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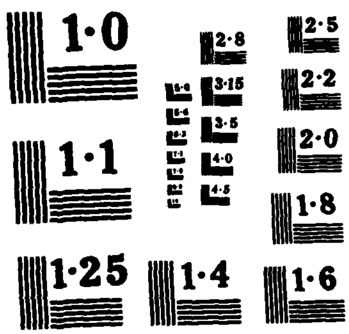

NATIONAL BUREAU OF STANDARDS
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SUPPLEMENT TO
A STUDY OF LIGHTNING PROTECTION SYSTEMS

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Supplement

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SUPPLEMENT I

REVIEW OF DEPARTMENT OF DEFENSE STANDARDS FOR LIGHTNING PROTECTION

All three services have adopted standards for electrical safety and for lightning protection that closely follow or extend the provisions of the National Electrical Safety Code and of the Lightning Protection Code, issued by the National Fire Protection Association. We have reviewed the standards and design considerations for lightning protection given in the following publications:

1. NAVSEA OP5 (Volume 1, 4th Revision, Chapter 4 on Electrical Requirements),

2. NAVFAC DM-4, Design Manual for Electrical Engineering, through change #3c, April 1977,

3. AMC Regulation AMCR 385-100, Safety Manual,

4. Army TM-811-3/ Air Force AFM 88-9, Electrical Design, Lightning and Static Electricity Protection, Aug. 1978,

5. AF Regulation 127-100, Safety (Explosives Safety Standards).

In general, we find these to be informative, usually well written, and representative of the current standards for lightning protection practices. If these standards were met in all field installations, we expect that the incidence of lightning-induced troubles would be lower than observed. There are however, some problems that must be addressed in these standards and some changes can be suggested that would improve the protection possible against lightning; our review follows:

A. Warning of lightning hazards

There appears to be no general DOD standard giving a uniform criterion for warning of the development or approach of lightning hazards to ordnance plants. There are also no standard instruments for the detection and warning of these hazards.

NAVSEA OP5 Vol.1, paragraph 4-9.1.2 recommends closing all operations involving electro-explosive devices or open powders and explosives whenever a storm warning system indicates an electric field strength in excess of 2,000 volts per meter. The nature and character of the storm warning system needed to make that decision is not specified in the naval publications.

AFR-127-100 (page 6.6) specifies:

"6-19. Procedures in the event of electrical storms:

1. When an electrical storm (thunderstorm) approaches the near vicinity, personnel will be evacuated (according to a written plan) from locations containing explosives which could be initiated by lightning, unless a minimum work force must remain to carry out an urgent operational mission.

   (a) An electrical storm may be considered "in the near vicinity" when the time between the lightning flash and the thunder report is 15 seconds or less. (this will place the flash approximately 3 miles from the observer.)..."

The Army Safety Manual, AMCR-85-100, states under Section 16-13, PROCEDURE IN EVENT OF ELECTRICAL STORMS:

"a. Whenever an electrical storm approaches the establishment, personnel shall be evacuated from locations at which there is a hazard from explosives which could be initiated by lightning. ..."

"c. A responsible and qualified person would be empowered with final decision as to the necessity for evacuation. Where operations are of such nature as to require advance warning from shutdown, a net of volunteer observers or an electronic static detector may be utilized. ..."

Under Section 26-20, EVACUATION OF BUILDINGS:

"a. Evacuation plans shall be developed and coordinated with storm prediction systems. When an electrical storm is anticipated a first warning should be given whereupon the quantity of explosives in process should be reduced to a minimum until danger of the storm has passed."

"b. If a melt-pour building is equipped with an effective lightning protection system, melt loading may continue after the second warning (indicating the storm is imminent) until all molten explosives in the building can be run into the item or receptacle involved. ..."

"c. In operating lines or buildings where serious explosive incidents are possible, suitable means for warning personnel to evacuate the building line, or area should be installed. A visual or audible warning system or combination of both is considered satisfactory. The warning alarm system should be interlocked or connected to the deluge system in a manner that actuation of the deluge system will also actuate the alarm system."

The plans for action, after an electrical storm is perceived to be imminent, are reasonable and proper in these standards but the criteria--for anticipating such a storm and for providing the warnings--differ significantly. As presently implemented, these criteria depend primarily on the use of human observers. AFR127-100 (p 6-8) points out that "since untrained personnel cannot always evaluate the (weather) situation accurately, it may be safer to ask the local weather unit for an evaluation". At most of the ordnance plants that we visited, there was no local weather unit and little in the way of suitable meteorological and atmospheric electrical instrumentation to give guidance to the Safety Directors. The need for such instrumentation was widely recognized however, and a number of the Safety Directors had purchased proprietary, commercial devices. The results obtained with several types of these devices were variable and it was clear that most of them were inadequate for the early detection and warning needs.

The "storm prediction systems"--electric field meters and flash-to-thunder techniques discussed in the various regulations--need to be developed, tested, standardized and specified for use where lightning may cause hazards. With the present technology and knowledge of atmospheric electricity, several useful instrumental techniques for detection and for warning of atmospheric electric hazards are available and should be incorporated in ordnance plant operations for increased safety.

B. Lightning Arresters

The desirability and utility of lightning arresters is insufficiently recognized in these standards. They are specified as required in the power distribution systems, but many of the sketches illustrating power distribution systems do not include them. The desirability of lightning arresters and transient suppressors on all primary and secondary power circuits and on all signal and communication circuits is not discussed nor are the principles involved discussed or even mentioned. We think that this is a major shortcoming in these standards.

As is discussed in the next section, we found that in field installations lightning arresters were rarely employed other than in the primary distribution systems where they were supplied by the power companies. None of the secondary, low voltage distribution systems employed lightning arresters (to the knowledge of the personnel who showed these systems to us) and few of the telephone systems had them. In the standards, no mention of low pass filters, transient barriers or voltage overflow devices was found.

C. Impedances in ground connections

The DOD standards for lightning protection appear to have been written with principal concern for conducting large. direct currents, to ground. Adequate wire sizes were specified in the standards but insufficient concern was expressed for the effects of transients which cause many of the difficulties produced by nearby lightning strikes. It seems to us that more attention should be given to the electro magnetic effects associated with the sudden onset of lightning currents. These lightning induced effects may be important whenever large areas are surrounded by conducting loops and when conductors carrying large current make abrupt bends that compress the magnetic field lines. We have seen large and authoritative sparks associated with the occurrence of nearby lightning, jump distances in excess of 6 feet from wires connected to ground but making 90^{o} bends. Similarly, we have measured magnetic field rates of change in excess of 15 Teslas per second during the early stages of nearby lightning strikes. These are sufficient to produce potential differences of as great as 1200 volts in wire circuits spanning loops of up to 10 meters in diameter even though there may be no direct connection or strike to the affected circuit.

These electro magnetic considerations cause us to be concerned about the separate "ordnance ground" specified in NAV-SEA OP5 (page 411 in change 4). Since the ordnance grounds are tied to the facility ground girdle and not to the electrical ground buses, any oscilloscope or test equipment that is used should have its ground reference tied to the same ordnance ground rather than to the power line ground. Otherwise, electro-magnetically excitable loops may exist, comprised of the test equipment, its supply ground, the ground girdle, the ordnance ground and finally the ordnance item under test. These should be of little concern during static conditions but, during nearby lightning, large potential differences may develop and cause local sparking where it is least tolerable: at the explosive device check-out station. To minimize the size of any loops, all test and ordnance items should have a common ground with low impedance connections to earth. The ground from non-contiguous conductors should go to the facility ground in a dendritic, "river and tributary" fashion without developing loops or circuits broken by small gaps. One solution to the problems caused by separate grounds may lie in the use of isolation transformers for all test equipment which then can be referenced to the ordnance ground.

Another deficiency that is related to this category is the lack of emphasis on the necessity for low impedance connections (as differentiated from the ohmic resistance which is very well emphasized) from the air terminals to the earth. AMCR 385-100 page 8.4 specifies the radius of curvature in these connections to earth to be no less than 8 inches with no turn angles of greater than 90^{o}, but the illustrations in the same standard in figures 8-1 to 8-5 indicate sharp 90^{o} bends with negligible radii of curvature. Better illustrations of bends with more desirable radii of curvature are shown in NAVFAC DM4 figures 5.1 through 5.4 but definitive quantitative statements on these desirable radii of curvature are hard to find and should be specified and emphasized on the figures.

D. Overhead grounds above power and communication lines

The desirability of earthed overhead lines above any elevated power and communication lines leading to explosives buildings is not generally recognized in these standards. These are specified in NAVFAC DM-4, page 4-5-9 (although they are apparently treated as optional on page 4-2-8 in the same manual). An even better requirement would be for shielded, underground conducts for signal and power lines equipped at each end with lightning arrestors and transient barriers.

Overhead ground wires provide significant protection to elevated circuits and their use should be encouraged wherever possible. As indicated in the design manual, these should be grounded at frequent intervals with low impedance paths to earth.

E. Air terminals

We note that various types of lightning rods and air terminals ranging from pointed rods, capped rods and masts to overhead horizontal wires are specified without any particular reasons for the preferences being given. Similarily, the specific lengths for the rods vary widely. The various air terminal configurations do have different properties and need to be evaluated. A discussion of some of these is provided in Appendix III of this report.

F. Resuscitation

A general failing in these standards where discussion of corrective measures is given is the lack of recognition that all personnel who may be exposed to lightning or electrical shocks should be aware of the applicable cardio-pulmonary resuscitation techniques. Many victims of electrical shock succumb because the shock has stopped their heart. If given the simple CPR technique, in which the heart is promptly restarted by blows to the chest while respiration is continued by mouth-to-mouth techniques, a large fraction of these deaths could be prevented. Basic training in CPR techniques should be given routinely.

G. Review of Specific Documents

In addition to these general points, there are specific comments that can be made on the various DOD lightning protection documents.

1. NAVSEA OP5 (Vol 1, 4th edition, change 4, page 4-16A)

In paragraph 4.9.1 (General), it is stated that "lightning protection systems safeguard...by providing a conductive path of low impedance for the dissipation of the energy in the lightning strike". This is not the best statement that can be made here for, by conservation principles, if the lightning energy is dissipated by and in the path of the lightning conductor, the energy is not destroyed: rather it will be released in the conductor and possibly cause local problems. The last part of the quoted statement would read more correctly "by providing a lightning strike with a conductive path of low impedance to earth".

The word "dissipate" in the next sentence is similarly inappropriate. "Lightning protection systems should 'shield' against the electrical charges and currents induced..."

In paragraph 4-9.1.2, the statement is made that "lightning strikes do not occur normally in the vicinity where electric field strengths are less than 10,000 volts per meter". This statement is incorrect; lightning strikes are commonly observed when the electric field at the earth is no stronger than 3000 volts per meter and nearby strikes to the earth have been observed during intervals when the local field strength was less than 100 volts per meter. There is often a zone of low field strengths at the earth's surface beneath an active thunderstorm that arises from the dipolar distribution of the electric charges overhead. For this reason, isolated field strength measurements alone cannot be used as a guide to judge the imminence of a lightning hazard. Further, development of a lightning strike is not usually governed by the pre-existing field strength at the earth; the field strength in the electrified cloud overhead causes the initiation of a lightning flash which then propagates on its own. The field strength aloft may be well shielded against observation from below by intervening free charges and, therefore, it is not possible through field strength measurements alone to predict the imminence of a discharge. A better statement here might be "When electric fields produced by an approaching storm exceed this value (2,000 volts per meter), it is an indication that the fields aloft are much stronger and there is an increasing probability of lightning as the local field strengthens. Therefore, 2000 V/m....".

2. TM5-811-3/AFM-88-9.

In chapter 2 section 2-1 of this report, there are a number of statements that could be corrected and improved:

In section a, discussing lightning phenomena: "Thunderstorms feed electrons back to earth by an opposite electron (!) potential gradient of perhaps 10,000 V/m within a thundercloud..." Actually, thunderclouds feed electrons back to earth via lightning channels and by extracting positive, point discharge ions from the earth as the result of strong potential gradients at the earth's surface (of the order of 10,000 V/m). Within thunderclouds, the potential gradients reach values in excess of 100,000 V/m but, due to the low concentration of ions and of mobile charge carriers there, conduction currents are almost negligible, except when electrical breakdown occurs in stronger potential gradients, causing lightning or point discharge.

Later in the same section: "so-called positive cloud-to-ground strokes consist of low power energy transmissions from earth to small positive charge pockets in a thundercloud." In rebuttal: These discharges are not always low power energy transmissions: some of the most intense and damaging discharges known have been of this type. Many of these discharges propagate from cloud-to-ground rather than from earth to charge pockets aloft as stated. In fact, positive streamers propagate easier and often with lower initiating field strengths than are required for negative ones.

We think that this misleading discussion could just as well be deleted but if it is retained, at least, it needs to be improved.

Later still in the same section: "As a leader approaches the ground its effects are made and it is sucked from the air near the earth creating an ionized streamer that meets the advancing streamer".

There is no sucking involved: the approach of the leader streamer to the earth intensifies the electric fields at the earth's surface. The best exposed, elevated conductor in the vicinity on the earth may have the electric field strength at its upper surface intensified so much that local electric breakdown occurs with electron accelerations and photoionization.

A positive plasma streamer propagates upward and joins the approaching, negative leader streamer. When they connect, 100 m or so above the earth, electrons in the leader drain away rapidly to earth, down the ionized channel. Thereafter, earth potential and a positive current move up the ionized channel toward the cloud as electrons aloft continue to drain down the channel: In this manner, a return stroke develops. For this reason, the statement on page 2.1, second column that "lightning is not an alternating current since the transferred recharge current moves back to earth", is incorrect and should be revised.

The discussion on non-conventional systems for lightning protection, section 2.1.d in TM5-811-3 gives an accurate statement on the status of these systems. Later on, unfortunately, it implies that the system may be suitable for protection, "when it is clearly justified on an economic basis".

Actually, these systems are modern day rediscoveries of the point discharge phenomenon that led Benjamin Franklin to invent the lightning rod in 1750. As discussed in main report, after inventing the lightning rod, Franklin found that his elevated, sharpened rods frequently were the preferred channels to ground for nearby discharges, a result which shows they did not dissipate the electricity overhead in these cases and that lightning was not prevented. We now know that point discharge currents flow from the earth from all exposed conducting objects beneath thunderclouds and while these limit the electric strength at the earth to values of the order of 10 kV per meter, they do not discharge the cloud overhead and they do not prevent the occurrence of lightning. Increasing the ease of point discharge by use of barbed wire, elevated towers and by use of radioactive points cannot discharge clouds sufficiently to prevent lightning nor can they dissipate the electrified clouds. For these reasons, there are presently no "charge dissipation arrays" that are effective in preventing lightning. In fact, we have seen numerous photographs of lightning striking such proprietary arrays at Eglin Air Force Base and at Kennedy Space Center in Florida where they have clearly been ineffective in providing lightning protection.

We think that the implied favorable mention of these "lightning dissipation systems" should be deleted from these DOD publications. If these systems cannot protect against or prevent lightning, they clearly cannot be justified on any basis, let alone an economic one.

The discussion of static electricity and its hazards in NAVSEA OP5 (vol 1, 4th revision, page 4.9) is correct and informative. On the other hand, the discussions of the same phenomenon in TM5-811-3, page 3-2 are incorrect; they need to be corrected and augmented. Section b-3 of the TM5-811-3 states that "lightning static results from the accumulation of extremely high voltage discharge... that rapidly generate hazardous and explosive accumulation to static electricity in these condensors, (ungrounded insulated metal)".

This explanation is incorrect and further, as we have indicated earlier, the electro magnetic effects of dynamic electricity are far more important and potentially hazardous than is any static electricity accumulations that may have been produced by the lightning.

Nevertheless, significant accumulations of the charges that give rise to "static electrical" hazards often occur whenever any dry dielectric materials are moved relative to other dielectrics. Each sheet of hot paper discharged from an electrostatic copier can carry a net charge that is accumulated in the receiving tray as more sheets of charged paper arrive. Local sparks can be developed, particularly under conditions of low humidity; and these charges cannot be removed merely by grounding the receiving tray.

Blowing dust, metal powders, sugars and other combustible substances moved in semi-conducting ducts by air, can develop large electrostatic charges that culminate in sparks which may ignite or even explode some of the dispersed materials. Water sprayed into oil tanks can be inductively charged again resulting in sparks that can explode oil vapors. Since many of the structures containing these potential hazards are already grounded, further grounding cannot eliminate the dangers. More attention to the hazards of static electricity in ordnance plants is needed in the Safety Manual.

SUPPLEMENT II

SUMMARY OF VISITS TO ACTIVE ORDNANCE PLANTS

In the course of this study, we visited five representative ordnance plants to acquaint ourselves with the practice of lightning protection in the plants where ordnance is manfactured.

The buildings and equipment in these installations ranged in age from pre WW II to new installations, now under construction. The equipment and techniques observed in these plants similarly were of widely differing ages; the technologies employed were also widely varied. We observed many sophisticated operations and we also saw some that were archaic.

The concern about lightning hazards expressed by the Safety Directors at the various installations varied widely, some Directors expressed great concern with atmospheric electrical hazards and others considered that these were relatively negligible at their site.

Since we visited the plants to observe current practices and were not there as inspectors, in the summary that follows we do not identify locations where various problems were observed. When we did observe problems at a given site, we discussed them with the Safety Director for that site before we departed. There is, therefore, no need to follow up specifically the problems that we observed or the situations that we consider to be undesirable.

We found that the Safety Directors were knowledgeable of the appropriate portions of the pertinent safety manuals that had to do with lightning protection, the subject of our visit. Many of them were justifiably concerned with how the safety manual should be interpreted and requested more information. Summarized below are some of the problems that were common to a number of the installations that we visited.

A. Detection of lightning hazards

We found no adequate, general means of identifying the incidence and severity of lightning hazards. At one plant, we were told that the first discharges in developing storms had occurred several times directly over the ordnance plant and that these had caught the Safety Director unawares with hazardous operations in progress. Some relatively primitive warning instrumentation was observed at several of the sites, but little of it was in good operating condition. Much of the instrumentation was based on poor physical principles, and the personnel responsible for it had relatively little training in operating the equipment and in interpreting the results. At one plant, we did find a progressive Safety Director who had an electric field mill that appeared to give him appreciably more information than he could interpret.

The criterion for shutting down operations ranged from human detection of nearby lightning with "flash-to-bang" times ranging from 3 sec (3300 ft from the observer to the closest part of the lightning channel) to 15 sec (about 3 miles to the closest thunder source). At one plant, six seconds "flash-to-bang" was used because it was interpreted there as equivalent to a 2 mile distance to the lightning and an acceptable warning time! (A six second time interval actually indicates lightning at a 1.2 mile slant range.) There was no electric field strength criterion in use at any of the plants that we visited.

In our view, since lightning channels commonly travel distances much greater than 2 miles, flash-to-bang times of 3 sec indicate that the storm is essentially overhead and, at this time, hazardous operations should already have been secured.

From our observations, an appropriate detector of atmospheric electric hazards should be devised and placed in ordnance plants where atmospheric electric disturbances may be hazardous to operations with explosives in order to provide some advanced warning.

B. Grounding of overhead metallic structures

We observed a number of lightning rods from which the ground leads were misssing and other lightning rods in which the leads from rod to earth had 90 degree or greater bends or kinks. Metal ventilators at the tops of a number of the buildings were higher than the air terminals and were not grounded. Metal gutters and metal flashings around many of the buildings containing explosives were similarly not grounded.

Much of the grounding that was observed appeared to be designed for carrying steady state currents with little concern given the impedance to the surge for lightning currents. A nitroglycerin facility that we observed had the upper metal shield grounded through a tortuous path separately from the lower half of the building; in effect, the shields comprised a giant loop with gap separations of only a centimeter or so across which sparks might be induced to jump by a nearby lightning flash outside the building.

Despite the provisions of the various safety manuals, numerous buildings in which explosives were handled had elevated power and telephone lines entering directly with little or no lightning protection within the building.

C. Lack of standardization in elevated lightning protectors

The air terminals that we observed were constructed in many different ways and ranged from sharp points, blunt rods, and horizontal elevated wires with no standardization. Many of the vertical air terminals were mounted in rows connected to a horizontal ground wire by sharp 90° joints. Again, it was evident that there was no consideration of the resulting high impedance to fast rise current surges.

D. Lightning arresters

In talking with the Safety Directors, we understood that modern lightning arresters were not in wide use on individual pieces of electrical equipment, although they were frequently incorporated into the primary power distribution systems. In at least one plant, we were told that motor failures occurred quite frequently during thunderstorm periods and that these motors were not equipped with any surge protection. Since some of these motors were being used in chemical engineering operations involving explosive mixtures, loss of stirring motors and of cooling pumps as the result of lightning transients could have far more serious consequences than is evident in considering the replacement cost of the motor alone.

E. Surge protection

Surge protection on various electrical signal lines entering the buildings from outside appears to us to be at a level much less than minimal requirements dictate for safe operations. With the projected increase in computer controlled processing, problems arising from lightning induced surges could be far more serious than present practices indicate.

Conclusions

In our view, the Safety Directors at all of the installations were diligent, concerned, and in need of at least minimal level of technical support.

We found lightning protection in several plants to be of a generally primitive level, arrived at by rules of thumb with little technological support for warning, for protection against nearby lightning strokes, or for surge protection. Many of the lightning protection systems were installed under earlier lightning protection codes, and much of their protection has now degraded because of corrosion or of mechanical impact so that, often, conducting leads to earth were either missing, misconnected, or unterminated.

Where many problems were observed, we understood that little modernization of the equipment was planned: the current intended usage of many of the buildings frequently did not justify the cost of meeting the already existing requirements for lightning protection.

SUPPLEMENT III

RECOMMENDATIONS FOR REVISIONS OF CHAPTER 8, "LIGHTNING PROTECTION" "Safety Manual" AMCR-385-100, C-2 (Now DARCOM R-385-100).

In an effort to consolidate the existing standards into a generally correct and useful one, we have examined Chapter 8 of the Safety Manual, on a sentence-by-sentence basis and have the following comments and recommendations for its modification.

Page 8-1, Paragraph 8-1, (Sentence 4)

Lightning protection should be required for all facilities where ordnance is handled during the occurrence of storms regardless of the frequency of the storms. It should be the DOD policy to consider the lightning protection system as a vital part of the explosives building structure rather than being treated as an add-on, corrective measure.

Page 8-1, Paragraph 8-1, (Sentence 2)

This sentence is poorly written and provides insufficient guidance for decision by the reader. Either delete the sentence or require:

"(1) All exposed structures in which initiating fuses, electric explosive devices and similar sensitive but hazardous devices are handled during electrical storms should have an external lightning protection system of the first type, defined below.

(2) All exposed structures in which non-fused explosive materials are handled or stored should have at least the integrally mounted system specified in paragraph 8-3."

Similar specifications for other hazardous situations should be supplied by the Explosives Board.

Page 8-2, Paragraph 8-2, (Sentence 4)

We think the matter of supervision of the lightning protection system needs to be discussed. The use of a "commercial testing laboratory" as specified may not be a sufficient guarantee to provide adequate or "total" protection of explosive handling or storage systems.

Page 8-2, Paragraph 8-3a, (Sentence 2)

Delete all mention of a "cone of protection", for such a "cone" does not exist. The concept is poorly based in the physics of streamers. It is a mixture of the radius of the electric-field collection-zone concept and of the striking distance concept of a return stroke streamer. These distances and areas vary with the local geometry and with the exposure and are not quantifiable with our present state of knowledge. Golde (1967) pointed out that lightning has struck buildings within the "protected" zones suggested by various authorities; he had reached the conclusion that to speak of a fixed space of protection was "inadmissible".

Page 8-2, Paragraph 8-3b, (Sentence 1)

Replace first sentence with "The reason for using air terminals is that they may provide direct paths to ground for the large currents associated with a lightning strike."

Page 8-2, Paragraph 8-3b, (Sentence 3)

Air terminals should be...."electrically continuous with the down-conductors to the earth with minimum impedance to transient surges." They should also be connected with low impedance connections to ridge cables when they are used.

Page 8-2, Paragraph 8-3b, (Sentence 4)

Delete "T form..." and require "with gentle bends of 8 inches minimum radius of curvature.

A sharp bend in a down-conductor increases, locally, the conductor's impedance to current surges thus causing it to act as a poorly-terminated transmission line. Surges are partially reflected at such impedance discontinuities. Whenever the local impedance is greater than that of the straight line, the reflection has the same polarity as that of the original surge. In this situation, the amplitude of the reflection is added to that of the original surge and increases, momentarily, the local potential differences between the down conductor and its surroundings. This effect can produce "side flashes" to objects in the vicinity from a sharply-bent down-conductor that otherwise has a low dc resistance to earth.

The adequate conduction of lightning currents to ground must allow for the dynamic effects encountered in current surges and transients.

Page 8-2, Paragraph 8-3b, (Sentence 5)

The air terminals should be at least 4 feet high. Heights of 6 feet above surrounding structures are preferable from lightning interception considerations.

Page 8-3, Figure 8-1

Show gentle bends of not less than 8 inches minimum radius of curvature at the air terminal connector to the down-conductor, to the ridge cable, at the ground connection and all other places where the conductor to earth changes direction.

Page 8-3, Figure 8-1

In general, multiple conductors to ground should be provided at each end of all structures where explosives are being handled or stored. A direct down-conductor to earth from the ridge pole is preferable to one that follows the roof contour (upper figure).

Page 8-3, Figure 8-1

The tripod shown should be replaced by two blunt lightning rods extending directly above the two down-conductors shown. When tripods are used to support air terminals, they should be connected to an integral part of the down-conductor with a low impedance connection.

Page 8-3 & 4, Paragraph 8-3b, (Sentence 8)

Lightning rods less than 4 feet high should not be allowed as part of the lightning protection system for buildings where explosives are handled or stored.

Page 8-4, Paragraph 8-3b, (Sentence 9)

Tripods bracing air terminals should either be made of dielectric materials or else all of their attachment points to the structure should be connected to the down-conductor with low impedance, gently curved connectors.

Page 8-4, Paragraph 8-3

From our view, the protection of explosives buildings with lightning rods is less safe than if elevated cables formed a canopy overhead. For this reason, we think that a paragraph describing improved protection methods should come ahead of section 8-3b. Much of the discussion in this section on page 8-4 needs to be improved or replaced with a presentation of the overhead cables. A discussion of them is given in the main text.

Section 8-3c should come ahead of any residue of section 8-3b but all courses and contours should have 8 inches minimum radii of curvature.

Page 8-5, Figure 8-2

Blunt lightning rods should be better than sharp ones based on our analysis in the main text. All bends and connections shown should have 8 inches minimum radii of curvature. The connection from the vertical air terminal to the horizontal run of the down-conductor should obey this 8 inches minimum radius requirement. When possible, the air terminal should be connected directly to earth with a straight run of down-conductors.

Page 8-6, Paragraph 8-3d, (Sentence 2)

Down-conductors should not be coursed over the extreme outer portions of a building, but should be inserted through, or punched through, intervening structures, or led directly toward earth with necessarily following building contours and roof overhangs. The impedance to transient surges introduced by such bends and contours defeats the purpose for the down-conductor: to provide direct paths to ground for the large currents associated with a lightning strike. On new structures, such direct path connections should be part of the original building design.

Page 8-6, Paragraph 8-3d, Next to last sentence

Use of symmetry in down-conductors is not as important as is the use of a large number of low-inductance connections to earth.

Page 8-7, Figure 8-3

All changes in conductor direction should be made with 8 inches minimum radii of curvature. Twice the number of down-conductors shown is desirable for protection of explosives buildings. Connections to earth should be directly from the bases of the vertical air terminals rather than from mid points in the horizontal runs of ridge cable.

Page 8-8, Figure 8-4

The air terminals should extend higher above the roof and directly above the vertical down-conductors. The peripheral air terminals should not be set in from the edge of the roof.

Page 8-9, Figure 8-5 (Top)

Same recommendations as for Figure 8-4 above. Minimum radius of curvature for all changes in down-conductor direction should be 8" or greater.

Page 8-9, Figure 8-5 (Bottom)

Air terminals should be on the ends of the gable roof and should be connected directly to a vertically-going, down-conductor. Connections to ridge cables and to dormers should have 8 inches minimum radius of curvature. If possible, an air terminal on a dormer (on an explosives building) should connect directly to earth with a vertically running, down-conductor.

Page 8-10, Figure 8-6

All connections and changes in conductor direction should have 8 inches minimum radius of curvature. The best exposed air terminals (at the corners of buildings) should be connected directly to down-conductors rather than having the down-conductors connected to the mid point of a horizontal ridge cable as shown. For buildings over 300' in perimeter, overhead cables (as shown in the replacements for figures 8-6 and 8-7) should provide much better protection.

<u>Page 8-11, Figure 8-7</u>

Same recommendations as above.

<u>Page 8-12, Figure 8-8</u>

Same recommendations as above.

<u>Page 8-13, Paragraph 8-3f, (Sentence 4)</u>

Protection should be given to ground connections against corrosion. The reinforcing steel used in explosives buildings should be connected electrically and adequately to the grounding electrodes so as to minimize internal corrosion of the reinforcing steel. A copper cable should be welded to the "rebar"; the weld and the steel should then be insulated from the ground water and earth. The correct procedure here should be developed in consultation with experts in corrosion prevention.

<u>Page 8-13, Paragraph 8-3g</u>

When new construction is planned for the handling of sensitive explosives, it should include a buried metal mesh of large diameter wires beneath and around the explosive building to establish a ground plane. Down-conductors should connect to the buried mesh on all sides of the building. Copper grounds should be connected to the "rebar" before the footings for a new building are poured. As much concern should be given to the transient impedance of the connections to earth as is presently given to the static, dc resistance. Methods for measuring and monitoring the transient impedance of the grounding system are needed and should be developed. Electrical system grounds and telephone system grounds should be connected to one point on the lightning protection ground system.

<u>Page 8-15, Paragraph 8-6b, (Sentence 7)</u>

Begin a new paragraph 8-6c: "When no water system..." because the discussion following this opening does not fit the conditions set above for section 8-6b. The last three sentences now in paragraph 8-6b belong under section 8-6a, after the first or second sentence.

<u>Page 8-16, Paragraph 8-10</u>

In our view, igloo-type magazines need air terminals only above exposed conducting ventilators (if unable to conduct lightning currents directly) and above the front wall if personnel are to be entering or leaving the magazine during stormy weather. The magazine's conducting ventilators should be bonded to the magazine's rebar. Remove all air terminals at earth-level; no air terminals are needed on the earth mound itself. All circuits brought into the magazine should be equipped with effective transient suppressors, rf filters and lightning arresters.

Page 8-16, Paragraph 8-10, last sentence

Why do not steel doors on magazines need the same #6 grounding lead specified in Section 8-3e?

Page 8-17, Paragraph 8-11a

A dynamic impedance test is needed. The dc resistance may be easy to specify and to measure but the dynamic impedance is of far greater importance than is the dc resistance.

Page 8-17, Paragraph 8-11c, (Sentence 1)

The "cone of protection" concept is "inadmissable" as stated above and should be deleted. The radius of the electric-field collection zone is about 5/10 of the mast height so that the mast spacing as specified here is too great. Use of overhead cables with grounded guy wires will extend the dimensions of the area protected without requiring a great increase in the number of masts.

Page 8-18, Paragraph 8-12a

This type of lightning protection, when properly executed, provides a better defense against direct lightning strikes than do the systems discussed above. The overhead wire concept should be developed and its use encouraged on all explosives-handling facities. Multiply-grounded guy wires and down-conductors should be used as extensively as possible. A "maypole" configuration (with a mast above the center of the building and with guying down-conductors extending outward and downward to lower masts onto the earth so as to enclose the explosives structure) should provide significantly better protection than is now in use.

Page 8-18, Paragraph 8-12a, (Sentence 4)

Discharges are not "reversed". The wording should reflect the earlier statements about gentle turns in the down-conductor with changes in direction never exceeding 90° and with 8 inches minimum radii of curvature.

Page 8-18, Paragraph 8-12b, (Sentence 3)

The "zone of protection" specified is much too wide for the probable width of the protected area. The width of the electric-field collection zone is of the order of 1.2 times the wire height and therefore, the recommendation of a zone width 4 times the pole height should be revised downward.

Page 8-20, Figure 8-9

A blunt air terminal should be mounted on the wood pole and should be connected to the guy cable and to a down-conductor with an 8 inches minimum radius of curvature conductor (properly oriented).

Page 8-19, Paragraph 8-13a

The fences on either side of every gate should not only be grounded, but also they should be connected by an underground or overhead cable or by a metal bar at least 1/0 in size which spans the region of the gate. Note lightning accident report from Camp Drum (740719).

Page 8-20, Paragrph 8-14

Overhead pipes entering metal-framed buildings containing explosives should also be attached to the metal frame of the building at the point of entry of the pipes. When horizontal elevated pipes extend outside the building, they should also be connected to earth at intervals of 200 feet or less.

Page 8-23, Paragraph 8-18

We recommend that the wording in OP-5A Section 4-9.4.4 replace that in AMC 385-100 Section 8-18.

Page 8-23, Paragraph 8-19

Interconnection of metal bodies. All power line grounds and neutrals should be connected only to the primary lightning ground system at one place. If there are long runs from an installation to the sole power-line ground, auxiliary grounds through low voltage lightning arresters should be made to local grounds. These should conduct only during strong surges thus preventing both ground loops and the establishment of high potentials arising from the surge impedance of the primary ground connector. Primary and secondary grounds should be interconnected as extensively as possible so as to approach the concept of a grounded, conducting plane beneath and around the structure to be protected.

Page 8-25, Paragraph 8-20e

We recommend that the air terminals not be tapered but be smoothly finished cylinders about 3/4" in diameter and 4 to 6 feet high with hemispherical ends or 4 to 6 foot high rods at least 3/8" in diameter terminated at the tops in 1" diameter spheres. Pointed rods should not be used.

Page 8-26, Paragraph 8-21

Testing and Inspection.

(1) Testing of connections to ground and of down conductors should be made especially during the dry portions as well as in the different seasons of a year.

(2) Dynamic testing of surge impedance to earth in down-conductors should be developed and used.

(3) Inspection of lightning arresters should be made periodically, frequently, and preferably after each major lightning storm. (Lightning arrestors should be mounted so that inspection of their condition is possible.)

(4) A review procedure should be established for checking on the protection adequacy of all add-on wiring, telephone services, signal cables, and power connections after installation. Copies of all work orders calling for these installations should go to the lightning protection safety officer so that he can be aware of wiring changes and ensure their adequacy for lightning protection.

(5) Testing procedures given in OP5 sections 4-9.2.4 and 4-9.2.5 should be incorporated into AMCR-385-100.

Page 8-28, Figure 8-10

This figure should show the desirable gentle changes in down-conductor directions.

Page 8-29, Figure 8-11

No elevated ground terminals should be required above buried structures constructed with grounded, reinforcing steel. Blunt air terminals over a metal ventilator and over the front wall and connected directly to ground and to the rebar are desirable.

Page 8-30, Paragraph 8-21f

A test of the electrical continuity across a gate in an extended fence row is essential.

Page 8-32, Figure 8-13

The recommended electrical connection bridging across the gates should be shown in this figure.

Page 8-35, Figure 8-13

The requirement that no changes in down-conductor direction exceed 90° is violated in this figure where the down-conductor follows the tank contour. This requirement is important and no illustration should show this incorrect practice.

Additions

To supplement the revised text for Chapter 8 of the Safety Manual, we recommend the inclusion of sections which discuss the following topics:

(1) Specific criteria for establishing the onset of a lightning hazard. The criteria should be graduated according to the sensitivity of the explosives operations being conducted and to the amount and quality of the lightning protection that has been provided. For the operations that we observed during the field visits, we believe that flash-to-thunder times of less than 20 sec should be considered as indicating the existence of a lightning hazard. Warning devices as discussed in the main text should be developed, standardized, discussed and required in a revised standard.

(2) Lightning surge suppression in signal power and communication lines. The revised standard should require lightning surge suppression on all electrical lines leading to or from an explosives handling or storage facility.

(3) Surge impedances in ground connections. When lightning strikes a facility, the surge impedance to ground is of far greater importance than is the dc resistance which, because of the ease with which resistance can be measured, is presently the only specification on the quality of ground connections. The 10 ohm resistance requirement can be met with #30 wires but these could not conceivably carry the full lightning discharge current. These standards are presently incomplete in that they do not specify the response of a lightning protection system to the equivalent of an actual lightning pulse. Surge impedance and lightning conduction measuring techniques need to be developed, standardized and specified for these explosive facilities.

(4) Use of overhead, grounded conductors above power, signal, and communication lines attached to all explosives facilities. As stated earlier, exposed and elevated electrical circuits provide significant inputs of electrical transients into these facilities. The harmful effects of these transients may be significantly reduced by use of overhead grounded conductors above all circuits and of suitable lightning transient suppressors on all incoming and outgoing circuits.

The provisions of NAVFAC DM-4 paragraph 4-5-9 should be included and extended in the revised standard.

(5) A section on cardio-pulmonary resuscitation techniques should appear explicitly in the chapter on lightning protection. Many people who do not normally work with electrical power systems are exposed to lightning. Some of the people who are affected by nearby lightning strikes have heart stoppages that could be restarted if the CPR technique were promptly applied.

separately from the usual discussion of electrical shocks. First aid classes that include the demonstration of this technique should be held periodically at all explosives plants under the auspices of the safety director.

END

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