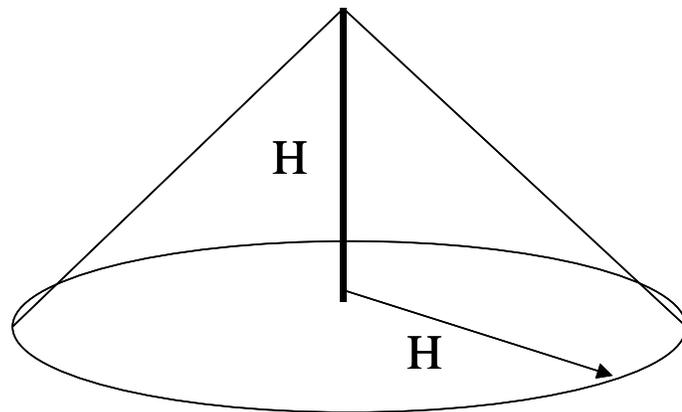

Depiction of approximate protected area from a lightning protection mast.

4.2.1.4 Materials for Strike Terminations:

Air terminals: Copper, 3/8 inch thick minimum, blunt (rounded) tips are recommended. Length of the air terminal will be no less than 10" but no greater than 24".

Metal parts: 1/8" thick steel or 3/16" copper or aluminum (minimum, thicker is permissible).

Overhead wire: Steel cable, ¼ inch or greater diameter.

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[1] A more advanced description of the protected zone is available using the electrogeometrical, or rolling ball, model in NFPA 780. The conical protected zone approximation is used for the small structures here for the sake of simplicity.

4.3 Downconductors

The downconductor system conveys the lightning current from the strike terminations to the ground electrode system.

For personnel protection, the downconductor system also needs special consideration. The primary consideration is prevention of flashover to persons near the downconductor.

A downconductor must be provided for each corner of the structure at a minimum. Given a typical shelter structure, a minimum of four downconductors are needed. If the separation between downconductors exceeds 60 ft., more are needed.
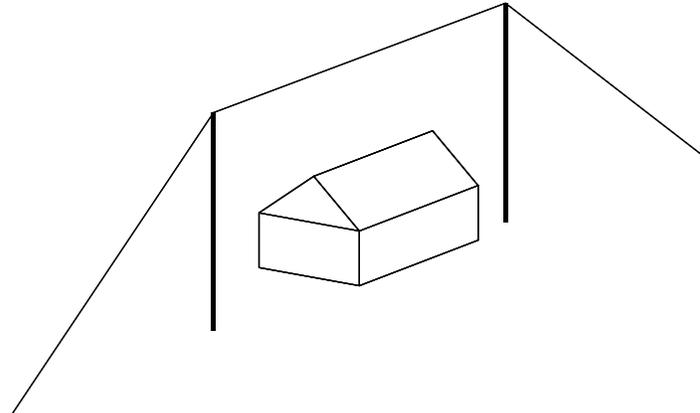

Diagram of overhead wire system.

Structural steel is permitted for use as the downconductor system. If structural steel is used, separate downconductor systems are unnecessary. Bonding the downconductor to the structural steel must be done by compression or exothermic means and have a minimum contact area of 3 sq. in.

Downconductors will be run as directly and as short a path as possible. Bends must not exceed 90 degrees with a minimum of 8 in. bend radius.

4.3.1 Downconductor Materials:

Copper, #2 AWG with minimum strand size of #17AWG per strand. Main sized Class I copper lightning protection cable (NFPA 780-1997) may also be used.

Conductors will be fastened or anchored at a maximum of 3 ft. intervals.

4.3.2 Downconductor Flashover/Touch Potential Protection System:

Copper conductors must be guarded by nonconductive barriers to prevent flashover. Schedule 80 PVC pipe is recommended for this purpose. The downconductor must be guarded from grade to 8 ft above grade or to the eave of the structure. Using insulated wire is less desirable since it will be subject to damage.

Although structural steel downconductor systems have much less inductive reactance than copper wire downconductor system, there is still a touch potential hazard. To prevent these

hazards, the structural steel should be insulated. In cases where this is impractical, establishing equipotential (essentially a Faraday cage) all around the structure, including the floor surface, will minimize flashover hazards. In many cases, insulation of the structural metal will be impractical. Personnel should then remain away from the supports during electrical storm activity (post sign to this effect). Recommend 3 ft. separation distance.

4.4 Grounding system

The purpose of the grounding system is to transfer the lightning current from the downconductor system to earth. In order to do this effectively, it must have a fairly large area in contact with the ground and have a low resistance. Minimization of step potential hazards is also an important consideration for personnel shelters and adds other aspects to the grounding system design.

4.4.1 Grounding Electrodes

-A grounding electrode (ground rod) at each downconductor termination at grade. Other electrodes are permissible where ground rods are not practical.[*] Ground rods should be a minimum of 8 feet below grade.

4.4.2 Step Potential Protection Subsystem Requirements

To protect against the effects of step potential it is important to make an equipotential surface. Current can't flow between two points of the same voltage, thus preventing electrical hazards. (This is how birds can sit on an energized wire without harm.) In the same way, personnel can be protected against step potential. The best solution, although not practical, is to have a metal floor. The requirements in this section attempt to replicate a as closely as possible, a conductive surface on or below the shelter floor. To provide some further protection in the event the equipotential surface is not perfect, a high resistance material is specified for the top layer in order to minimize any current flow through the body that may develop.

4.4.2.1 Subsurface Mesh Specifications

Subsurface mesh must be installed with not more than 3 ft. spacing. (New construction) Mesh should be constructed of main-sized copped wire (#2 AWG) and be installed at least 18 in. but not more than 30 in., below grade. Mesh crossovers must be wire tied together with copper wire.

A crushed rock or gravel top layer should be provided, 6 inches deep minimum. (This serves as an additional insulating barrier to limit currents induced by step potential.) Other insulating materials are permissible under engineering supervision.

Where concrete flooring is used, a mesh made of rebar is acceptable. The rebar within the concrete must be wire tied together for electrical bonding and the rebar must be bonded to any earth electrodes and the downconductor system. There should be at least one bond to each downconductor. Bonding for this should be by compression fitting or exothermal bond, with a minimum of 3 sq. in. contact area.

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[*] See NFPA 780 or MIL-HDBK 419 for detailed instructions on grounding system implementations.
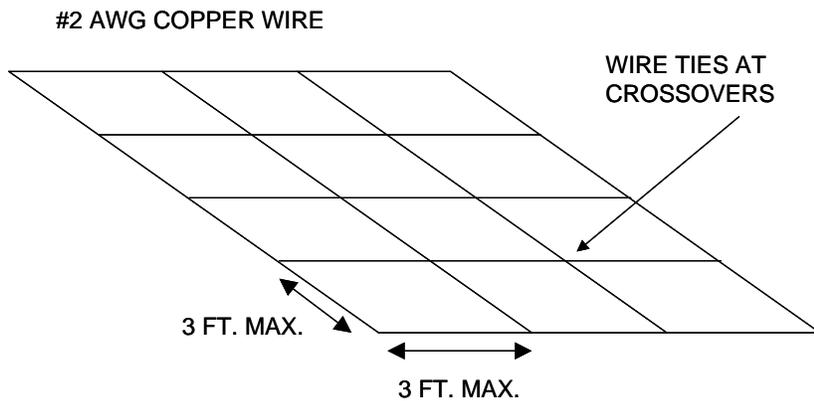
#2 AWG COPPER WIRE

WIRE TIES AT
CROSSOVERS

3 FT. MAX.

3 FT. MAX.

Illustration of subsurface grounding mesh for the prevention of step potential hazards.

4.4.2.2 Subsurface Equipotential Surface for Old Construction:

In many cases where lightning protection is applied to old construction, installation of a subsurface mesh may be impractical. In this case a grounding perimeter wire, or counterpoise, needs to be installed. The counterpoise needs to be a main-sized copper conductor and bonded into all electrodes, downconductors, etc.

#2 AWG COPPER
WIRE

CRUSHED
STONE OR
GRAVEL
FILL

GROUND
RODS
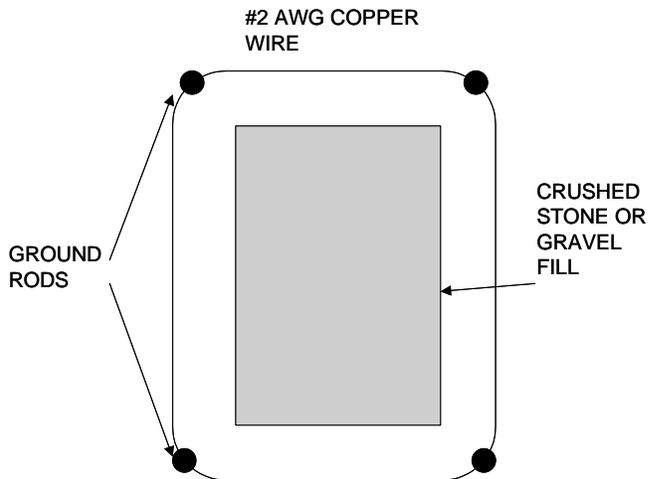
Plan view of counterpoise and stone fill for old construction.

If there is no improved flooring (dirt floor) in the shelter, a minimum of 6 inches of gravel is recommended as an insulating barrier. Existing concrete flooring can be used.

4.4.2.3 Common Grounding:

Electrically bonding metal parts ensures equipotential. Any metallic apertures to the shelter can become energized from lightning or other sources. Single-point bonding reduces the possibility of high current flow through unintended paths in the event of a lightning strike.

4.4.3 Bonding of Dead Metal Parts

All dead metal parts within the shelter must be bonded into the ground electrode system for the same reason as any electrical system grounds. This includes permanent benches, tables, lockers, etc.

All other grounding systems, such as that provided for electrical service, or for telecommunications, must be bonded to the lightning protection system ground at one point only. This bonding should be done IAW National Electrical Code (see references) or IAW local construction codes/standards and policy.

4.4.4 Bonding Conductors Specification

Copper, #6 AWG with minimum strand size of #17AWG per strand, is permitted for use for bonding purposes.

4.5 Site Considerations

Local terrain can affect the performance of the shelter. Terrain factors must be considered when choosing the site for the shelter.

Hilltops should be avoided for the shelter, or similar areas of high lightning risk. Having the shelter in a high-risk area merely increases the probability of strike and might place personnel trying to reach the shelter at significant risk.

The area near the shelter should be cleared of trees or other upward projections to a range of at least 15 feet. It is possible that a lightning event to a tree or other nearby projection that is not bonded electrically into the grounding system will flashover to personnel inside the (open) shelter.

5.0 References

ANSI/IEEE Standard 80-1986, *IEEE Guide for Safety in Substation Grounding*, 1986.

IEEE Standard 142, *Recommended Practice for Grounding of Industrial and Commercial Power Systems*, Institute of Electrical And Electronics Engineers, New York, 1991.

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Military Handbook 419A, Volumes I & II, *Grounding, Bonding and Shielding*, Department of Defense, 1987.

National Fire Protection Association 70, *National Electrical Code,* 1999.

National Fire Protection Association 780, *Standard for the Installation of Lightning Protection Systems,* 1997.

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Tobias, J.M., *Lightning Protection Measures for Personnel A Review of Facilities and Procedures at Fort Jackson, South Carolina,* U.S. Army Communications Electronics Command, 2000.