# LIGHTNING PROTECTION AT PETROCHEMICAL FACILITIES – PART 1 HISTORY AND BACKGROUND SCIENCE


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***Abstract*** – Development of lightning protection standards for petrochemical processing and storage facilities has progressed significantly over the past 20 years. Standard requirements have become more stringent and prescriptive. Understanding of development and propagation of lightning has grown with the advent of 3-D detection systems. This is Part 1 of a 3-part primer on lightning protection systems for petrochemical production, storage, and processing facilities. Part 1 covers the basic science behind lightning strikes, and the history of lightning research, protection systems, and models of attachment. The purpose of this paper, and the primer series, is to update the design and operating engineer's knowledge of lightning protection at petrochemical facilities, and to increase the safety of these facilities to workers and equipment.

*Index Terms* – Lightning Protection, Petroleum, Flammable, Hazardous, Tanks, Tank Battery, History,

## I. INTRODUCTION

Lightning: The word strikes a response in most everyone ranging from fear to awe and intrigue. To the uninitiated, lightning is an act of God, so nothing can be done about it. We will agree to the act of God, but like rain which we manage when we stay dry, lightning can be managed [1,2,3,4,5,6 ,7,8,9,10,11,12,13,14,15,16,17,18,19].

Fundamentally, lightning strikes higher points with a somewhat conductive path to ground. Those properties are extremely important to the petroleum handling industry since vessels tend to be higher than the surroundings, the structures are somewhat to very conductive, with the added risk of highly flammable products and vapors.

The basics of lightning control have been known since Dr. Benjamin Franklin and related work in the 1750's. Nevertheless, over the past 20 years, there have been significant advancements in the understanding of lightning development and the intricacies of control.

Most electrical engineers succumb to the myths and mysteries of lightning and protection. Our objective is to address the science of lightning through history up to the development of industry standards. Keep in mind that lightning is just another electrical circuit [12].

## II. BASIC CHARACTERISTICS OF LIGHTNING DEVELOPMENT AND ATTACHMENT

In order to understand the necessities and technology of lightning protection, a basic understanding of the physical properties of lightning is necessary. Inside a thundercloud physical processes, such as friction of rain droplets, cloud ice, riming graupel, and high velocity convection, separate the electrical charge inside the cloud by freeing electrons. In a "typical" lightning cloud, the top of the cloud has a positively charged layer at an elevation of around 10km. A negatively charged layer exists at around 6km. Field strength in the clouds are 100 - 200 kV/m, with the highest recorded field strength of 400 kV/m [20]. Whereas up to 90% cloud-ground lightning events involve negatively charged lower layers, this scenario will be adopted as typical.

At the same time that this negatively charged layer is formed, it is inducing positive charge on the ground beneath the cloud. An electric field at the ground level is developed and ranges from 5 – 20 kV/m in intensity. This field is intensified around sharp and exposed objects, which develop some localized breakdown of air (3,000 kV/m at sea level). Consequently, positive charges are "emitted" into the space above the corona. The space charge developed from this corona process limits the field to 5 – 20 kV/m, rather than the 100 kV/m that would generally be expected based on the cloud charge.

During the storm process, the electric field generated by the charged cloud layers intensifies. If this field strengthens to the point that there is a breakdown of the dielectric layer (wet air) between the upper and lower charged layers, then intra-cloud lightning occurs. The majority of lightning discharges are intra-cloud or cloud-cloud lightning.

Under some circumstances, however, a different mechanism occurs. For some yet unclear reason, a local breakdown of the electric field inside the negatively charged lower layer occurs. Rison et al define this phenomenon as fast positive breakdown events, which result purely from dielectric breakdown [20,21,22]. Competing theories, including relativistic electron runaway events unnecessarily complicate the phenomenon. Regardless of the theoretical explanation, these breakdowns are characterized by fast E-field changes inside the cloud, recognized by drastic changes in the μS timeframe. In short, lightning events are initiated by locally strong electric field regions [23].

The charge and discharge across the dielectric is exactly equivalent to the capacitive and resistive effects we have observed in partial discharge tests on high dielectric insulations such as magnesium oxide.

Regardless of the initiating event, a localized breakdown creates a mildly ionized pathway that transfers charge from the negatively charged layer to the tip of the pathway. The energy transfer process is known as a stepped leader and progresses in steps of approximately 50 m downward from the cloud bottom (for cloud – ground strokes). The speed of these downward leaders is in the range of 1.5 – 2 x $10^5$ m/s. Oftentimes more than one stepped leader develops from each pathway tip, resulting in the branching of lightning, which is commonly observed.

As these stepped leaders near the earth, the electric fields on the ground objects intensify to the point that positively charged pathways, called upward streamers, develop upward from the objects. Once the downward leader is within ~150 m of earth, the likelihood of the energy attaching to some point is near 100%.

When the downward stepped leader gets within ~100 m of the upward streamer, the leader diverts towards one or more of the upward streamers. As the downward leader and upward streamer meet, the path is complete, and charge flows along the ionized path.

In many instances, the initial stroke does not effectively equalize the charge between ground and cloud. In these cases, additional return strokes occur, typically in the same lightning channel. Rakov et al determined that around 80% of lightning events contain multiple strokes [20]. Of these, only 86% of the subsequent strokes travelled in the same channel. When multiple termination points were present, they were separated by an average of 1.7 km, much larger than the footprint of all but the largest structures [21]. In other words, multiple termination points are not associated with the same ground region.

Typical lightning events range in voltage from 300 kV to 1,000 kV. Average lightning current values are around 40 kA, with max values around 240 kA. Lightning frequencies are in the Megahertz range, with harmonic frequencies in the 100 MHz range [12].

## III. HISTORY OF LIGHTNING PROTECTION RESEARCH

### *A. Franklin and Dalibard – Original Research*

Modern scientific research into the characteristics of lightning began on May 10, 1752, in Marly-la-Ville, France. This experiment, conducted at the direction of Thomas-François Dalibard, was comprised of a 13-meter iron rod, insulated from ground with silk ropes and wine bottles. The structure, successfully drew sparks when a thunderstorm passed over the experimental site [1]. As shown in Fig. 1, Dalibard's experimental set up was specifically aligned with Franklin's proposal "to determine whether thunderclouds are electrified" [2]. Dalibard acknowledged that his team had followed the path that Franklin had traced for them. Franklin himself, just weeks after the Dalibard experiment and before the results were published, successfully drew sparks from a key attached to the conductive string of his "electrical kite", which itself was insulated from earth by a silk ribbon. Dalibard's observations were important in that they validated Franklin's hypothesis that tall, grounding "lightning rods" could serve as "preservatives", protecting structures from lightning damage.

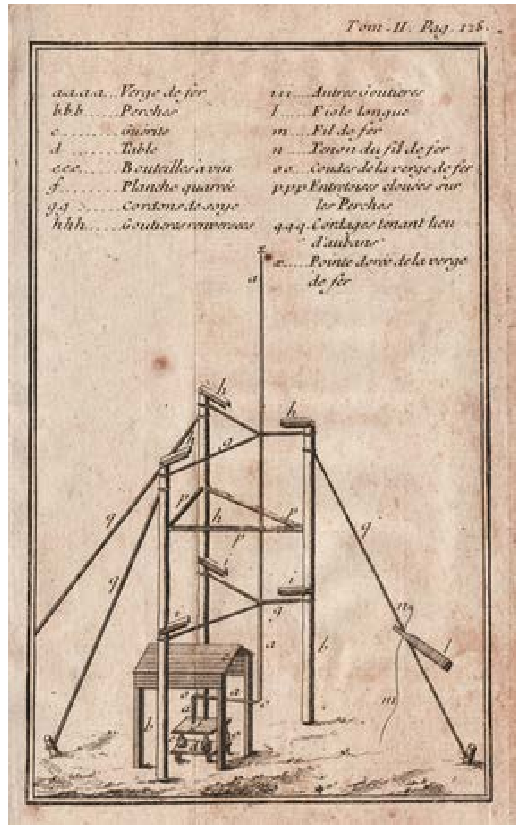


Fig. 1 - Franklin's "Sentry Box" Experiment [2]

Franklin further developed his lightning research by installing, in his house, an iron rod connected to earth only through an air gap between two hemispheres. Using this apparatus, Franklin would measure the polarity and characteristics of electricity from the thunderstorm, comparing them to static electricity generated by rubbing a glass sphere with wool or silk. Based on these experiments, Franklin stated "that the Clouds in a ThunderGust are most commonly in a negative State of Electricity, but sometimes in a positive state". This led Franklin to conclude "that for the most part in Thunder Strokes, 'tis the Earth that strikes into the Clouds, and not the Clouds that strike into the Earth" [2] .

Based on this research, Franklin proposed and supervised installation of lightning protection systems at the Academy of Philadelphia and the Pennsylvania State House later that same year (1752). These systems, further improved over the next 10 years, were composed of four components, each common in lightning protection systems (LPS) today [1]:

1. Large, steel air terminals 5-6 feet (2m) long, tapered to a sharp point;
2. Any building greater that about 100 feet (30 m) should have a rod on each end connected with a ½" (1.3 cm) conductor between them;
3. Vertical down conductors, routed outside the building of at least ½" (1.3 cm) connected to a grounding conductor;

4. Grounding conductor comprised of an iron bar driven 10-12 feet (3-4m) into the earth, and at least 10 ft (3m) away from the foundation.

250 years of empirical data, scientific studies, experimental results, computer modeling and advancement in the understanding of lightning development and attachment have validated the basic principles of this design. As evidenced in his later correspondence, Franklin's design parameters and spacing of rods was based on an understanding that lightning rods protected structures at some distance from the rod based strictly on the height of the rod above the earth and the height of the structure. This method of protection became known as the "angle method" of protection. This method dominated the design of LP systems for the next 200 years.

*B. 1800s – French Studies and Electric Fields*

In 1823, The Report of the Commission of the French Academy of Sciences, authored by Gay-Lussac, proposed that the "radius of the protected circular area around the base of the rod is equal to twice its vertical height". By 1876, the distance protected, as delineated by the Parisian Committee on Construction of Lightning Conductors in the City of Paris, had been reduced to "1.45 times the height of the rod".

In 1880, William Preece published his analysis of the area protected by a lightning rod. Preece's analysis considered the area between the rod and the cloud as an electric field, based on the research of Faraday and Maxwell. Preece's base assumption was that a lightning stroke developed in a field equal to the breakdown strength of the air, which would cause the lightning stroke to follow the shortest possible line between the cloud and the object to which it attaches.

Preece concluded that the protected area was "a conic space whose height is the length of the rod, whose bases is a circle having its radius equal to the height of the rod, and whose side is the quadrant of a circle whose radius is equal to the height of the rod."[3] This is the first known reference to a curved protective area. Fig. 2 shows a comparison of the areas of protection proposed by Gay-Lussac and the much smaller volume proposed by Preece.

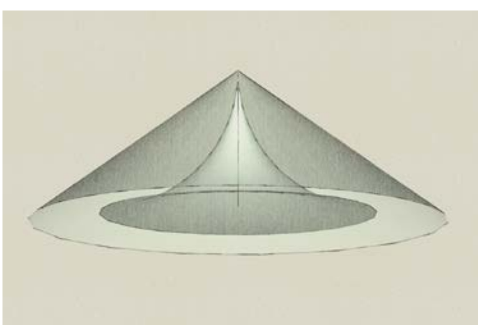

Fig. 2 - Comparison of Gay-Lussac and Preece Protected Regions

It is interesting to note that immediately after publication, Le Conte challenged Preece's conclusion as too conservative because it did not take into account the "neutralization due to the power of points, constituting the preventive action of lightning-conductors". LeConte further stated that "the whole subject of the 'power of points', although one of the best-established and most conspicuous phenomena in electricity, is sadly in need of experimental investigation. This class of electrical phenomena is pretty much in the same condition in which Franklin left it more than a century ago."[4] This is the same argument propounded by proponents of lightning array or charge transfer systems today. The weakness of these systems, and lack of scientific support for them, will be discussed in detail in a future work which will comprise Part III of this primer.

*C. Early 1900s – Theoretical and Experimental Development*

Some 30 years after Preece published his hypothesis of lightning protection, the father-son team of Sir J.L. Larmor and J.S.B Larmor published a study of lightning development and protection in the Proceedings of the Royal Society. This work was the first that identified breakdown of the "electric weakness of a rarified gas" (dielectric strength) at a "point of most intense force" (electric field intensity) as the initiator of a lightning discharge. This discharge is further propagated by "the electric rupture of the gaseous medium" (ionization). [5] This is the first known work proposing gas ionization as a method of lightning propagation.

Further Larmor & Larmor applied Maxwell's Equations on electrical and magnetic fields into the zone of protection of an air terminal. As a result, they identified the curved zone of protection, based on field theory and gas ionization, used in the Electro-Geometric Model (EGM) today.

Experimental examination of high-voltage dielectric breakdown continued through the 1920s at GE Labs. Peek, in his 1929 book "Dielectric Phenomena in High-Voltage Engineering" examined the effect of electric fields on lightning attachment, along with other high-voltage phenomena such as corona. [24] This work provided experimental support for the hypotheses proposed by Preece and Larmor & Larmor, that protection from lightning follows a curved pattern controlled by the electric field.

Due to the complexity of calculating a curved angle of protection, Peek recommended conical protection angles of 64-76º, or a protective ratio (width to height) of 2:4. This is similar, to the Gay-Lussac cone shown in Fig. 2.

In 1941, Wagner et al published the results of both theoretical and experimental work at Westinghouse Laboratories regarding failures of transmission line shield wires to protect transmission lines [25]. Wagner recognized that low-current lightning strokes bypassed conventional shield wires and could result in back-flashovers of the tower to the phase conductors. Wagner examined, but discarded, previous works showing a curved zone of protection. When discussing the work of Peek and others Wagner stated, "No data of any consequence such as tests on models of different scales have been presented in an attempt to show that model work is applicable to actual size systems…".

As a result, Wagner proposed that a 30º angle of protection (2:1 ratio) from overhead shielding provides adequate protection from lightning damage. This served as the basis for protection of transmission lines, and other structures in the ensuing years, and was codified in the Lightning Code as discussed below. The problems with Wagner's method became clear as failures of transmission lines protected by this method, especially 230kV and 345kV, lines continued. Nowhere was this more obvious than facilities used for the production, storage or processing of flammable vapors such as tank batteries, where facilities "protected" by this 2:1 method continued to be damaged by lightning.

### *D. The Electrogeometrical Model*

By 1945, R.H. Golde, working under the auspices of the British Electrical and Allied Industries Research Association formulated the first reference to the electrogeometrical model (EGM) of lightning protection. Golde stated that a lightning stroke develops in a field much smaller than those assumed by Peek. As a result, the protected volume is smaller than Peek proposed [26].

Golde based his work on a breakdown of 300 kV/m, 10% of the dielectric strength of dry air, and a 2-dimensional model of the line (structure) to be protected. Based on historical data and theoretical calculations, Golde proposed Equation (1) which recognized that the protected distance varies with the current of the lightning discharge [25,26].

$$r_s = A * I^b \qquad (1)$$

where

| | | |
|---|---|---|
| $r_s$ | Distance Protected | meters |
| I | Lightning Current | kA |
| A | constant | |
| b | constant | |

From Equation (1) Golde demonstrated that the smaller the "angle" of protection that is assumed, then the design is inherently more robust, and more lightning flashes are intercepted. Golde then expanded the formulae to relate the area protected to the height of a tower to be protected and the height of the shield wire above it.

Many researchers through the 1960s and 1970s worked to validate and further define the constants "A and b". With the result being that, by the 1970s, A = 10 and b = 0.65 were generally accepted as reasonably representing real-world conditions.

In the 1960s, the Edison Electric Institute launched RP-50 "Mechanism of Lightning Flashover" chaired by E.R. Whitehead of the Illinois Institute of Technology [27]. This study was a compilation of shield failures resulting in flashovers on transmission lines throughout the country. Based on 4600 locations, a statistical analysis of the effectiveness of protective systems on lines was conducted.

Based on this analysis, Whitehead et al determined that the effectiveness of a protection system could only be analyzed using a three-dimensional solution. He also confirmed that the effectiveness was not only based on the geometric configuration of the structure and the protective system (shield wire) but also on the amplitude of the lightning current. Whitehead determined that a circular arc of a radius defined as the "striking distance" adequately described the boundary of the protected zone. Essentially, the striking distance is defined as a set of points equidistant from the tip of the lightning channel, inside which lightning can attach. The striking distance is smaller for lower amplitude strokes, and larger for higher amplitude strokes. The result of the study was a series of "protection angles" based on the relative heights of the protective device and the structure to be protected.

### *E. Rolling Sphere Method*

In 1978, Ralph Lee published his seminal work "Protection Zone for Buildings against Lightning Strokes using Transmission Line Protection Practice."[7] Lee consolidated that data from RP-50 with theoretical data from Golde and others. Lee characterized the lightning event as follows:

- Stepped leaders propagate from the cloud downward in steps of 10-80 m, with the predominant length of 50 m
- When the leader tip comes within ~100 m of an object of opposite polarity, the steps propagate in a direction toward that oppositely charged object.
- At about 100 m, an upward streamer is developed from a grounded object, which then connects to the downward leader, completing the circuit and causing a return lightning "stroke".
- The average value of the stepped leader current is around 100 A, while the average value of the return strike is 20,000 A.

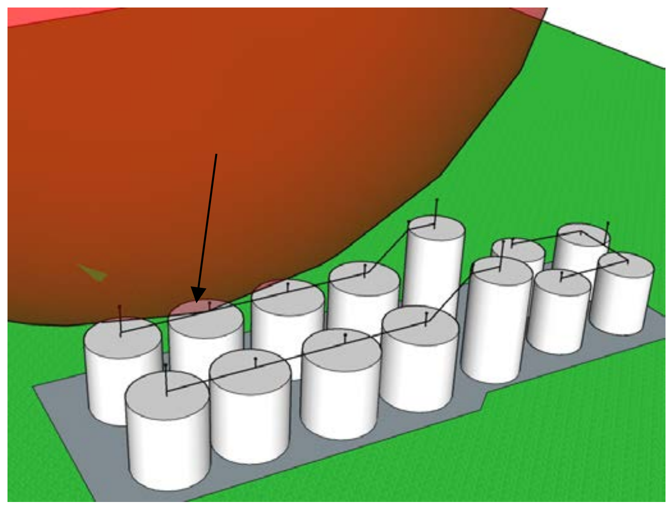

Fig. 3 - Rolling Sphere Method

Lee identified a characteristic of the RP-50 data that corresponded to the theoretical description of the stepped leader: that is, the protected distance from an air terminal can be reasonably defined as an arc with a radius of 150 ft (~50m). Lee further proposed: in order to take into account the 3-dimensional nature of the lightning event, that a "rolling sphere" of 150 ft should be used as an analytical tool. The rolling sphere is tangent to the earth, and to the properly grounded protective device. The volume "under" the sphere (between the sphere and earth) is protected, while any volume inside the sphere is unprotected. This method is demonstrated in Fig. 3. The sphere is Lee's rolling sphere. The arrow points to portions of the tank which are unprotected from the air terminal located in the center of the tank.

Lee also proposed that the same method be used to describe the protected area from two or more air terminals, by resting the sphere on both terminals. The unprotected area then "sags" below the height of the terminals, based on the 150 ft radius.

As Lee concluded "The hypothesis of W. H. Preece of 1881, shows that he was 100 years ahead of his time in concept.

Recognition of his work would have been highly advantageous to the utility industry. Since these utilities have now proven this approach to be the correct one for their use, there is little reason to delay its adoption for other structures."[7] Lee's recommendation was subsequently adopted into the 1980 edition of NFPA 78, the *Lightning Protection Code* for taller structures (over 50 ft). The applicability of the Lee's method has subsequently been expanded to essentially all structures.

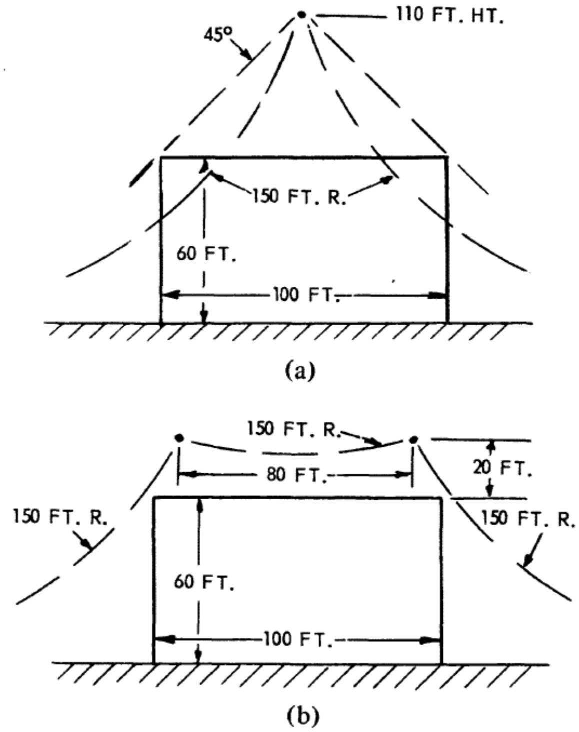


Fig. 4 - Example of Protected vs. Non Protected Areas from Lee [7]

Lee furthered his analysis of the RP-50 data and expanded the reach of his rolling sphere method. Lee recommended that the appropriate striking distance for calculating a protected area is related to the sensitivity of the object protected. Lee recommended that for hazardous locations, such as oil and gas tank batteries, a striking distance of 100 ft be employed. For personnel protection, a striking distance of 50 ft be employed, if and only if personnel could not be moved indoors. The recommendation for hazardous locations has subsequently been adopted into NFPA 780. His decreasing zone of protection in essence increased the probability an object in the zone would be protected.

### *F. Computer Modeling and Field Measurements*

Moore and Rison researched real-world results of lightning protection systems by collecting data from actual lightning events in the mountains outside Albuquerque, NM, USA. Based on this research, some important modifications to long-held assumptions were made. Since Franklin's original research, lightning rods with sharp points had been used, with the expectation that the sharper the point, the more likely corona will be developed, and the upward streamer initiated.

According to Rison and Moore's recent research, however, a moderately blunt-tipped rod is more effective at creating a mature, stable upward streamer than a sharp-tipped rod. In fact, over the 12 years of the field study, none of the sharp-tipped rods were struck by lightning, despite being exposed to the same ambient fields as the blunt-tipped rods. Corona current measurements indicate that, although the sharp-tipped rods initiate streamers earlier than the blunt-tipped rods, the space charge generated by the corona discharge tends to suppress these upward streamers if the E-field intensity is not very high.

In contrast, the blunt-tipped rods "save up" the charge, and emit it in a larger burst, in the presence of a stronger E-field. This allows the upward streamer to move past the space charge before it is fully developed. According to Rison, the ultimate rod is topped with a hemisphere of ~ 19 mm diameter for typical installations [9].

Rizk furthered the theoretical examination of Rison's field results, as well as some of Rakov's triggered lightning events. He determined that the ratio of rod radius to rod height is not a constant, but is a function of rod height, maximum ground-level E-field, and ambient relative air density. He also demonstrated the advantages of a lightning rod that is less prone to corona formation prior to descent of the downward leader [10].

Additional work continues under the direction of Rakov et al at the University of Florida, and in cooperation with the US National Air and Space Administration. Much of this research centers around charge transfer and wave shape during a rocket-triggered lightning event [20,28]. Rakov has also shown that, following a lightning stroke, the ionosphere is measurably affected, including the development of Sprites, Elves, Halos and a lowering of the ionosphere subsequent to first return strokes within a 100 - 330 kM radius. This lends credence to the hypothesis that the lightning path includes the ionosphere returning with 75 miles (120 km) postulated by Durham, Durham and others [12].

Work on the characteristics of lightning continues currently with the recent implementation of 3-dimensional lightning detection systems both fixed and portable. Fixed stations exist in at least six locations in the U.S: Oklahoma, North Texas, New Mexico, North Alabama, Washington DC and Kennedy Space Center, Florida. In addition, portable systems have been placed in various locations of high isokeraunic activity, including volcano initiated lightning events. Data from these systems continue to expand the knowledge base of where, how and when lightning forms inside Franklin's "ThunderGust" [21,22,28,29,30].

## IV. HISTORY OF GROUNDING RESEARCH

Dr. Franklin was aware of the three components of a lightning system: rod to attract, conductor to carry current, and a connection to ground. He even set up parlor games with a conductor into his house to show friends the intrigue of lightning.

Post Franklin, with the introduction of electrical lightning distribution systems, grounding invokes significant discussion.

Once the necessity of grounding was stabalized, the nuances of lightning protection grounding evolved.

Durham and Durham addressed the problem of distances to ground connections when they evaluated the high frequency reactance of the grounding conductors. The work was first observed at petroleum facilities in Gulf coastal Alabama. Because of the rate of rise of lightning transients, the effective length of a grounding conductor is in the order of 20 ft (7 m) [17,18,19].

The original concept of grounding was simplistic at best. Franklin's first design was simply an iron rod shoved into the earth. There was no concern (or knowledge) of factors such as inductance or impedance. There were no "wires", as there was simply a single rod.

Essentially, this concept of grounding survived the 1800s until the advent of distributed power distribution systems. With the advent of these networks, the necessity for "earthing" those systems became evident. These grounding systems were designed for the use in DC or Extremely Low Frequency (50-60 HZ) systems where impedance is dominated by the resistive components, and inductance plays little to no factor in efficacy.

These power grounding systems, however, were adopted and applied to lightning protection systems where the reactive components tend to dominate. Efforts to combat this led to many improvements, primarily in the lightning conductors. Beginning in the middle of the 20$^{th}$ Century, standards started requiring bends in downcomers to avoid sharp bends, in order to address the inductance of the path. Similarly, basket-weave conductors which are inherently lower inductance were developed [17].

Generally speaking, increasing the number of ground rods in the system reduces contact impedance with the earth and improves the effectiveness of the system. Beginning in the 1930s, Dwight recognized that capacitance effects of multiple ground rods decreased the effectiveness of the additional rods, if the rods were spaced too close together [32]. Dwight recommended spacing of the rods by at least 2.2 times the length of the rod (>22 feet separation for 10-foot rods).

Ufer recognized, beginning in the 1960s, that encasing grounding electrodes in concrete increased the effectiveness of the rod.[33] This was then adopted into lightning protection standards as a means to improve grounding in high-resistance, dry, rocky soils [30].

The 1990s brought enhancements to Dwight's calculations on ground resistance, including development for concepts and calculations for expected contact resistance based on the number of rods and spacing [18,19]. Further, Durham and Durham addressed the concept of a ground ring to enhance ground effectiveness of lightning protection systems [19]. Beginning in 2017, NFPA 780 requires ground rings (or ground loop conductor, which serves the same function) for LP systems at facilities containing storage and processing of flammable liquids or liquids containing flammable vapors [30].

Current research is primarily centered around mathematical Finite Element Analysis in evaluating grounding systems in solid with multiple layers. Additional work is being developed on modeling overloading of soils during lightning events.

## V. HISTORY OF STANDARDS

### *A. Lightning Rod Conference of 1882*

Standards for the design and installation of lightning protection systems could be said to have begun with Franklin's Poor Richard's Almanack of 1753, the technical aspects of which were discussed earlier. However, modern attempts and standardization, which have led directly to the standards in place today, began in 1882 [13]. In that year delegates from the following societies met to establish rules for the installation of LPS in Britain:

- Meteorological Society
- Royal Institute of British Architects
- Society of Telegraph Engineers and of Electricians
- Physical Society

From this Conference, a 3 ½ page, 1100 word "Code of Rules for the Erection of Lightning Conductors" was generated. The code did not establish a zone of protection other than "there is no recorded instance of building being struck by lightning within a conical space, the radius of whose base was equal to its height, and we think that the adoption of this rule may reasonably be expected to yield that security in the future, which as far as we know, it has done in the past."

Additional points of interest of the code include

- *downcomers* - "down the side of the building which is most exposed to rain";
- *curvature* - "The rod should not be bent abruptly to form sharp corners. In no case should the length of the rod between two points be more than half as long again as the straight line joining them";
- *bonding*;
- *earthing*;
- *protection* from theft and
- *inspection* "Before giving his final certificate, the architect should have the conductor satisfactorily examined and tested by a qualified person".

### *B. National Fire Protection Association*

After publication of the Report of the Lightning Rod Conference, the National Fire Protection Association (NFPA) developed a set of standards for use in the United States. The first version of NFPA 78 *Specifications for Protection of Buildings against Lightning* was published in 1904 under the direction of W.S. Lemmon, B.H. Loomis and R.P. Barbour [32] . At the same time, the Lightning Research Committee in Britain adopted a similar set of rules [35]. The entire set of rules is shown in Fig. 5.

Revised versions of the NFPA specifications were adopted in 1905, 1906, 1925, 1932 and 1937 [14]. The NFPA Technical Committee on Lightning and the American Standards Association Committee on Protection Against Lightning were merged in 1945 under the joint direction of NFPA, the National Bureau of Standards and the AIEE (Predecessor of the IEEE).

In 1946, the NFPA issued NFPA 78 *Lightning Protection Code* including text from previous versions, as well as ASA and AIEE input. Further revisions of the standard took place yearly until 1952, then approximately every three years until 1992, when the numerical designation was changed to NFPA 780.

In 1995, the name of the document was changed to *Standard for the Installation of Lightning Protection Systems*. At this point, clarification was added to the scope of the Standard to clarify that non-conventional systems, such as Early Streamer Emissions (ESE) and Charge Transfer Systems (CTS or DAS) were not included.

Additional Revisions were made in 1997 and 2000. After issuance of the 2000 edition of NFPA 780, the NFPA sought input on the scientific validity of the requirements of NFPA 780, pending removal of the standard and disbandment of the

Technical Committee. As a result of this request, substantial documentation was received from the American Geophysical Union and the Federal Interagency Lightning Protection User Group, among others, supporting the requirements of NFPA 780 [15,16]. This resulted in NFPA reversing its decision and continuing issuance of the standard in 2004, 2008, 2011, 2014 and 2017.

CHAPTER III.

THE LIGHTNING RESEARCH COMMITTEE'S SUGGESTIONS AND RULES, 1905.

**THE Lightning Research Committee in their report put forward the following suggestions for practice, which are the result of their investigations:—**

1. Two main lightning rods, one on each side, should be provided, extending from the top of each tower, spire, or high chimney stack by the most direct course to earth.
2. Horizontal conductors should connect all the vertical rods (*a*) along the ridge, or any other suitable position on the roof; (*b*) at or near the ground line.
3. The upper horizontal conductor should be fitted with aigrettes or points at intervals of 20 or 30 feet.
4. Short vertical rods should be erected along minor pinnacles and connected with the upper horizontal conductor.
5. All roof metals, such as finials, ridging, rain-water, and ventilating pipes, metal cowls, lead flashing, gutters, &c., should be connected to the horizontal conductors.
6. All large masses of metal in the building should be connected to earth, either directly or by means of the lower horizontal conductor.
7. Where roofs are partially or wholly metal-lined they should be connected to earth by means of vertical rods at several points.
8. Gas pipes should be kept as far away as possible from the positions occupied by lightning conductors, and as an additional protection the service mains to the gas-meter should be metallically connected with house services leading from the meter.

Fig. 5 - 1905 Lightning Protection Rules

The 2017 version contained a complete rewrite of Chapter 7, *Protection for Structures containing Flammable Vapors, Flammable Gasses, or liquids that Can Give Off Flammable Vapors.* Key changes include the requirement for a ground ring encircling these facilities, clarification on which tanks are self-protected, clarification on applicability of the standard to Operating Facilities, and adoption of IEC62305-2 risk assessment for these facilities. Part II of this primer series will deal in depth with the updated requirements for hazardous locations, including risk assessment and proper grounding (earthing).

*C. Underwriter's Laboratories (UL)*

UL maintains two standards applicable to lightning protection. UL 96 is the *Standard for Lightning Protection Components* and covers the configuration and testing requirements for physical products, such as air terminals, lightning conductors, and bonding clamps. UL 96A is the *Standard for Installation Requirements for Lightning Protection Systems*, and covers practices and procedure for installation requirements, and largely tracks NFPA 780. One key difference is that UL 96A specifically excludes structures used for the handling or storage of flammable liquids or gasses, and as such has limited import to this discussion and will be addressed only briefly.

UL began issuing requirements for installation of lightning protection systems in 1916. Between 1916 and 1958, at least five numbered, and multiple unnumbered editions of the requirements were issued. Beginning in 1958, UL instituted Master Labeled Lightning Protection System certification with the sixth edition of the Standard. The current version of UL 96A is the thirteenth edition, dated March 2016.

UL 96 covers specific requirements for the construction, testing and verification of individual lightning components. UL 96 requirements were first listed in 1977 and has undergone 5 revisions in the subsequent years. Current requirements are included for air terminals, supports, conductors, fittings, clamps, bonding plates and ground electrodes. One key component is that stainless steel air terminals or conductors are not allowed for Class I and Class II equipment, which is equipment used in protection of petrochemical operation and storage facilities.

*D. American Petroleum Institute (API)*

The API has promulgated two standards that, to some degree or another, deal with lightning protection of flammable vapor/liquid storage tanks. API RP-2003 is *Protection Against Ignitions Arising out of Static, Lightning and Stray Currents.* It was first promulgated in 1956 and contains provisions mainly towards static and stray currents. Sections that address lightning are directly referenced back to NFPA 780 for specific requirements.

API 545 *Recommended Practice for Lightning Protection of Aboveground Storage Tanks for Flammable or Combustible Liquids* was issued a single time in 2009. It contains provisions specifically for welded, steel tanks. The provisions contained in this RP are de-minimus and are covered by the provisions contained in NFPA 780. It is unclear whether API 545 is an active standard at this time, or has been inactivated, as it overlaps API 2003.

*E. International Electrotechnical Commission (IEC)*

IEC lightning standards include a family of four standards under the number IEC62305. These standards were first promulgated in 2006 and updated in 2010. The IEC standards are grouped as follows:

Part 1 – General Principles
Part 2 – Risk Management
Part 3 – Physical damage to structures and life hazard
Part 4 – Electrical and electronic systems within structures

Specific requirements and provisions of this standard family will be addressed in Part II.

## VI. FUTURE WORK – OTHER PARTS OF PRIMER

To fully understand and describe lightning protection systems for petrochemical production, storage, and processing facilities, two more Parts of this primer are needed. In Part II, we will explore the current standard requirements for lightning protection at petrochemical facilities. Part III will address non-conventional lightning protection systems claims, science and challenges.

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## VIII. VITAE

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The decades of honed skills are now brought to bear on behalf of the numerous subrogation claims handled by Donato Minx Brown Pool, P.C. A skilled litigator, Tommy heads up trial teams bringing cases in New Mexico, Colorado and across Texas involving all matter of complex technical litigation. Over the past several years, Tommy has worked on numerous lightning protection cases across the nation, developing a first-hand knowledge of the interplay between science, law, and the ever-evolving standards that rule the world of lightning protection systems.

## APPENDIX A

## ADDITIONAL READING


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