

Background for the AMS Statement on Lightning Protection Systems

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Lightning is the primary natural cause of fires and, throughout recorded history, has damaged structures built by humans. That it preferentially strikes tall objects has long been recognized; Artabanis, an advisor to Xerxes, is quoted as saying 2300 years ago: "(God's) bolts fall ever on the highest houses and tallest trees". In his poem, *De Rerum Natura* published in 55 BC, Titus Carus Lucretius asked about thunderbolts "Why has he (Jupiter) a special fondness for high places so that we see most traces of his fire on mountain tops?" and "Why does he demolish the holy shrines of the gods and his own splendid abodes (which were located on high places) with a devastating bolt?". Although this preference of lightning for striking elevated objects has long been known, no successful efforts using this knowledge for lightning protection were recorded until Benjamin Franklin announced in 1752 that the strikes to a tall metal rod could be conducted to Earth by a wire, without damage to the structure on which the rod and wire were installed (Franklin, 1753). Franklin made this discovery when he erected an iron rod with a brass wire tip in an effort to neutralize the electricity in thunderclouds passing overhead by the emissions from the sharp-tipped rod. Earlier, he and his associates had discovered that these emissions could discharge electrified objects when he approached them while holding a metal needle in his hand. Franklin then speculated that the same discharge process might take place if a sharp-tipped, grounded rod were placed beneath a thundercloud. When he carried out this experiment, his rod, instead of discharging the thundercloud overhead, was struck by lightning. Thereafter, Franklin held the view that this result was due to the "power of the point" and that his lightning rods would either discharge electrified clouds or, if that failed, would be the preferred receptor of any strikes in the vicinity and could conduct them harmlessly to Earth through a suitable "down conductor" that was connected to another rod driven into the ground. Following Franklin's announcement of his discovery in his publication, *Poor Richard's Almanac*, lightning rods were soon installed on many buildings in Europe and in America. Several, very tall structures had been repeatedly damaged by lightning but, after the installation of Franklin rods, no further damage occurred. The success of these rods in preventing damage by lightning was so noticeable that in 1778, the Senate of Venice issued a decree ordering the erection of lightning rods throughout the republic. For political reasons in Great Britain, there was long a reluctance to install Franklin rods but, after more than 220 ships of the Royal Navy suffered damage or were lost as a result of lightning strikes during the Napoleonic wars, the Admiralty was finally convinced in the 1830s by Sir William Snow-Harris to install lightning rods and down conductors on its sailing ships whereupon the damage caused by lightning ceased to be a problem.

THE ORIGINS OF STANDARDS FOR THE INSTALLATION OF LIGHTNING PROTECTION SYSTEMS.

The use of lightning protection on land-based buildings increased greatly during the early 19th century but the information on how best to install lightning protection was not widely known. There were no texts or standards and, in America, the installation of lightning rods became a fertile field for itinerant "lightning-rod-men" whose excesses and practices cast doubts on the utility of lightning protection. In 1879, in his book, *Lightning Conductors - Their History, Nature, and Mode of Application*, Richard Anderson (Anderson, 1879) wrote: "America stands pre-eminent above all other countries in the numerous schemes that have been devised for the protection of buildings from the effects of lightning, and probably no other nation has been so systematically victimized and swindled in the matter. The tramping 'lightning-rod men' of the United States have been notorious for extortion and ignorance; they use all kinds of fantastic and peculiar shaped terminal rods and conductors, the main object apparently being to make as great a show with as little material as possible. Their work is almost entirely confined to the upper portion of the conductor, to the absolute neglect of the most important part - the earth terminal. The majority of the lightning conductors in America are consequently untrustworthy..." On the recognition in 1878 that there were no authorized or well-matured directions for the installation of lightning protection systems in England and that the practices in vogue were so varied and anomalous, the Royal Meteorological Society convened a lightning rod conference in an effort to take action for the public. The Report of the Lightning Rod Conference (Symons, 1882) provided the code of rules for those who installed lightning protection systems in Britain.

In 1904, following the British code, W. S. Lemmon, B. H. Loomis and R. P. Barbour (Lemon et al., 1904) prepared Specifications for Protection of Buildings Against Lightning which was adopted for American use by the National Fire Protection Association in Quincy MA. After periodic revisions over the years as more was learned about the physics of lightning and as the technology has advanced, these specifications have been issued as NFPA 780, the current standard for the installation of lightning protection systems (NFPA, 2001).

THE PROTECTION PROVIDED BY LIGHTNING RODS EQUIPPED WITH DOWN CONDUCTORS.

The protection provided by lightning rods equipped with down conductors. In the years since the specifications for protection of buildings against lightning were adopted and suitable protection systems were installed on buildings, significant protection against the damage caused by lightning has been demonstrated. During a seven-year period beginning in 1907, the reports of fire losses to protected farm buildings in Iowa (comprising about one half of the insured buildings) were 1.3% of the damage to unprotected buildings. During the years 1919-1924, the value of the damage to the half of the insured

buildings that were "rodded" was about 7% that of the unrodded structures. About 5% of the lightning-caused fires took place in barns supposed to be protected by lightning rods but, on investigation, about one third of these so-called "rodded" barns were found to have had defective protection systems. When opinions were expressed by the fire-insurance companies, they were to the effect that if buildings were properly "rodded", they would be practically safe from damage by lightning.

During World War II, the decision as to whether lightning protection would be provided for certain manufacturing facilities operated by private contractors for Army Ordnance was left up to the contractor. Records show that from

1943 to 1946 the unprotected Indiana Ordnance Works lost approximately 500,000 pounds of explosives, an explosives magazine, a shipping house and operating building, and had other damage exceeding \$100,000 as the result of six lightning strikes. In contrast, the immediately adjacent protected Hoosier Ordnance Plant reported no losses from lightning. A survey by Army Ordnance of the lightning experience for the period 1944 through 1948 shows that protected structures were struck 330 times with negligible damage whereas the unprotected structures were struck 52 times and the damage exceeded \$130,000. The efficacy of lightning rods in preventing damage from strikes has been established so well over the years that lightning protection is now routinely required on large buildings open to the public.

THE INITIATION OF LIGHTNING STRIKES. Lightning strikes usually begin in thunderclouds from which a "leader" carrying negative charges descends toward the Earth. Schonland and Collens (1934) discovered that the negative leader descends in a step-wise fashion from a thundercloud, provoking upward-going positive streamers from exposed objects on the ground as a result of the local intensification of the atmospheric electric field beneath the negative stepped leader. One or more of the rising positive streamers may intensify into a positive leader which connects to the approaching negative leader and allows negative charge to drain to the Earth as a "return stroke" when Earth potential moves up the negative channel. Less frequently, lightning strikes lower positive charges to earth. When these strikes occur, they are often more damaging than the negative ones; positive strikes usually are more energetic and have sustained "continuing currents" that can ignite fires.

Of special interest for lightning protection is the determination of which object on the Earth is most likely to furnish the successful upward-going streamer that provides the connection to the descending leader. From studies of the physics of lightning and of long sparks, it is now known that the development and propagation of plasma streamers and of the more conductive leaders occur only when the local electric fields are very strong. It is also known that the tips of curved electrodes concentrate and intensify any ambient electric fields to which they are exposed. This provides an explanation for why elevated objects are the preferred recipients of lightning strikes; the strong fields around their tips caused by the charges carried by approaching leaders provide the conditions necessary for the generation of upwardly propagating leaders that rise to connect with downward-moving leader, thus completing the strike discharge path to earth and determining the strike point.

PROTECTION AGAINST DIRECT LIGHTNING STRIKES. The fundamental principle in the protection of life and property against lightning is to provide a means by which a lightning discharge can enter or leave the earth without resulting damage or loss. In practice, this is accomplished by providing preferred receptors for nearby strikes then conveying these discharges to Earth and distributing the charges brought down by lightning into the ground so that they do not cause local hazards.

As pointed out in the 1882 Report of the Lightning Rod Conference, it is important that the tips of the designated strike receptors "be high enough to be the most salient features of the building no matter from what direction the storm cloud may come". While Franklin invented lightning rods with sharp tips because he thought that their emissions could neutralize a cloud and prevent lightning, we now know that this does not occur. Instead, the primary function of a Franklin rod is to be a strike receptor. For this purpose, a sharp tip is not ideal. The emissions from sharp-tipped lightning rods under the influence of strong electric fields act to weaken the fields locally thus decreasing the likelihood that the tip will serve as a strike receptor. In order that a sharp-tipped rod be "struck", it is necessary that the local electric field be intensified more rapidly than it is weakened by the formation and motion of ions around its tip and that the rod respond successfully before competing streamers form above some other objects in its vicinity. The early successes with Franklin rods came from sharp-tipped rods exposed on tall structures, as Franklin taught, well above any competing objects. The optimum configuration for the tip of a lightning rod has been studied recently and was addressed in the recent edition of NFPA 780.

Another aspect of lightning physics that has been studied recently is that of the efficacy of ground rods in transferring lightning discharges to the earth. It is well known that large potential gradients develop at ground level when lightning strikes an isolated tree; the resulting voltages appearing on the ground surface between the legs of animals standing nearby may exceed hundreds of kilovolts, causing fatal currents to flow through their legs. Arcing occurs radially outward from ground rods when the current from lightning discharges conducted to the rod exceeds 20 kA. The use of radial ground conductors buried below ground level is now recommended in the 2000 edition of NFPA 780 as a means of distributing lightning charges to their ultimate destination, the surface of the earth.

THE NEED FOR A STANDARD TO GUIDE THE INSTALLATION OF LIGHTNING PROTECTION SYSTEMS. It is now well established that properly installed and maintained lightning-rod based protection systems significantly decrease lightning damage. Since the installation of an

adequate lightning protection system is not simple, a standard is needed to ensure that proper procedures are followed by the installer. To be effective in providing protection for a structure that is struck, the following requirements must be met:

1. A sufficient number of rods must extend above the upper portions of the structure to be protected and their tips must be so exposed that one of them becomes the locally-preferred strike receptor upon the close approach of an initiating leader, descending from a thundercloud,
2. The connection between the strike receptor and the Earth, the "down conductor," must be able to carry the lightning current without significant heating,
3. The impedance to the flow of current in the down conductor must be sufficiently low that "side flashes" to objects in the vicinity do not occur as a result of high voltages developed by the passage of the current,
4. The connection from the down conductor to the Earth must allow the lightning current to flow into the ground without the development of large electrical potential differences on the earth's surface and without creating hazards to personnel or structures nearby,
5. All large metal components of the structure should be connected electrically to its down conductor system to minimize capacitance effects and to allow the transfer to Earth of the "displacement currents" that flow when the external electric fields are changed abruptly by the lightning discharge.
6. Surge protection should be provided for the electrical service and for all electronic equipment within the structure.

Given these complexities, standards that specify the requirements which must be met in order to ensure the adequacy of each lightning protection installation are essential and are required by most industrial countries. As given above, the standard that is widely used in the United States is National Fire Protection Association standard for the installation of Lightning Protection Systems (NFPA 780) which originated in 1904 and which is revised every three years by an NFPA Technical Committee to incorporate new findings and experiences. This American standard represents the consensus of specialists in the physics of lightning, of manufacturers of lightning protection equipment and of lightning protection installers.

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