BY ORDER OF THE
SECRETARY OF THE AIR FORCE

AIR FORCE INSTRUCTION 32-1065

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Civil Engineering

GROUNDING SYSTEMS

COMPLIANCE WITH THIS PUBLICATION IS MANDATORY

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This instruction implements AFPD 32-10, *Installations and Facilities*. It assigns maintenance responsibilities and requirements for electrical grounding systems on Air Force installations. This includes systems for equipment grounding, lightning protection, and static protection. This instruction also implements the maintenance requirements of DoD 6055.9-STD, *Ammunition Explosives Safety Standards*, Chapter 7, Lightning Protection, August 1997, for potentially hazardous explosives facilities. Send all recommendations for changes or improvements to this instruction on AF Form 847, **Recommendation for Change of Publication**, through the major commands (MAJCOM) and HQ AFCESA/CESE, 139 Barnes Drive, Suite 1, Tyndall AFB FL 32403-5319 to HQ USAF/ILEO, 1260 Air Force Pentagon, Washington DC 20330-1260. See **Attachment 1** for glossary of references and supporting information used in this instruction.

SUMMARY OF REVISIONS

This document is substantially revised and must be completely reviewed.

This revision incorporates the latest changes to DoD 6055.9-STD.

Section A—Maintenance Policy

1. Responsibilities.

1.1. The Base Civil Engineers (BCE):

1.1.1. Maintain lightning and grounding systems specifically identified in **Table 1.** according to the procedures in this instruction.

1.1.2. Make sure that user organizations identified in **Table 1.** are aware of their maintenance responsibilities.

1.1.3. Train users to perform their responsibilities to inspect and maintain lightning and grounding systems as identified in **Table 1.** when requested.

Table 1. Scheduled Maintenance for Grounding Systems.

FACILITY	ACTION REQUIRED	FREQUENCY	RESPONSIBILITY	REFERENCE
1. Exterior Electrical Distribution	Visual inspection of equipment fencing, pole grounds, and neutrals	2 years	Base Civil Engineer	AFJMAN 32-1082
2. Electrical Sub-station	Resistance check (5 ohms max)	5 years	Base Civil Engineer	This AFI
3. Exterior Lightning Arresters	Visual	Annually	Base Civil Engineer	AFJMAN 32-1082
4. General	a. Visual inspection and resistance check of facility grounds (25 ohm max for single electrode system)	5 years	Base Civil Engineer	This AFI, NFPA 70
	b. Visual inspection of lightning protection system	1-3 years	Base Civil Engineer	This AFI
5. POL Facilities	a. Resistance check on static grounds (10,000 ohms max)	When installed or physically damaged	Base Civil Engineer	AFM 85-16
	b. Visual inspection and check tightness on ground conductors	Quarterly	Base Civil Engineer	AFM 85-16
6. Aircraft Parking Apron Grounds and Hangar Floor Static Grounds	Resistance check on static grounds (10,000 ohms max)	When installed or physically damaged	Base Civil Engineer	AFM 88-9, Chapter 3
7. LOX Storage	Resistance check on static ground (10,000 ohms max)	When installed or physically damaged	Base Civil Engineer	This AFI
8. Rail Car Offloading Spur	Visual inspection of rail bonding	Quarterly	Base Civil Engineer	AFM 85-16
9. Communica-tion Facilities (Including TEMPEST)	Resistance check (10 ohms max is design objective)	Quarterly for first year after installation; then every 21 months	Base Civil Engineer	AFI 32-1063; MIL-HDBK-419A

FACILITY	ACTION REQUIRED	FREQUENCY	RESPONSI-BILITY	REFERENCE
10. Communi-ca-tion Facilities	Checks involving in-house electronic equipment ground	Determined by user	User	AFI 32-1063
11. Hazardous* Explosive Area (Weapons)	a. Visual inspection of static wires and bonds	Before using equipment each day	User	AFMAN 91-201
	b. Continuity check from equipment to stat-ic ground bar (1 ohm max)	3 months or ac-cording to spe-cific item T.O.	User	AFMAN 91-201; this AFI
	c. Conductive floor grounding check (spe-cific ohmic re-quire-ments contained in AFMAN 91-201)	6 months	Base Civil Engineer	AFMAN 91-201; this AFI
	d. See non-hazardous explosives require-ments 12c, 12d, 12e, and 12f.		Base Civil Engineer	AFMAN 91-201; this AFI
12. Non-Hazard-ous* Explosive Area (Weapons)	a. Visual inspection of static wire bonds	Quarterly	User	AFMAN 91-201; this AFI
	b. Continuity check on static bond from equip-ment to static ground	24 months	User	AFMAN 91-201
	c. Visual inspection of lightning protection	12 months	Base Civil Engineer	AFMAN 91-201; this AFI
	d. Resistance check on lightning protection earth ground system (25 ohms max except Ground Loop System)	24 months	Base Civil Engineer	AFMAN 91-201; this AFI
	e. Continuity check on air terminals, bonds, and conductors (1 ohm)	24 months	Base Civil Engineer	AFMAN 91-201; this AFI
	f. Static bus bar conti-nuity to ground (1 ohm)	24 months	Base Civil Engineer	AFMAN 91-201; this AFI

FACILITY	ACTION REQUIRED	FREQUENCY	RESPONSI-BILITY	REFERENCE
13. Protective Aircraft Shelter (PAS)***	a. Ground system resistance check	24 months	Base Civil Engineer	This AFI
with Weapon Storage and Security System (WS3) Vault	b. Visual inspection of system	6 months	Base Civil Engineer	This AFI
	c. Continuity between arch and ground	24 months	Base Civil Engineer	This AFI
	d. Test door hinges (1 ohm max)	24 months	Base Civil Engineer	This AFI
	e. Continuity between vault lip (flange) and ground (conduit)	24 months	Base Civil Engineer	This AFI
	f. Continuity of installed (permanent) bonds between metal masses and steel arch	24 months	Base Civil Engineer	This AFI
14. Fuels Lab	a. Visual and continuity check of ground wires	Monthly	User	AFOSH STD 91-38
	b. Visual inspection of facility grounds	Monthly	User	AFOSH STD 91-38
15. Medical** Facilities	a. Resistance check (25 ohms max)	Every 5 years	Base Civil Engineer	NFPA 99
	b. Effectiveness of grounding system by voltage and impedance measurements	Before accept-ance of new or after modifica-tion	Base Civil Engineer	AFI 41-203; NFPA 99
	c. Verification of continuity of receptacle grounding circuits	Annual (semi-annual for critical care areas)	Base Civil Engineer	AFI 41-203
16. Airfield Lighting Grounds	Resistance check (25 ohms max)	2 years	Base Civil Engineer	This AFI
17. EMP Hardened Facilities	(These facilities may have special requirements)		Base Civil Engineer; user	DNA-A-86-60, Vol 1-3; this AFI
18. PMEL	Continuity and resist-ance test of facility ground (25 ohms max)	2 years	Base Civil Engineer	This AFI

* As defined in NEC Article 500

** Base Civil Engineers will perform if separate medical facility maintenance branch does not exist.

*** Also known as Hardened Aircraft Shelter (HAS)

1.1.4. Review the lightning protection system on each facility at least annually or after repair actions have been completed.

1.2. Users. Users will maintain lightning and electrical grounding systems as identified in **Table 1.**

2. Codes and Specifications. Follow applicable codes and specifications in **Attachment 1** unless modified in this instruction, or deviations are justified due to local conditions.

3. Required Maintenance. Perform required maintenance at the frequencies specified in **Table 1.** When possible, plan for and schedule maintenance when facility users will be least affected.

4. Recordkeeping and Review.

4.1. Inspectors and testers must compile and maintain records of their inspections and tests to include:

4.1.1. A sketch of the grounding and lightning protection system showing test points, and where services enter the facility. Sketch should also show the location of the probes during the ground resistance test. (Separate sketches are suggested for static, earth ground, and lightning protection systems on large complex facilities.)

4.1.2. Date action was performed.

4.1.3. Inspector's or tester’s name.

4.1.4. General condition of air terminals, conductors, and other components.

4.1.5. General condition of corrosion protection measures.

4.1.6. Security of attachment for conductors and components.

4.1.7. Resistance measurements of the various parts of the ground terminal system.

4.1.8. Variations from the requirements of this instruction.

4.1.9. Discrepancies noted and corrective actions taken.

4.1.10. Date of repairs.

4.2. Review records for deficiencies; also analyze the data for undesirable trends. If test values differ substantially from previous or original tests obtained under the same test procedure and conditions, determine the reason and make necessary repairs.

4.3. Keep test and inspection records for a minimum of six inspection cycles.

5. Forms. Suggest the use of Air Force general purpose forms (3100 series) to record tests. Use the format listed in MIL-HDBK-419A, *Grounding, Bonding, and Shielding for Electronic Equipments and Facilities* for communications facilities. Provide copies of completed forms to the facility user. For munitions facilities maintained by host nation civil engineers, the using agency must receive a copy of the completed forms.

6. Personnel Qualifications. Workers maintaining, repairing, modifying, and testing grounding systems must be thoroughly familiar with test equipment operation; lightning protection, grounding, and bonding theory and practices; referenced codes and standards; and specific requirements and procedures in this instruction. Attachments 2 through 5 provide information suitable for use in training and familiarization.

7. Developing Procedures. The organization performing inspections and tests must develop procedures based on the requirements in this instruction.

Section B—Grounding Resistance and Continuity Tests and Visual Inspections

8. Testing Requirements. See **Attachment 6** for resistance and continuity test requirements for typical systems. Instruments must be able to measure 10 ohms ±10 percent for ground resistance tests, and 1 ohm ±10 percent for continuity testing. Only instruments designed specifically for earth-ground systems are acceptable for ground resistance testing. Follow the manufacturer's instruction manual except as modified herein when using the instruments. Earth ground resistance should be less than 25 ohms unless specified different in this document. Periodic tests should be made at approximately the same time each year to minimize confusion resulting from seasonal changes (see **Attachment 2**). If the resistance measured during continuity tests is greater than 1 ohm, check for deficiencies and repair, then retest. When performing a continuity test over very long lengths of conductors (more than 20m with no parallel paths), readings above one ohm but less than 3 ohms may occur. This is acceptable. The MAJCOM electrical engineer may modify the test procedures due to local conditions, as long as the intent of the test is still achieved.

9. Visual Inspections of Lightning Protection Systems. Inspect all visible parts of the system. Pulling or tugging on conductors and connections to insure soundness is a necessary part of these inspections, but be careful not to damage the system in the process. Visual/physical inspection must determine if:

9.1. The system is in good repair.

9.2. There are loose connections that might cause high resistance joints.

9.3. Corrosion or vibration has weakened any part of the system.

9.4. Down conductors, roof conductors, and ground terminals are intact.

9.5. Braided bonding wires are excessively frayed (cross sectional area reduced by half).

9.6. Ground wires on lightning protection masts are damaged by lawn mowers or other equipment.

9.7. Conductors and system components are securely fastened to mounting surfaces. Relocate connections as necessary to better protect against accidental displacement.

9.8. Additions or alterations to the protected structure require additional protection.

9.9. Surge suppression (overvoltage) devices appear damaged.

9.10. The system complies with applicable sections of NFPA 780, *Standard for the Installation of Lightning Protection Systems* (**Attachment 4**).

10. Visual Inspection of Facility Grounds. Unless otherwise specified by references in **Table 1.**, conduct visual inspections as follows. Inspect all visible and accessible parts of the system. Determine if they are in good condition and the installation meets NEC requirements (**Attachment 2**). Typical items to check:

10.1. The system is in good repair.

10.2. There are no loose connections.

10.3. The system neutral is grounded at the service entrance (this includes the connection to the grounding electrode).

10.4. Separately derived systems are properly grounded.

10.5. Flashover protection is installed on insulating fittings on underground metallic pipelines entering the facility.

10.6. Grounding systems within the facility are bonded together at ground level or below.

Section C— Grounding and Lightning Protection Requirements

11. Introduction. This section covers requirements for grounding and lightning protection systems, including systems installed on or in areas such as explosives buildings, magazines, operating locations and shelters. Use these requirements when inspecting to determine compliance and when repairing or modifying systems. See AFMAN 91-201, *Explosive Safety Standards*.

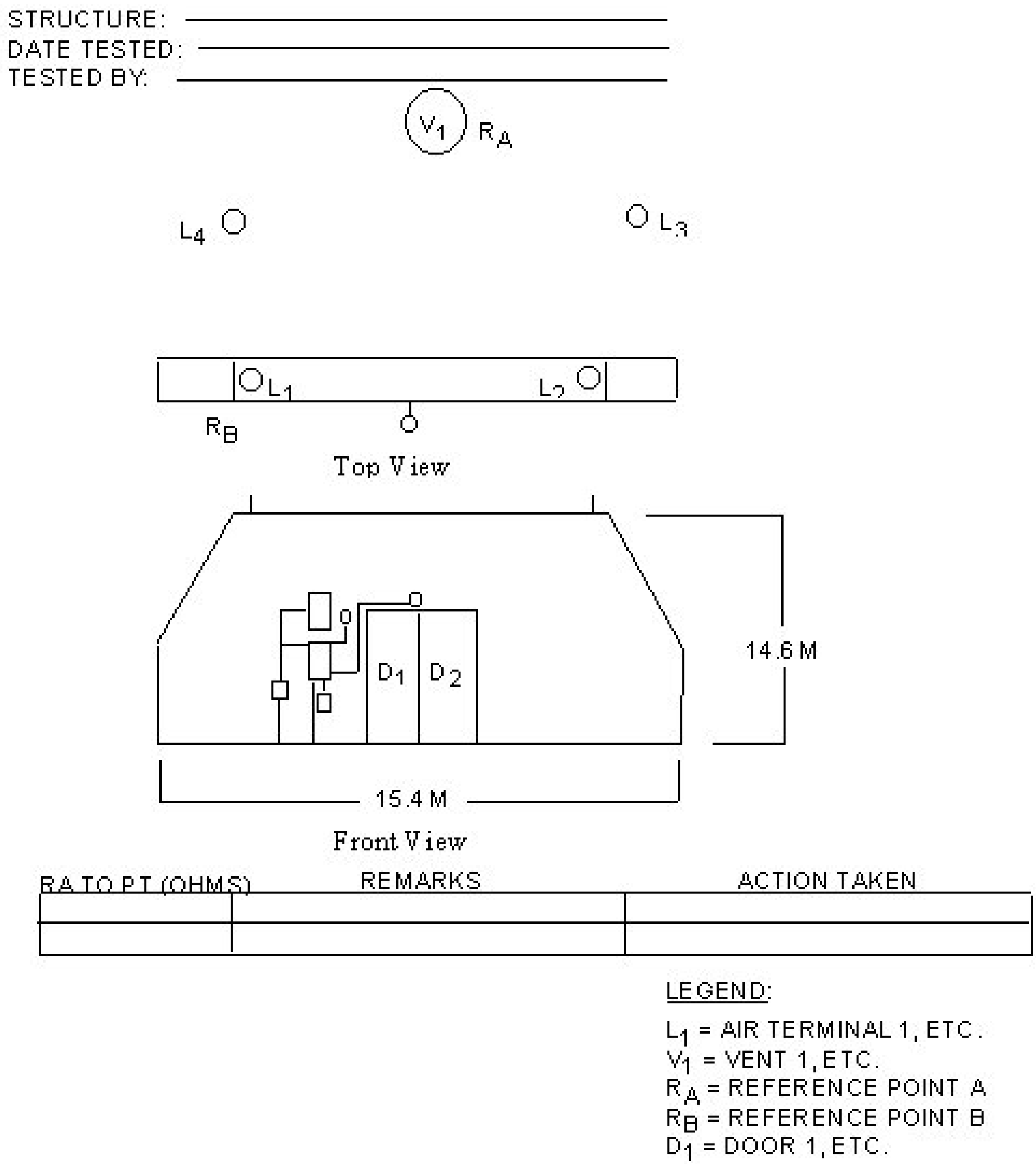
12. Testing and Inspecting Static and Lightning Protection Systems and Grounding:

12.1. Procedures. Use **Attachment 4** and **Attachment 5** as a guide for establishing proper maintenance procedures and a check during self inspections.

12.2. Inspection and Testing. Inspect the static and lightning protection systems and grounding for buildings and facilities visually and electrically according to Sections A, *Maintenance Policy* and B, *Grounding Resistance and Continuity Tests and Visual Inspections,* and the special requirements in this section.

12.3. Records. Keep records of test and inspections for explosives facilities for a minimum of six inspection cycles (see paragraph **4.**). **Figure 1.** is an example sketch of a grounding and lightning protection system with test points.

Figure 1. Example Sketch of Test Points (Typical).



13. Static Protection.

13.1. Equipment Grounding. The best methods to eliminate or reduce the hazard from static electricity are bonding and grounding. Bonding minimizes potential differences between conductive objects.

Grounding minimizes potential differences between objects and the ground. Inspect and test facilities for compliance with NFPA 77, *Static Electricity*, which contains the minimum acceptable static grounding and bonding requirements for Air Force activities, except as modified herein.

13.1.1. Bonding and grounding wires must be large enough to withstand mechanical damage. Minimum size for existing bonds is AWG No. 8. Make repairs with wires no smaller than AWG No. 6 copper. Static grounds for portable or movable equipment must use braided cable for added flexibility.

13.1.2. Static grounds must be 10,000 ohms or less, unless otherwise stated. Static electricity creates extremely small (milliamps) currents, so even this large resistance is small enough to bleed off static charges. But because the static grounding system must be connected to the facility grounding system, resistances of less than 25 ohms are common.

13.2. Static Bus Bars. Static bus bars are usually 2- by 1/4-inch copper bars installed on the interior wall of the facility. Bond static bus bars directly to each lightning protection down conductor where it crosses the down conductor if separation between the two is within NFPA 780 bonding distance and the bus or down conductor cannot be relocated. They must also be connected directly to the facility grounding electrode system. See **Attachment 6** for testing requirements. Use static bus bars only for static grounding. Do not connect telephone grounds, electrical conduit or intrusion systems to this bus. Static bus bars must not be used as a grounding medium for these systems. As a general rule, do not connect a static bus to any facility metal body or use this bus to ground structural components of a facility; however, coincidental connections of the bus bar through its anchoring/mounting system are acceptable as is the mounting of the static bars on the skin of a metal structure. Portable grounding straps from equipment to the static grounding bus are not real property. Visual inspections and continuity checks for these straps are the responsibility of the user.

13.3. Belting Requirements. On equipment such as belt-driven compressors and conveyor belts, if static electricity is a hazard, use non-static-producing belting. Belting must have a resistance not exceeding 1,000,000 ohms when measured according to IEEE STD 142, chapter 3.

13.4. Conductive Floor Grounds. If the facility requires conductive floors, the resistance of the floor must be less than 1,000,000 ohms. Additionally, the resistance between the floor and ground connections must not be less than 25,000 ohms. This requirement protects personnel from electric shock hazard and allows bleed off of static buildup in people and operating equipment. See **Attachment 6** for testing requirements. The testing and using agency must keep a record of test results.

14. Lightning Protection Systems. AFMAN 91-201 identifies explosives facilities that require lightning protection systems. Many other structures housing critical or sensitive supplies or equipment also require protection. The following requirements may be used as a guide for facilities that require lightning protection.

14.1. General. Systems must comply with NFPA 780 and AFM 88-9, Chapter 3, *Electrical Design Lightning and Static Electricity Protection* (except as modified herein). Early streamer emission systems or charge dissipation systems are not permitted. Parts and materials must carry the Underwriters Laboratories (UL) label or equivalent. Otherwise, such components must be approved by the MAJCOM electrical engineer in charge of lightning protection. Facilities in foreign countries may use host nation codes and standards if they offer equivalent protection, as determined by the MAJCOM electrical engineer with concurrence from HQ AFCESA/CESE and approval of the DoD Explosive Safety

Board (DDESB). Otherwise, the Status of Forces Agreement (SOFA) must permit their use. Where the SOFA requires compliance with host nation codes, translate those required codes into English, make them available to all appropriate personnel, and perform necessary training. Maintain all installed systems according to this instruction. If not required, remove the system with coordination through the using agency.

14.2. Bonding Requirements. Adequate bonding is more important than grounding. Bonding ensures all metallic objects are at equal potentials, preventing dangerous flashovers. Inspect and test facilities for compliance with NFPA 780 and **Attachment 3** of this instruction.

14.3. Grounding Resistance. Low resistance is desirable but not essential for lightning protection. For most facilities, resistance to ground should be less than 25 ohms. If this cannot be achieved where only ground rods are used (no ground loop conductor), install a ground loop conductor. The resistance to ground of a ground loop system is acceptable even if greater than 25 ohms. See **Attachment 2**.

14.4. Lightning Protection For Explosives Facilities. Use the basic practices in **Attachment 4**, with the following additions:

14.4.1. The system must be designed for a 30.5-meter (100-foot) striking distance.

14.4.2. Installation of ground wells (hand holes) at corner ground rods is recommended to aid access for testing.

14.4.3. Replace existing bolted connectors on down conductors and roof conductors needing repair with high compression or exothermic-weld type connectors. Connections to air terminals are an exception, but they must be tight and in good repair. Bolted connections to aluminum bodies (such as vents) and to metal bodies for the purpose of bonding are also acceptable. Brazing to metal bodies is allowed but not recommended due to the possibility of a cold weld with inadequate strength.

14.4.4. Structural elements of a facility may serve as air terminals, down conductors, or the earth electrode.

14.5. Explosives Facilities with Large Perimeters. New explosives facilities (including igloos) with a perimeter over 91.4 meters (300 feet) that require lightning protection and do not use the structural steel as the air terminals must use either a mast system or an overhead wire system. See **Attachment 4** for requirements. Since these systems provide better protection, and maintenance is easier, consider using this type of protection for other kinds of facilities. The MAJCOM may waive this requirement (overhead or mast system).

14.6. Protective Aircraft Shelters (PAS) (also known as Hardened Aircraft Shelter (HAS)). PASs with interior steel arches or interconnected rebar (i.e., floor rebar that is connected to wall rebar) and grounded ventilators of metal at least 4.78 millimeters (0.188 inch) thick do not need air terminals. Metal ventilators less than 4.78 millimeters (0.188 inch) thick must be protected by an air terminal. All metal bodies in the PAS must be properly bonded and grounded. See **Attachment 3**. An adequate grounding system is also required.

15. Surge Protection.

15.1. Entering or exiting metallic power, intrusion detection, communication antenna, and instrumentation lines must have surge protection sized for lightning surges to reduce transient voltages to a harmless level. Install the surge protection as soon as practical where the conductor enters the interior of the facility. Devices commonly used for this include metal oxide varistors, gas tube arresters, and transzorbs. The lines must enter the facility in shielded cables or metallic conduits run underground for at least 15.24 meters (50 feet) from the facility. The antenna leads from antennae on the facility and within the zone of protection do not have to go underground.

15.2. Steam, water, and air conditioning lines must be bonded to the facility's lightning protection system before entering the structure. For explosive facilities, all metallic utility lines must run underground for at least 15.24 meters (50 feet) from the facility.

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Attachment 1

GLOSSARY OF REFERENCES AND SUPPORTING INFORMATION

References

DoD Publications

DoD 6055.9-STD, *Ammunition Explosives Safety Standards*

MIL-HDBK-419A, *Grounding, Bonding, and Shielding for Electronic Equipments and Facilities*

Federal Information Processing Standards (FIP) Pub 94, *Guidelines on Electrical Power for ADP Installations*. (Available from National Technical Information Center, US Department of Commerce, Springfield VA 22161.)

Air Force Publications

AFI 32-1063, *Electrical Power Systems*

AFI 41-203, *Electrical Safety in Medical Treatment Facilities*

AFMAN 91-201, *Explosive Safety Standards*

AFJMAN 32-1082, *Facilities Engineering, Electrical Exterior Facilities*

AFM 85-16, *Maintenance of Petroleum Systems*

AFM 88-9, Chapter 3, *Electrical Design Lightning and Static Electricity Protection*

AFOSH STD 91-38, *Hydrocarbon Fuels*

Other

ANSI C2, *National Electrical Safety Code (IEEE)*. (Copies available from The Institute of Electrical and Electronics Engineers, 345 East 47th Street, New York NY 10017.)

DNA-A-86-60, V1-3, *DNA EMP Engineering Handbook for Ground-Based Facilities*

*IEEE STD 142, *IEEE Recommended Practice for Grounding for Industrial and Commercial Power Systems (Green Book)*

*IEEE STD 446, *Recommended Practice for Emergency and Standby Power (Orange Book)*

**NFPA 70, *The National Electrical Code*

**NFPA 77, *Static Electricity*

**NFPA 99, *Standard Health Care Facilities*

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

Additional References

*IEEE STD 81, *IEEE Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a ground System*

*IEEE STD 1100, *IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (Emerald Book)*

*Available from The Institute of Electrical and Electronic Engineers, 345 East 47th Street, New York NY 10017.

**Available from National Fire Protection Association, 1 Batterymarch Park, Quincy MA 02269-9990.

Abbreviations and Acronyms

ANG—Air National Guard

ANSI—American National Standards Institute

AWG—American wire gauge

BBF—basic bonding formula

DDESB—Department of Defense Explosive Safety Board

DoD STD—Department of Defense Standard

EMP—electromagnetic pulse

FIPS—Federal Information Processing Standard

IEEE—Institute of Electrical and Electronics Engineers

IG—isolated ground

LOX—liquid oxygen

MAJCOM—major command

MIL HDBK—Military Handbook

MOV—metal oxide varistor

NBN—no bonding needed

NEC—National Electrical Code

NFPA—National Fire Protection Association

PAS—Protective Aircraft Shelter (also known as Hardened Aircraft Shelter (HAS))

POL—petroleum, oils, lubricants

PMEL—Precision Measurement Equipment Laboratory

SDS—separately derived system

SOFA—Status of Forces Agreement

T.O.—Technical Order

WS3—Weapon Storage and Security System

Terms

Air Terminal—The component of the lightning protection system intended to intercept lightning flashes, placed on or above a building, structure, or tower. A building's grounded structural elements may be used as an air terminal. Sometimes air terminals are referred to as lightning rods.

Bonding—An electrical connection between an electrically conductive object and a component of a lightning protection system that is intended to significantly reduce potential differences created by lightning currents.

Conductor, Bonding—A conductor used for equalization potential between metal bodies and the lightning protection subsystem.

Catenary System—A lightning protection system consisting of one or more overhead wires. Each overhead wire forms a catenary between masts, and serves the function of both a strike termination device and a main conductor.

Conductor, Main—A conductor intended to carry lightning currents from the point of interception to ground terminals.

Copper Clad Steel—Steel with a coating of copper bonded on it.

Down Conductor, Lightning—The conductor connecting the roof conductors or overhead ground wire to the earth ground subsystem.

Ground Loop—A conductor, buried 3 to 8 feet from a structure, encircling the structure interconnecting ground electrodes. The conductor may be connected to buried copper or steel plates or ground rods. These are installed to establish a low resistance contact with earth. (Also referred to as counterpoise, loop conductor, or closed loop systems.)

Facility Ground System—The electrically interconnected system of conductors and conductive elements that provides multiple current paths to earth. The facility ground system can include the earth electrode subsystem, lightning protection subsystem, signal reference protection subsystem, fault protection subsystem, static ground subsystem, as well as the building structure, equipment racks, cabinets, conduit, junction boxes, raceways, duct work, pipes, and other normally non-current-carrying metal elements.

Ground—The electrical connection to earth primarily through an earth electrode subsystem. This connection is extended throughout the facility by the facility ground system.

Ground Terminal—The portion of a lightning protection system such as a ground rod, ground plate, or ground conductor that is installed for the purpose of providing electrical contact with the earth.

Inherent Bond—Where metal bodies located in a steel-framed structure are electrically bonded to the structure through the construction.

Integral System—A system which uses air terminals mounted directly on the structure to be protected.

Lightning Protection System—A complete system consisting of components (such as air terminals, interconnecting conductors, ground terminals, surge suppression devices, and other connectors or fittings) and subsystems required to assure a lightning discharge will be safely conducted to earth.

Mast System—A lightning protection system using masts that are remote from the structure to provide the primary protection from a lightning strike.

Overhead Wire System—System using conductors routed over the facility, at a specified height, designed to provide the required zone of protection. Also known as overhead shield wire system and catenary system.

Side Flash—Electrical arcing between metal objects caused by difference of potential from a lightning discharge.

Strike Termination Device—A component of a lightning protection system intended to intercept lightning flashes and connect these flashes to a path to ground. Strike termination devices include air terminals, masts, permanent parts of structures, and overhead wires in catenary systems.

TEMPEST—Unclassified name for investigation/study of compromising emanation.

Zone of Protection—Space below and adjacent to a lightning protection subsystem that is likely to avoid direct lightning discharges.

Attachment 2

BASIC REQUIREMENTS FOR GROUNDING SYSTEMS

A2.1. Types of Grounds. There are five basic types of grounding systems which must be inspected if present in a facility: static grounds, equipment grounds, electrical system grounds, lightning grounds, and signal reference grounds.

A2.1.1. Static Grounds. A static ground is a connection between a piece of equipment and earth to drain off static electricity charges before they reach a sparking potential. Typically, static grounding involves connecting large metal objects such as fuel tanks or aircraft to earth through a ground rod. Static grounds are not part of an electrical power system. But if an equipment grounding conductor is adequate for power circuits, it is also adequate for static grounding.

A2.1.2. Equipment Grounds. Equipment grounding involves interconnecting and connecting to earth all non-current-carrying metal parts of an electrical wiring system and equipment connected to the system. The purpose of grounding equipment is to ensure personnel safety by reducing any charge in an equipment item to near zero volts with respect to ground. Equipment ground must be capable of carrying the maximum ground fault current possible without causing a fire or explosive hazard, until the circuit protective device clears the fault. An example is the bare copper wire or green insulated conductor connected to the frames of electric motors, breaker panels, and outlet boxes. The equipment ground is connected to an electrical system ground (neutral) only at the electrical service entrance of a building and should not exceed 25 ohms to ground.

A2.1.3. Electrical System Ground. The purpose of electrical system grounds is to stabilize voltage to ground and give a low impedance path for fault currents. One wire or point of an electrical circuit in an electrical system ground is connected to earth. This connection is usually at the electrical neutral (though not always), and is called the "system ground." Examples of electrical system grounds are generator or transformer neutral points connected to earth, and the grounded neutral of an interior wiring system. The resistance of most electrical system grounds below 600 Vac should not be more than 25 ohms. Medium voltage systems (1-15kV) frequently are grounded through a resistor (or reactor) and may exceed 25 ohms. This limits ground fault current to a manageable level.

A2.1.4. Lightning Grounds. The purpose of lightning grounds is to safely dissipate lightning strokes into the earth. They are part of a lightning protection system which usually includes air terminals (lightning rods), down conductors, arresters, and other connectors or fittings required for a complete system. The sole purpose of a lightning protection system for a facility is to protect the building, its occupants, and contents from the thermal, mechanical and electrical effects of lightning.

A2.1.5. Signal Reference Grounds. The purpose of a signal reference ground is to provide a low impedance signal reference system for electronic equipment to minimize noise-induced voltages and thereby reduce equipment malfunctions. Common configurations include planes and grids. See FIPS Pub 94, *Guidelines on Electrical Power for ADP Installation*s, for details.

A2.1.6. Subsystem Grounds. Each of the grounding systems described above may be a subsystem of a total facility grounding system. All grounds (and subsystems) must be bonded together according to NFPA 780 and NFPA 70, *The National Electrical Code*. MIL-HDBK-419A contains example sketches of grounding subsystem interconnections.

A2.2. NEC Grounding Requirements. Electrical systems and circuit conductors are grounded to limit voltages during lightning and to facilitate overcurrent device operation in case of a ground fault. The NEC allows the system neutral to be grounded and limits the location of this neutral to earth connection to the source side of the service entrance disconnect or at a separately derived system (NEC, articles 250-23 and 250-26). Since the neutral will carry current under normal operating conditions, the NEC often refers to it as the *grounded* conductor. If a building service is at less than 1000 volts, a neutral conductor (if required by NEC, article 250-5) must be run to each service entrance from the servicing transformer and bonded to the disconnecting panel enclosure. In contrast to the neutral, the equipment ground conductor (green insulated or bare wire) is referred to as the *grounding* conductor. The grounding conductor is used to ground metallic enclosures and motor frames, and must be connected to neutral only on the source side of the service entrance disconnect.

A2.2.1. Facility Ground. The NEC requires a premises wiring system to have a grounding electrode at each service. This electrode may be of several different types or systems. Each of the types listed below must be bonded together to form the grounding electrode system. Where none of the listed electrodes are present, ground rods or ground plates must be used. Ground rods must be at least 2.44 meters (8 feet) in length (10 feet for lightning protection; see **Attachment 4**) and no closer than 1.83 meters (6 feet) from other rods or plates. Ground rods or plates must not be aluminum. The Air Force also prohibits stainless steel ground rods.

A2.2.1.1. Where a metal underground water pipe (uncoated) is in direct contact with the earth for 3.05 meters (10 feet) or more, do not bond around insulation flanges installed for cathodic protection. If the underground water pipe is the only electrode available, ground rods must supplement it.

A2.2.1.2. The metal frame of a building where the building is effectively grounded.

A2.2.1.3. An electrode encased by at least 51 millimeters (2 inches) of concrete, made of at least 6.1 meters (20 feet) of one or more steel reinforcing bars, located within and near the bottom of a concrete foundation or footing in direct contact with the earth. This is known as a Ufer ground.

A2.2.1.4. A ground ring encircling the building at least 0.76 meters (2.5 feet) deep. The ground ring must be at least 6.1 meters long and use at least AWG No. 2 copper (1/0 copper for lightning protection ground ring conductor; see **Attachment 4**).

A2.2.2. Separately Derived Systems (SDS). A separately derived system is a premises wiring system where power is derived from a generator, transformer, or converter. An SDS has no direct electrical (metallic) connection, including the neutral, to the supply conductors originating in another system. The neutral of an SDS must be connected to a nearby grounding electrode. In order of preference, this grounding electrode may be building steel, grounded water pipe, or a separate ground rod. The equipment grounding conductor (green wire) is bonded to the neutral at this point only. A ground rod can be used only when other types of grounding electrodes are not available. All grounding electrodes must be connected to the facility grounding systems.

A2.2.2.1. Dry type transformers (isolation and non-isolation) are common sources of SDSs in a facility. Usually, they are connected in a delta-wye configuration. SDS transformers are widely used in sensitive electronic installations (computer power distribution centers are essentially SDS transformers), since they effectively establish a local ground at the electronic equipment. This minimizes the impedance to ground as seen by the load.

A2.2.2.2. Standby or emergency generators are also common sources of separately derived systems. However, a generator connected to a facility through a transfer switch is not a separately derived system if the neutral conductor remains connected to the normal commercial power source neutral after transfer (the neutral is not switched along with the phase conductors). In this case, the required connection of the neutral to the facility's grounding electrode system for both the commercial power source and the generator must be made only on the supply side of the commercial power service disconnect. Providing an additional connection between the generator neutral and a grounding electrode at the generator would be a grounding connection on the load side of the service disconnect and a violation of the NEC. Refer to IEEE Standard 446, *Recommended Practice for Emergency and Standby Power (The Orange Book),* for additional information and requirements on grounding emergency and standby generators.

A2.3. Grounding Electrodes:

A2.3.1. Connection To Earth. The most practical method of connecting to earth is to bury a solid body, such as a metal rod, pipe, or sheet, and connect a grounding conductor to it. This solid body is known as a grounding electrode.

A2.3.2. Methods for Obtaining Better Grounds. Frequently a satisfactorily low electrode resistance cannot be obtained because of high soil resistivity. Use the following methods if it is necessary to lower the resistance of the electrode.

A2.3.2.1. Deeper Rod. As a rod is driven more deeply into the soil, it not only has more surface contact with the earth, but it also begins to reach soil which is more conductive. The deeper the electrode, the less the effect of surface moisture content and temperature changes.

A2.3.2.2. Parallel Ground Rods. Rods driven in parallel to each other should have space between them at least the length of the rods. Multiple rods connected by a conductor have a greater ability to equalize potential over the installation area.

A2.3.2.3. Soil Replacement. You can significantly lower the resistance of a ground rod by lowering the resistivity of the soil immediately surrounding it. Use a mixture of 75 percent gypsum, 20 percent bentonite (well driller's mud), and 5 percent sodium sulfate. This mixture is available from cathodic protection supply companies. The mixture is better than chemical salts because it lasts much longer and chemical salts may not be compatible with environmental requirements.

A2.3.2.4. Concrete Encapsulation. Encapsulating ground rods with concrete increases their effective diameter. The concrete absorbs water from the soil, increasing the conductivity directly around the electrode. When buried in the earth, the resistivity of concrete is about 3,000 ohm-cm.

A2.3.2.5. Other Methods. Other more elaborate methods include installation of a ground loop conductor and extensive wire networks.

A2.4. Grounding and Corrosion. Copper grounding has been the standard of the electrical industry almost from inception. Because it is cathodic to all common construction materials, corrosion often results when copper is in contact with ferrous structures. Bonding underground ferrous structures to copper grounding systems can create serious corrosion problems.

A2.4.1. Corrosion of Pipelines. A typical situation exists when a facility's copper grounding system is bonded to a coated steel pipeline (such as petroleum, oils, or lubricants (POL) or natural gas) entering the facility. Outside the facility the pipe is buried in low resistivity soil. Corrosion current will be high because of the potential between copper and steel, the low resistance circuit, and concentrated at the voids (holidays) in the pipe coating. One common solution to this problem is to use galvanized steel rather than copper ground rods. Another is to install an insulating fitting above the ground in the pipeline where it exits the soil and as it enters the building. Note that while the aboveground portion of the pipeline is grounded for safety, the underground portion is already grounded by contact with the soil. The resistance to earth of a typical coated piping system is usually 1 to 5 ohms.

A2.4.2. Hazardous Voltages. If insulating fittings are installed on a pipeline, take precautions against lightning flashover at the fittings or a dangerous potential difference between the pipe sections. Connect a metal oxide varistor (MOV) lightning arrester, zinc grounding cell, or an electrolytic cell across the insulating device. The clamping voltage should be 3.14 times the maximum output voltage of the rectifier of the cathodic protection system.

A2.4.3. Zinc Grounding Cell. A zinc grounding cell is made of two bars of 3.55 by 3.55 by 152.4-centimeter (1.4 by 1.4 by 60-inch) zinc separated by 2.54 centimeter (1-inch) spacers. Each bar has an insulated AWG No. 6 stranded copper conductor silver-brazed to a 0.64-centimeter (0.25-inch) diameter steel core rod. The unit comes prepackaged in a bag of low resistivity backfill (75 percent gypsum, 20 percent bentonite, and 5 percent sodium sulfate). The nominal resistance of a two anode grounding cell is 0.4 ohms. For lower resistance, a four cross-connected zinc anode cell with a resistance of 0.2 ohms is available. This resistance acts as an open circuit to the low dc voltage corrosion current, but like a short to lightning or 120 Vac commercial current.

A2.4.4. Electrolytic Cell. An electrolytic cell (Kirkcell) consists of multiple pairs of stainless steel plates immersed in a potassium hydroxide electrolyte solution with an oil film floating on top to prevent evaporation. The cell acts like an electrochemical switch, blocking low dc voltages in the cathodic protection range, but instantaneously shunting ac or higher dc voltages to ground.

Attachment 3

BASIC BONDING REQUIREMENTS

A3.1. Basic Requirements. The following are basic bonding requirements for lightning protection. See NFPA 780 for more details. Three different conditions or situations determine the requirement for a bond.

Condition 1	**Condition 2**	**Condition 3**
Long vertical metal bodies 18.3 meters (60 ft) in vertical length	Grounded metal bodies a. Structures 12.2 m (40 ft) and less b. Structures more than 12.2m (40 ft) in height (1) Within 18.3 m (60 ft) from top of structure (2) Below 18.3 m (60 ft) from top of structure	Isolated (nongrounded) metallic bodies

A3.2. Condition 1. This condition addresses long, vertical metal bodies, grounded and ungrounded, exceeding 18.3 meters in vertical distance. For steel framed structures these long, vertical metal bodies must be bonded as near as practical at their extremities to structural steel members. For reinforced concrete structures where the reinforcement is interconnected and grounded, these long, vertical metal bodies must be bonded to the lightning protection system (unless inherently bonded through construction) at their extremities. For other structures bonding is determined the same as condition 2.

A3.3. Condition 2. This condition addresses bonding of grounded metal bodies not covered by Condition 1. Where grounded metal bodies are connected to the lightning protection system at only one extremity, use the following formula to determine if additional bonding is necessary:

$$D = \frac{hK_m}{6n}$$

This basic bonding formula (BBF) is used in all Condition 2 subcategories. Only the parameter *n* may be defined differently. K_m is defined the same in all cases and is equal to 1.0 if the flashover is through air; or 0.5 if through dense material, such as concrete, brick, or wood.

A3.3.1. Condition 2a. For grounded metal bodies in structures 12.2 meters (40 feet) and less in height, the following apply.

D = the distance between a grounded body and a down conductor at which a bond becomes necessary.

h = he greatest vertical distance between the bond being considered and the nearest other lightning protection system bond (or to ground level if no other bond is present).

n = 1 where only one down conductor is within a 30.5-meter (100-foot) radius of the bond in question.

n = 1.5 where only two down conductors are within a 30.5-meter radius of the bond in question.

n = 2.25 where three or more down conductors are within a 30.5-meter radius of the bond in question.

Where any two down conductors are not separated by at least 7.6 meters, they must be considered as one down conductor. An example of this calculation is shown in **Figure A3.1.** The height of the building is 10.7 meters (35 feet). A is a metal pipe grounded at one end, but close to down conductor B. B is the only down conductor within 30.5 meters of the point in question, so n = 1. Since any flashover would occur through the wall, K_m = 0.5. The BBF is D = [h/6(1)](0.5) = (9.14/6)(0.5) = (1.52)(0.5) = 0.76 meters (2.5 feet). This means that if pipe A is 0.76 meters or closer to the down conductor at the point in question (9.14 meters in height), bond it through the wall to the down conductor.

A3.3.2. Condition 2b(1). For grounded metal bodies in structures more than 12.2 meters (40 feet) in height and where the bond in question is within 18.3 meters (60 feet) from the top of the structure, the following definitions apply.

h = the greatest vertical distance between the bond being considered and the nearest other lightning protection system bond (or to ground level if no other bond is present).

n = 1 where only one down conductor is within a 30.5-meter radius of the bond in question. Down conductors must be spaced at least 7.6 meters apart.

n = 1.5 where two down conductors are within a 30.5-meter radius of the bond in question. Down conductors must be spaced at least 7.6 meters apart.

n = 2.25 where three or more down conductors are within 30.5 meters of the bond in question. Down conductors must be spaced 7.6 meters apart.

Figure A3.2. shows bond fitting Condition 2b(1). The vertical height, h1, is 22.9 meters (75 feet). In this case, the two down conductors are within 30.5 meters of the bond at D1, and n equals 1.5. Again, the flashover would be through the wall, so Km = 0.5. The BBF is D1 = ([22.9/(6)(1.5)])0.5 = (22.9/9)(0.5) = 1.27 meters (4.17 feet). If pipe A is 1.27 meters or closer to the down conductor, bond it to the down conductor through the wall.

A3.3.3. Condition 2b(2). For grounded metal bodies where the bond in question is below the top 18.3 meters of a structure which is greater than 12.2 meters (40 feet) in height, the following definitions apply.

h = the vertical distance between the bond being considered and the nearest other lightning protection system bond (or to ground level, if no other bond is present).

n = the total number of down conductors (spaced 7.6 meters apart) in the lightning protection system.

This type of bond is shown in figure A3.2. Pipe B comes close to a down conductor at a height below the top 18.3 meters of the structure. Km would be 0.5 for a flash through the wall and *n* would be the total number of down conductors for the system (assume 4). The BBF would be D2 = ([h2/6(4)])0.5 = 10.7/24(0.5) = 0.22 meters (0.73 feet). The pipe B would have to be bonded through the wall to the down conductor at this location if it is 0.22 meters or closer to the conductor. Note that for buildings between 12.2 and 18.3 meters in height, Condition 2b(1) would apply.

Figure A3.1. Typical Bonding Conditions in Structures 12.2 Meters (40 Feet) or Less.

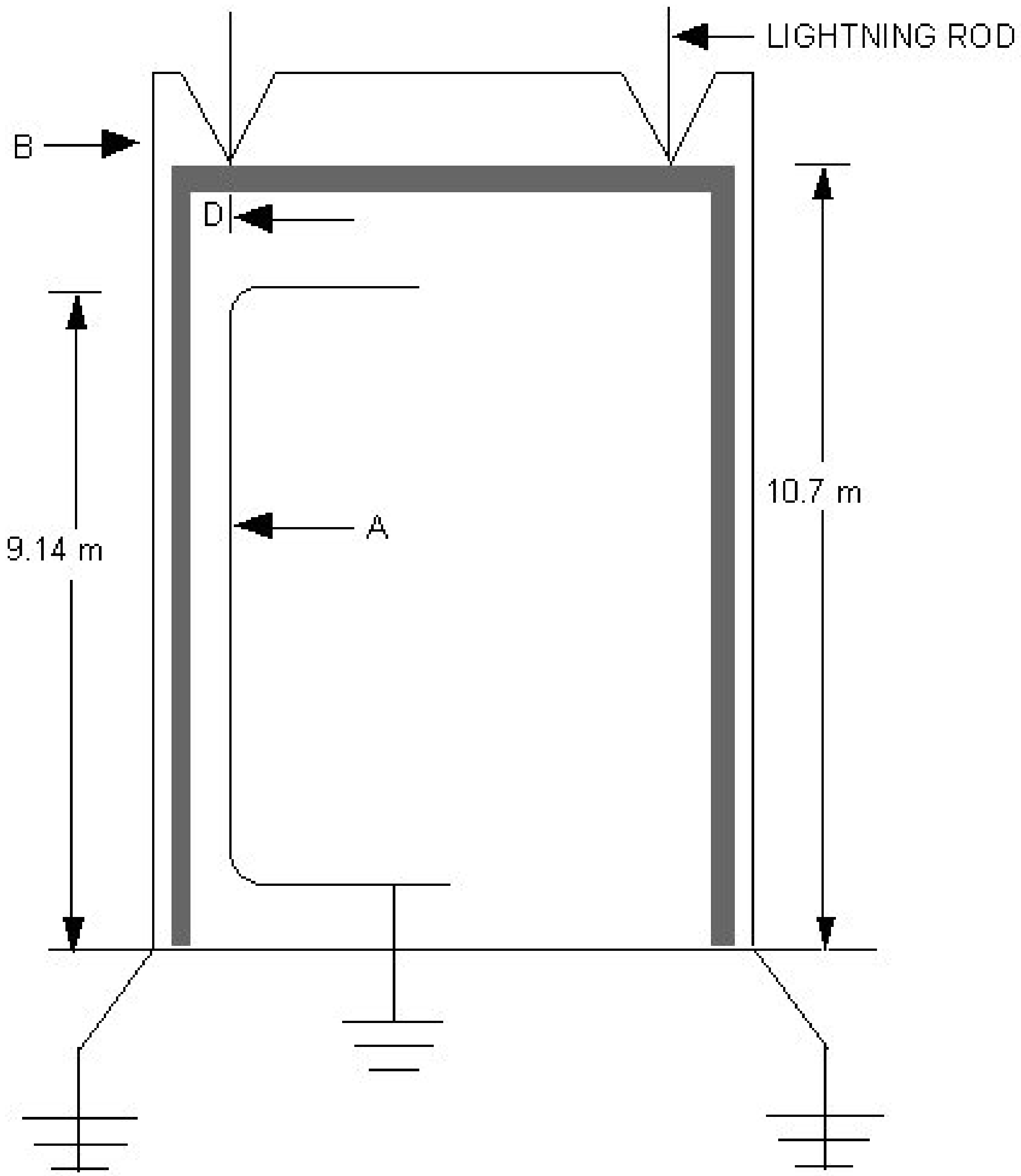
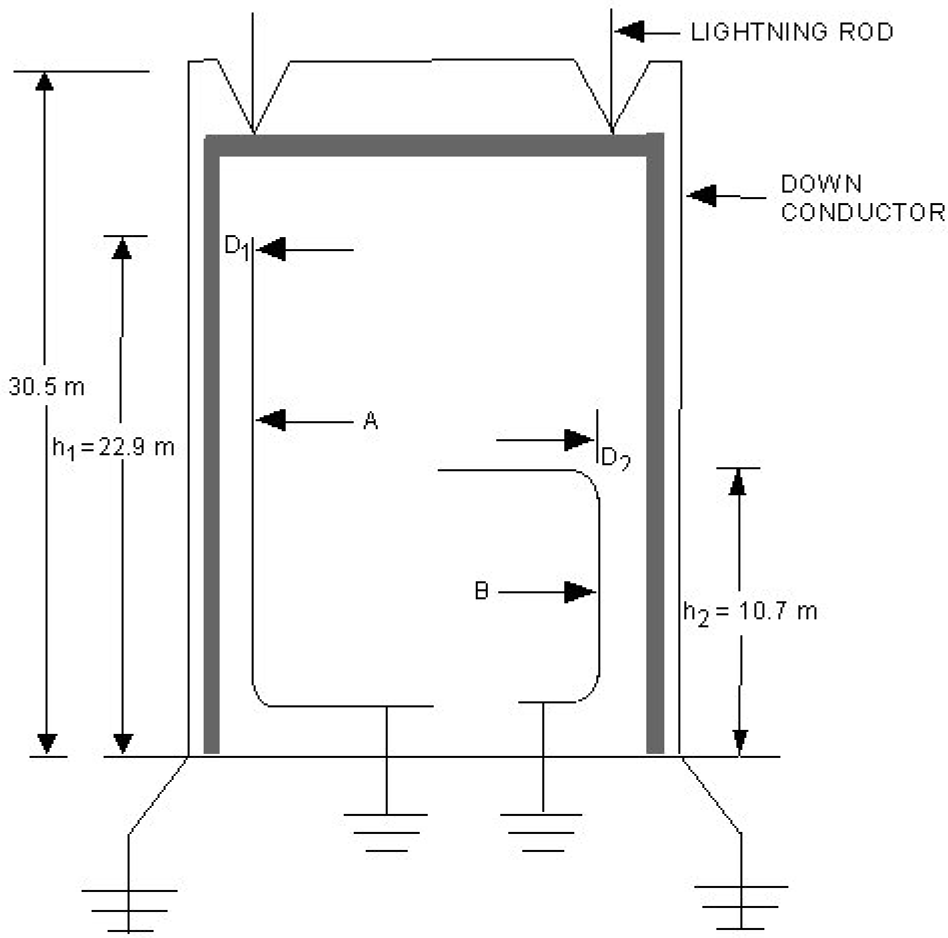
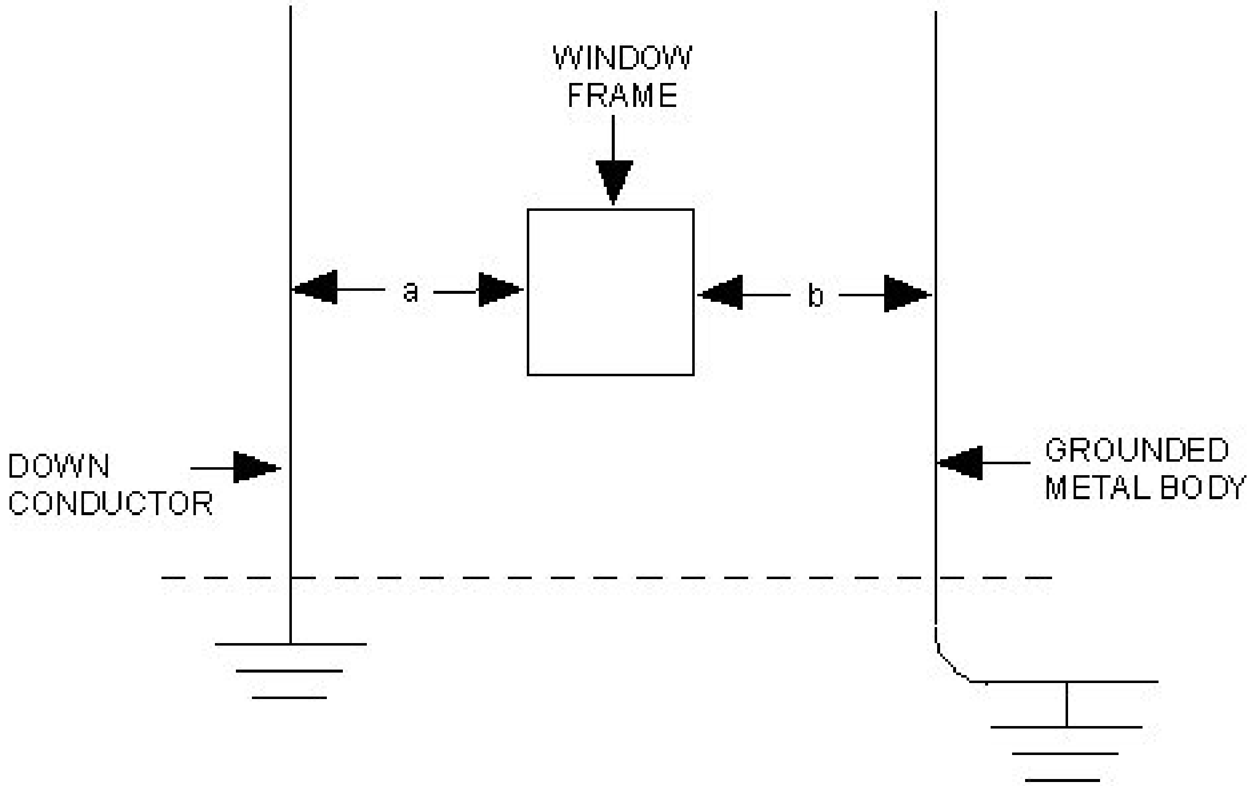


Figure A3.2. Typical Bonding Conditions in Structures Greater Than 12.2 Meters (40 Feet).



A3.4. Condition 3. Condition 3 concerns ungrounded metal bodies positioned to effectively short part of the separation distance between a grounded metal body and a lightning conductor. In **Figure A3.3.**, a window is locatedbetween a grounded metal body and a lightning protection down conductor. First, calculate the bonding distance between the grounded body and down conductor by using the BBF according to the correct condition [2a, 2b(1), or 2b(2)]. This will provide a distance for D. If the distance a + b is less than or equal to D, then the down conductor must be bonded directly to the grounded metal body. Note the window itself does not have to be bonded. Continuity tests should be performed to determine if the object is grounded, and not ungrounded, as it may appear.

Figure A3.3. Typical Bonding Conditions for Ungrounded Metal Bodies.



A3.5. Typical Air Force Situation. Figure A3.4. depicts a situation which typically occurs at Air Force bases. Objects 1 through 4 are various types of metallic electrical enclosures. These are required by the NEC to be grounded, and therefore constitute grounded metal bodies as defined by Condition 2 above. They would have to be bonded to the down conductor if separation from the down conductor is less than the distance determined by the BBF, Condition 2. Condition 3 would not apply between the door frame and the down conductor with objects 1 through 4 in between, because all are grounded. However, the BBF, Condition 2, has to be applied between the down conductor and the doorframe. On explosives facilities where such objects do not need to be bonded, recommend they be marked or labeled "NBN" (No Bonding Needed) for future reference.

A3.6. Explosives Facility Bonding. The following supplements the NFPA 780 bonding requirements for explosives facilities defined in chapter 3.

A3.6.1. **Figure A3.5.** gives approximate bonding distances as defined by NFPA 780. Note that this chart does not cover Condition 2b(2). The terms h, Km, and n are defined in paragraph **A3.3.1.**. To demonstrate the use of the chart, we will use the chart to solve the example in paragraph **A3.3.1.**

Figure A3.4. Bonding for Typical Air Force Structure.

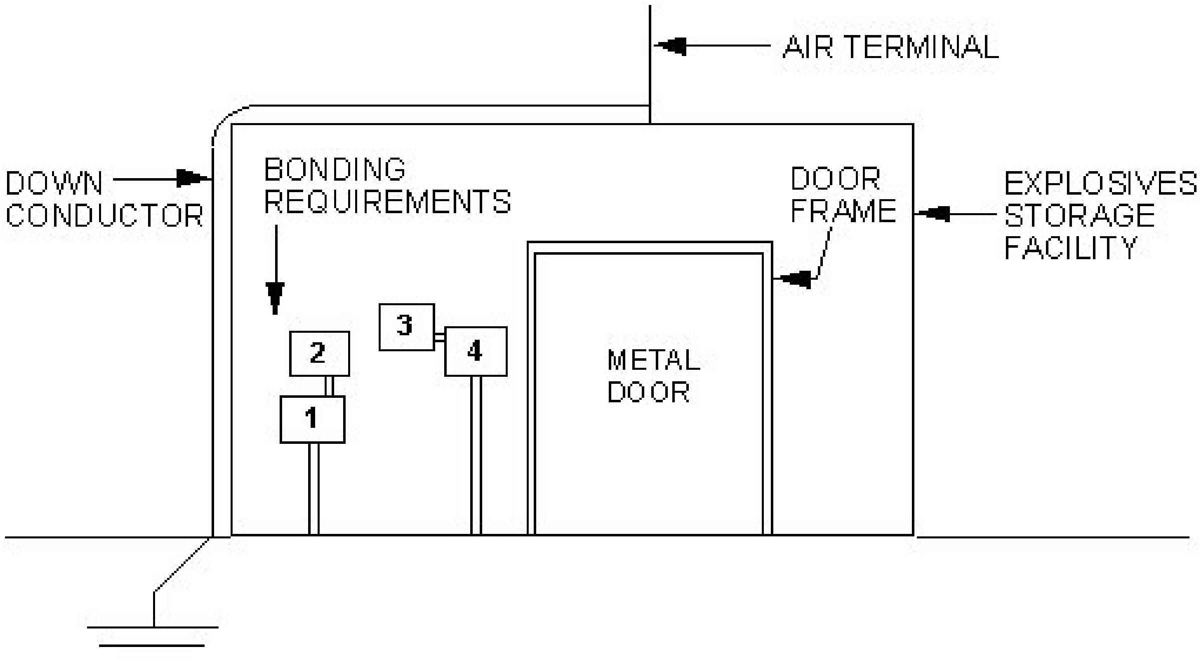


Figure A3.5. Approximate Bonding Distances.

h	K_m	n = 1.0	n = 1.5	n = 2.25
3.05 m	1	0.51 m	0.34 m	0.23 m
	0.5	0.25 m	0.17 m	0.11 m
6.1 m	1	1.016 m	0.68 m	0.46 m
	0.5	0.51 m	0.34 m	0.23 m
9.14 m	1	1.5 m	1.02 m	0.68 m
	0.5	0.76 m	0.51 m	0.34 m
12.2 m	1	2.03 m	1.37 m	0.91 m
	0.5	1.106 m	0.69 m	0.46 m

$$D = \frac{hK_m}{6n}$$

1. Find the height (h) (9.14 m) in the column labeled h.

2. Then select the row adjacent to the 9.14 m where Km is 0.5, since any flashover would occur through the wall.

3. Since there is only one down conductor, n equals 1. Find the intersection of the row selected in step 2 and the column labeled 1.0. The value in the cell is 0.76m. Therefore, D is 0.76.

Also notice that the greatest bonding distance for objects not covered by 2b(2) inside a facility less than 12.2 meters in height is 1.016 meters (3 feet, 4 inches).

A3.6.2. Steel magazine doors inherently in physical contact with the metallic door frame do not need a separate bond if this contact measures one ohm or less. Install a bonding strap if this contact measures greater than one ohm. The frame must be inherently grounded through the rebar or bonded to a down conductor.

A3.6.3. Objects such as metal desks, large metal trash cans, and ground level floor grates do not need to be bonded unless required by NFPA 780.

A3.6.4. Fences and railroad tracks within 1.83 meters (6 feet) of a structure's lightning protection system must be bonded to the structure grounding system.

A3.6.5. Blast valves must be inherently grounded through the rebar system or with a separate bonding strap.

A3.6.6. Metal bodies located within a steel framed structure that are inherently bonded to the structure through construction must be tested when the facility is new and the measurements recorded and kept with the other required measurements and observations. They do not need to be tested again unless there is reason to believe the bond has changed; e.g., corrosion or structural repair.

A3.7. Protective Aircraft Shelters (PASs). In PASs with interior steel arches, all grounded metal bodies within 0.305 meters (1 foot) of the steel arch must be bonded to the arch. In PASs without a steel arch, all grounded metal masses within 0.305 meters of a wall must be bonded to the nearest metallic electrical conduit if not already connected. Only those grounded metal bodies not inherently bonded (through metallic conduit or equipment grounding conductor) must be tested for continuity to the ground or conduit system. All metal doors must be grounded. Door hinges and door tracks are acceptable as a bonding strap if the doorframe or door track is grounded and there is less than 1 ohm between the door and ground. Additional requirements for PASs with WS3 vaults:

A3.7.1. Continuity between the steel arch and grounding system may be measured by ohming between the steel arch and any metallic electrical conduit. Two test points between different conduits and the arch are sufficient, if the test points are spaced on opposite walls and the conduit long. This is to ensure electrical continuity through the structural shell. If a maximum of 1 ohm is not achieved, a bonding strap must be installed.

A3.7.2. When testing continuity between the WS3 vault and steel arch, an acceptable test location is the vault lip or flange flush with the shelter floor. The vault does not have to be raised. Where there is no steel arch, test from a metallic electrical conduit on the PAS wall to the vault lip.

Attachment 4

LIGHTNING PROTECTION SYSTEMS

A4.1. Minimum Requirements. Engineers assigned specific responsibilities for lightning protection should review the lightning protection system on each facility at least annually or after repair actions have been completed.

A4.1.1. Air terminals must extend at least 0.25 meters (10 inches) above the object to be protected. ***NOTE:*** When replacing air terminals with terminals of a different length, required spacing around the perimeter must be reconfirmed and the zone of protection verified.

A4.1.2. Each air terminal (except pole- or tower-mounted terminals as exempted in NFPA 780) must be connected to at least two paths to ground. Note that for earth-covered igloos, these paths may be covered with soil.

A4.1.3. Each building with an integral protection system must have a minimum of two down conductors, one each at opposite corners (one each on all corners is preferred).

A4.1.4. Down conductors must present the least impedance to ground.

A4.1.5. Down conductors must not have sharp bends or loops. All bends must have a radius of 203 millimeters (8 inches) or greater and measure not less than 90 degrees from the inside of the bend. The 203-millimeter radius does not apply to "T" or "Y" splices. These splices, however, can be used only for the purpose intended.

A4.1.6. If the structure has metallic columns, these columns may serve as down conductors. Columns must not average over 18.3 meters (60 feet) apart.

A4.1.7. The average distance between down conductors must not exceed 30.5 meters (100 feet).

A4.1.8. Any down conductors subject to mechanical damage or displacement must be protected with a protective molding or covering for a minimum of 1.83 meters (6 feet) above grade. If a down conductor runs through a ferrous metal tube or pipe (usually for mechanical protection), the conductor must be bonded to both ends of the tube.

A4.1.9. Do not paint down conductor connectors unless they are the high-compression or exothermic (or welded) type. Conductors on roofs must be bare.

A4.1.10. Each down conductor must be connected, at its base, to a grounding electrode.

A4.1.11. Ground rods must be at least 3.05 meters (10 feet) long, made of not less than 0.75 inch diameter pipe or equivalent solid rod made of copper or copper clad steel. Stainless steel ground rods may not be used. Ground rods must be at least 0.91 meters (3 feet) from the building walls or footings and must penetrate 3.05 meters into soil. Ground rods with tops at least 0.31 meters (1 foot) below grade are recommended.

A4.1.12. Interior metal parts of a facility close to a down conductor may need to be bonded to that down conductor. See NFPA 780 and **Attachment 3**.

A4.1.13. Bonding materials must be compatible with the metallic mass and down conductor.

A4.1.14. On new facilities, down conductors entering soil with less than 10,000 ohm centimeters resistivity must be protected against corrosion by a protective covering beginning at point 0.91 meters

(3 feet) above grade and extending for its entire length below grade (to a ground rod or ground loop conductor).

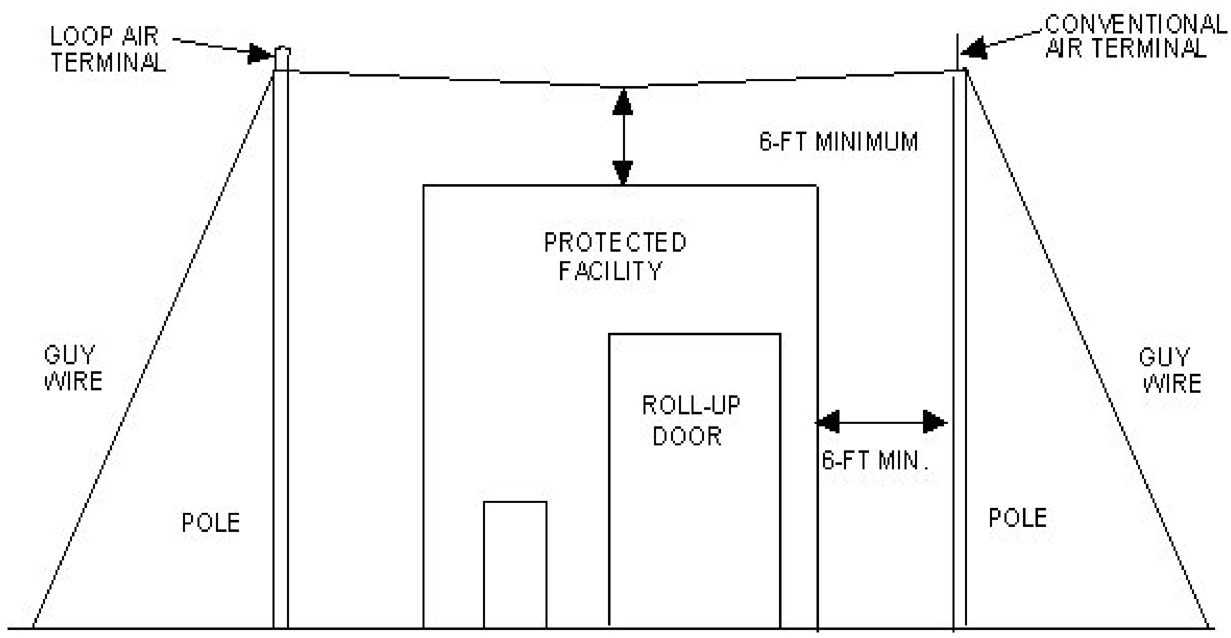
A4.1.15. Ground loop conductors must not be less than AWG No. 1/0 copper.

A4.2. Mast and Overhead Wire Systems:

A4.2.1. A mast-type lightning protection system uses masts located remote from the facility. The mast must be high enough to enclose the facility in the zone of protection according to NFPA 780. Separate each mast from any part of the facility by at least the bonding distance specified in Chapter 3 of NFPA 780, but not less than 1.83 meters (6 feet). Refer to **Figure A4.1.**

A4.2.2. If a single mast will not protect a facility adequately, install multiple masts or an overhead wire system. An overhead wire lightning protection system consists of grounded, elevated, horizontal metallic wires stretched between masts surrounding the facility. Each wire must be a continuous run of at least AWG No. 6 copper, or equivalent. Suspend each wire above the protected facility, and connect them to ground rods at each mast or pole. Interconnect all ground rods with a ground loop conductor. NFPA 780, chapter 3, specifies the minimum separation between the overhead wire and the protected facility, which must be at least equal to the bonding distance or side flash distance. A minimum of 1.83 meters (6 feet) is recommended. Supporting masts must be separated by the side flash distance, but no less than 1.83 meters.

Figure A4.1. Air Terminals on Masts (Typical).



A4.2.3. An air terminal extending above the top of the pole must be securely mounted to the top of the wooden mast and connected to the grounding system. An overhead ground wire or a down conductor, extending above or across the top of the pole, may serve as the air terminal. Each nonmetallic mast must have two down conductors. Metal masts do not require air terminals and down conductors, but must have two connections to the grounding system.

Attachment 5

MAINTENANCE GUIDELINES FOR EXPLOSIVES FACILITIES

A5.1. Has each facility been inspected to determine the type of protection system installed? Is the system integrally mounted or separately mounted (mast or overhead wire)?

A5.2. Are personnel from the testing agency familiar with lightning protection systems?

A5.3. Are all test agency personnel who could or do perform the tests or inspections familiar with this instruction?

A5.4. Are static grounding systems installed as separate subsystems? Are they connected only to a lightning protection system down conductor (when within side flash), or to a ground loop conductor? Are contact points free of corrosion, paint, grease, oil, or other agents that prevent good bonding?

A5.5. Are both the user and testing agencies aware of all facilities that have been identified as housing or being used to conduct hazardous operations? Are all familiar with any special test/inspection requirements?

A5.6. Are tests/inspections accomplished at the required frequency?

A5.7. Are tests conducted with the proper test instruments?

A5.8. Are personnel conducting tests familiar with the location of test points and the relationship between various components of the system being tested?

A5.9. Are visual inspections being performed as required?

A5.10. Are repair actions taken to render the facility safe?

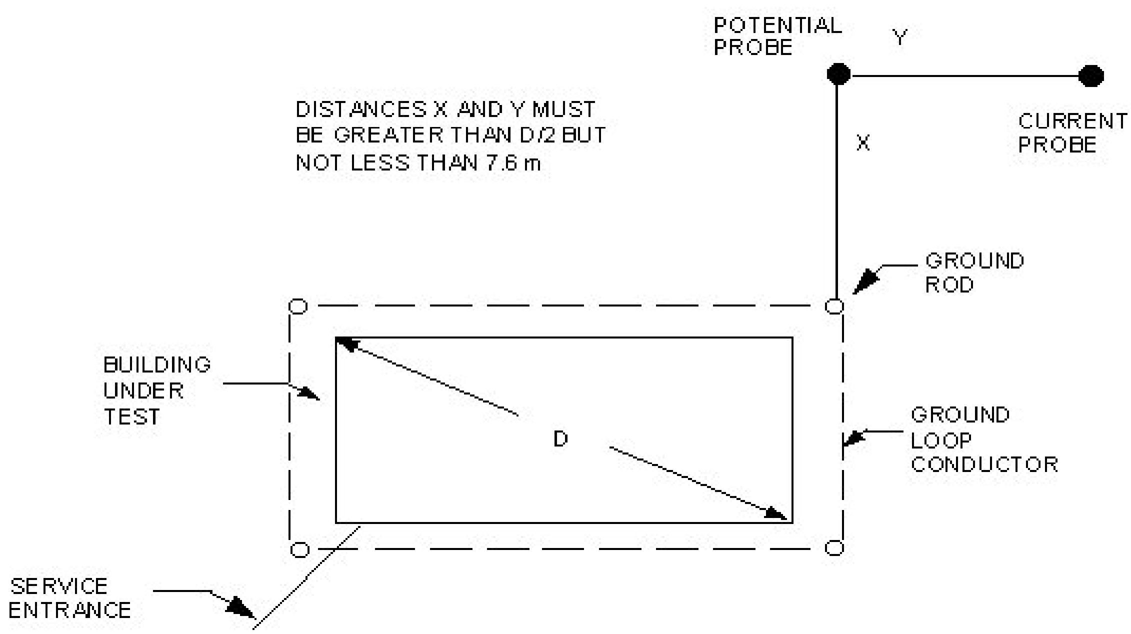
A5.11. After repair actions have been completed, are electrical tests accomplished to ensure the system integrity?

Attachment 6

TESTING REQUIREMENTS

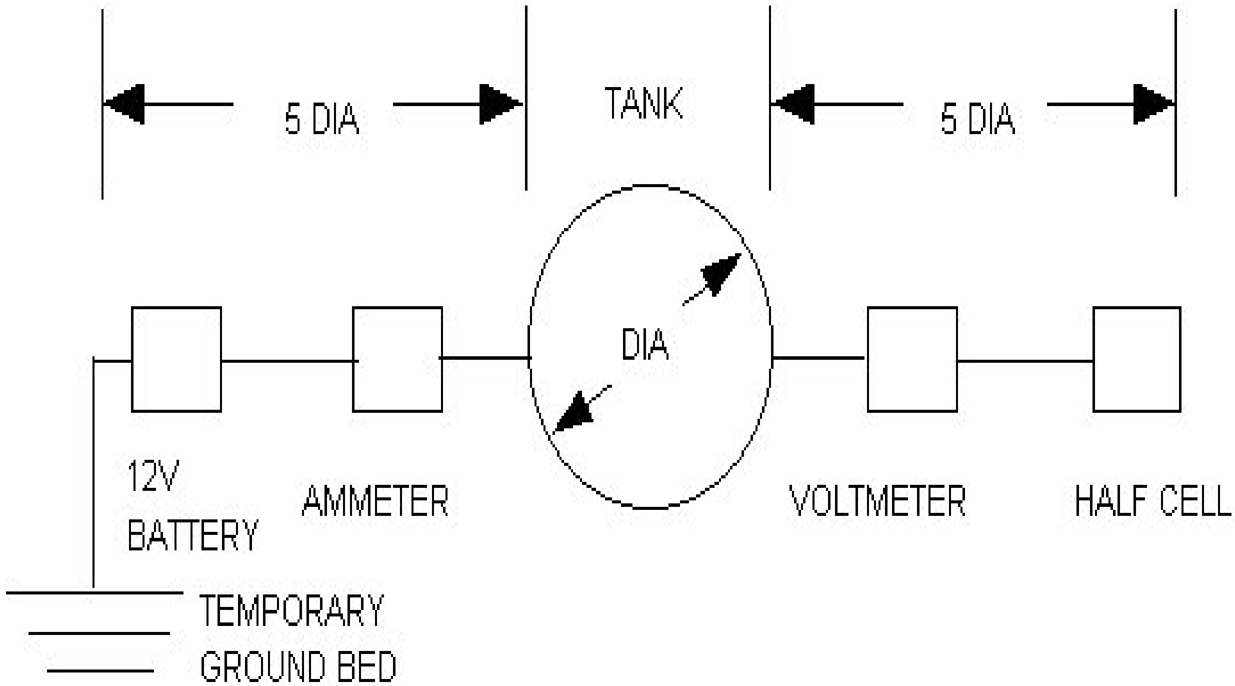
A6.1. Grounding System Resistance Test. Use the procedure described here or the procedure recommended by the test instrument manufacturer. **Figure A6.1.** illustrates auxiliary probe locations for fall-of-potential ground resistance tests. Where possible, conduct this test at the corner of the building opposite the electrical service entrance. Exercise caution: underground metallic piping may influence readings. Position probes as far as possible from the grounding system under test. You may temporarily disconnect electrical service from other ground connections; however, make sure you reconnect the ground or a shock hazard will result. Connect the appropriate lead of a fall-of-potential meter to the ground rod at the test site. Place the potential reference probe at a distance greater than one-half the diagonal of the building under test, but not less than 7.6 meters (25 feet). Place the current reference probe 90 degrees from the potential reference probe (in a direction away from the facility under test) and the ground rod under test, and at a distance greater than one half of the building diagonal, but not less than 7.6 meters from the potential reference probe. Note that the distances between probes are equal. For buildings without a ground loop conductor, perform this test at each ground rod. Resistance should be less than 25 ohms (10 ohms for communications facilities). Periodic tests should be made at approximately the same time each year to minimize confusion resulting from seasonal changes.

Figure A6.1. Auxiliary Probe Locations for Fall-of-Potential Ground Resistance Test.



A6.2. Resistance Test for Above-Ground Petroleum (POL) Tanks. The method described in paragraph **A6.1.** is appropriate for medium to small grounding systems. **Figure A6.2.** illustrates how to measure resistance to earth of larger, more complex systems such as a large POL tank or a substation. In areas where the soil resistivity is relatively high, a higher voltage supply may be necessary. Local cathodic protection technicians can usually furnish the material for the test. Make sure the tank is isolated from the utility systems by dielectric flanges. Also be sure the cathodic protection systems are disconnected.

Figure A6.2. Measuring Resistance to Earth of Large POL Tank.



A6.2.1. Install a temporary ground bed of three or four 1.52-meter (5-foot) ground rods at a distance equal to five tank diameters. Place a copper-copper sulfate half cell on the opposite side of the tank. Place it at a distance equal to five tank diameters and along an imaginary straight line through the center of the tank. Make sure it has good contact with earth.

A6.2.2. Between the temporary ground bed and tank, install a 12-volt common vehicle battery and a dc ammeter (multimeter with 1-amp scale may be used). Install a high impedance (10 megohm or greater) dc voltmeter with a 1-volt scale between the half cell and tank.

A6.2.3. With the battery disconnected, record the voltage reading at the voltmeter.

A6.2.4. Connect the battery and record the current at the ammeter and voltage at the voltmeter. Read voltage immediately after connecting the battery. Current output must be sufficient to effect a minimum 0.05 volt potential shift in the half cell reading.

A6.2.5. Calculate resistance of the tank to earth in ohms by dividing the potential change in volts, DV, by the current in amps; or R = DV/I. For large tanks, typical values would be 0.040 amps of current and a voltage change of 0.2 V.

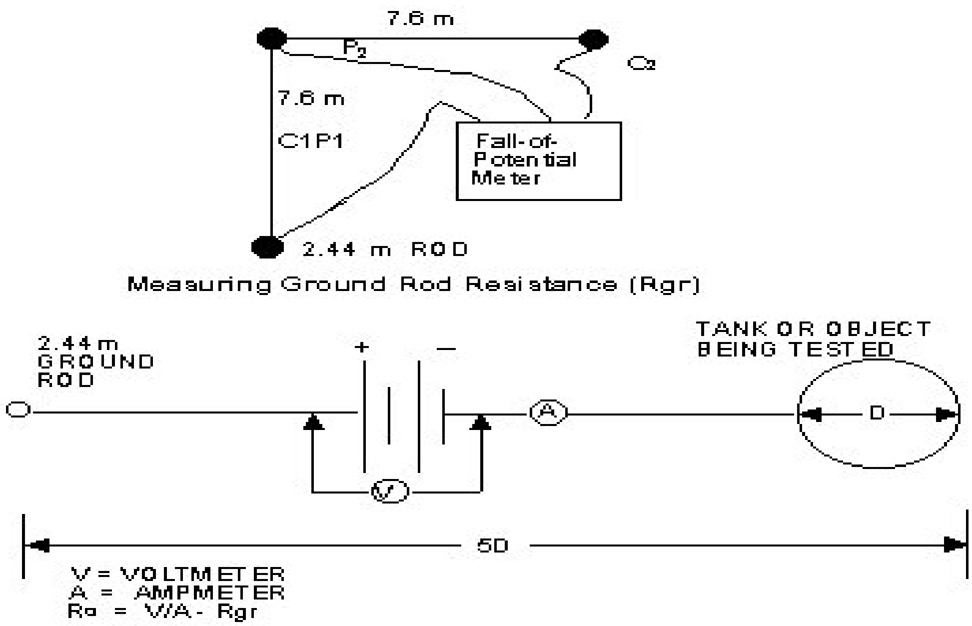
A6.3. Resistance Test for Large Objects. This procedure is an alternative to paragraph **A6.2.** for measuring the resistance to earth of large metallic objects or grids. Be sure to isolate the tank (or object) from the utility system and turn off any cathodic protection system.

A6.3.1. Install a 2.44-meter (8-foot) ground rod at a distance of five diameters from the tank (or object being tested). Measure the resistance of this rod to ground using a fall-of-potential meter. This is the value of Rgr.

A6.3.2. Next, hook up the circuit as shown in **Figure A6.3.** The resistance of the tank (or object) to earth is determined by Ro = V/A - Rgr, where V is the reading from the voltmeter and A is the reading from the ammeter. The ammeter typically reads between 0.1 amp and 2 amps with a 12-volt source.

A6.3.3. If soil resistivity is very high, increase the voltage until enough amps flow to be measurable.

Figure A6.3. Alternate Method of Measuring Resistance to Earth of Large Object.

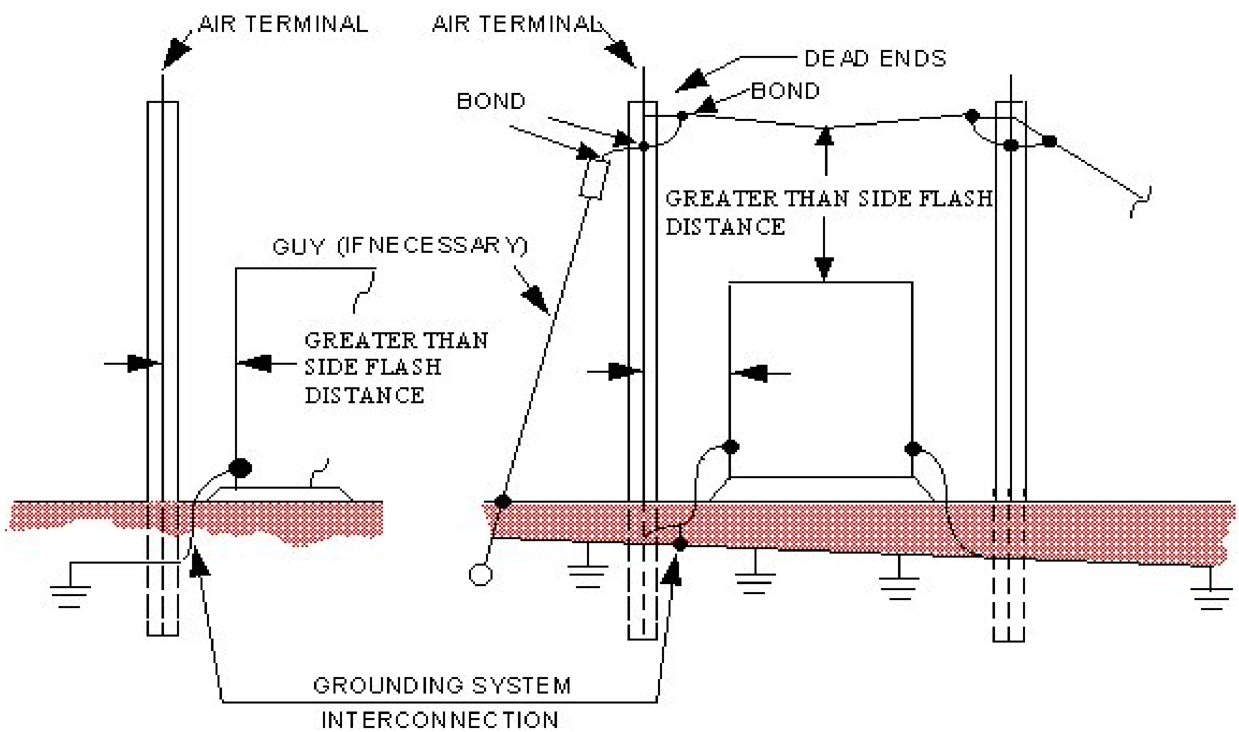


A6.4. Continuity Test/Check for Separately Mounted Lightning Protection Sys tem (Mast and Overhead Shield Wire). Figure A6.4. illustrates a mast and overhead shield wire protection system. To test the continuity of a mast, connect one lead of an ohmmeter to the top of the pole. Connect the other lead to the point where the conductor connects to the ground system, at the ground level. If the resistance is greater than 1 ohm, check for deficiencies and repair. For mast systems where the masts are metallic of seamless construction of a height to provide adequate protection, the continuity test can be conducted from the base of the mast. A seamless mast has all horizontal welds, completed 360 degrees circumferentially. For a system using overhead shield wire, visually inspect overhead shield wires with binoculars. If the system uses mechanical connectors, a continuity test must be conducted from the overhead shield wire to the point where the conductor connects to the ground system, at the ground level (the base of each mast or guy wire(s) when the guy wire(s) is used as the down conductor). If the resistance is greater than 1 ohm, check for deficiencies and repair. For systems which use only exothermic welds or high compression crimps, a visual inspection may used to verify shield wire and down conductor continuity. The visual inspection may be conducted from ground level using binoculars.

A6.5. Continuity Test/Check for Integrally Mounted Lightning Protection Sys tems. Perform this test by firmly attaching one lead of a ohmmeter to a corner ground rod. Next, connect the other lead consecutively to each of the air terminals located at the corners of the building, and the air terminal (or metallic body) with the highest elevation. Repeat the test from the ground rod located at the opposite corner of the building. For explosive facilities, test the continuity to each air terminal. If the continuity of the system is good, the resistance value at any given test point should be about the same. Investigate any reading over 3 ohms. ***NOTE:*** Tests can also be performed from ground rod to nearest corner air terminal and from that corner terminal to the other corner terminals.

A6.6. Testing for Static Bus Bars. Test static bus bars by connecting one lead of a digital ohmmeter to a ground rod of the facility grounding system. Connect the other lead (in turn) to all the free ends of the bus bar. Bolted connections between bus bar sections are not considered free ends. **Figure A6.5.** shows how a typical static bus bar test is performed. Investigate any reading more than 3 ohms and correct it. Perform a visual inspection to ensure materials and connections are in good condition.

Figure A6.4. Mast and Overhead Shield Wire Protection System.



A6.7. Conductive Floor Tests. Before using test instruments, be sure the room is free of exposed explosives. To determine floor resistance, measure between two electrodes placed 0.91 meters (3 feet) apart anywhere on the floor. Each electrode must weigh 2.27 kilograms (5 pounds) and have a dry, flat circular surface area 63.5 millimeters (2.5 inches) in diameter. The resistance between an electrode placed anywhere on the floor and a ground connection must not be less than 25,000 ohms. For more information see IEEE Std 142 and NFPA 99.

Figure A6.5. Testing Static Bus Bars in Typical Explosives Area.