Lightning Protection For Gas and LNG Facilities

By
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Natural Gas and Liquid Natural Gas Risk Factor to Lightning

Natural Gas and the Liquid Natural Gas version are highly volatile flammables. In terms of a fire hazard, they are an easily ignitable light hydrocarbon. The storage and process areas should be considered a “Class One” environment were the chance of fire or explosion resulting from a spark therein is very high. Therefore, it is obvious that any source of ignition should be eliminated from those areas.

Lightning activity in the Turkish area around Botas could produce up to 12 direct strikes to each square kilometer during an average year. This level of risk mandates a lightning protection system that prevents direct strikes and eliminates any secondary effects which can produce an arc. According to the latest version of the API Recommended Practices RP2003, there is only one protection system that offers both functions, the Charge Transfer System (CTS). However, the trademarked name is known as the LEC Dissipation Array® System.

Gas Plants and Liquid Natural Gas Plants perform any one of the following functions:

1. Pipeline Compressor Stations
2. Storage and Transfer Systems
3. Gas Processing, usually removes contaminants.
4. Dispensing Facilities
5. Gas Liquefaction Plants

All of these facilities can develop leaks and/or have some flammable vapors present which lightning can initiate ignition.

Lightning Eliminators & Consultants Inc. - The Company

Introduction

Over the past one hundred or more years there has been a great deal of misrepresentation associated with the performance of lightning protection devices. Most of the problems were the result of poor data, inaccurate assumptions or other less honorable motives.

LEC was formed to bring scientific rigor into the field of lightning protection and help clean up both the ethics and the data base. The past 25 years of successful lightning prevention systems prove that lightning protection, and strike prevention can be accomplished with predictable results. Recent developments in the Dissipation Array® System (DAS)® and other advanced protection technologies have made is possible to totally isolate facilities from any form of lightning or transient phenomenon.

Background

The founder, Roy Carpenter, Jr., formerly a senior engineer with the USAF in Massachusetts, moved to Downey, California with the manned space program. It was during his nearly 10-year tenure with the then North American Aviation, Space Division that he was introduced to the problems created by lightning activity. As Chief of the Apollo Reliability and Qualification Test Program, he began to realize that lightning technology was still in the “dark ages”.

That is, it lacked the engineering rigor related to all other engineering disciplines. The “standards” in vogue defined what to do, but not why; how to install, but not how to determine the adequacy of the installation. Further, these standards were known to be inadequate and often increases risk.

During the space program, Mr. Carpenter investigated the protection options and found that any council was always limited to: “Well you can try---”. No positive, assessable techniques were offered. At that time, the only counselors were Atmospheric Physicists (who defined the problem) or manufacturers (who sold a specific product for one special function).

After 25 years of various responsibilities in several military and space engineering fields, and after completion of the Space Shuttle Preliminary Design as Project Engineer, Mr. Carpenter left the space program in order to provide the country with the first and only engineering firm to offer a complete systems-engineered approach to lightning protection. By that time, he had collected a significant compendium of data on lightning, lightning related problems, the protection products available and the potential market.

The Beginning: Lightning Elimination Associates

In late 1971, Mr. Carpenter formed the company then known as Lightning Elimination Associates (LEA); now LEA Dynatech of Tampa, FL. LEA was formed in California as a Limited Partnership and in 1978, converted to a corporation. In 1982, it was sold to the Dynatech Corporation of Massachusetts.

The company started in business offering Consulting Services and a strike prevention system known as the Dissipation Array® System (DAS®). From the second year of business to the present, the company has produced a profit and grown at a comfortable rate. Since inception, the company has introduced a continuous stream of products that are designed to fill needs not addressed by existing suppliers. In addition to the DAS®, these products include the Series Hybrid Surge Eliminator, the Kleanline family of power conditioners, the Transient Eliminator family of Data Line Protectors, the electrostatic field sensing Lightning Warning System, the Spline Ball Ionizer, the Spline Ball Terminal and the Chem-Rod, a chemically activated grounding electrode, along with a host of other specialized products.

In February 1984, Mr. Carpenter left LEA Dynatech to form a new company and meet a yet unfulfilled need.

The Present: Lightning Eliminators & Consultants (LEC)

LEC was also formed under the laws of the State of California. It was formed as a wholly owned Subchapter S Corporation. After LEC was formed, Mr. Carpenter repurchased the rights to the DAS and several other market products from LEA Dynatech. In the fall of 1988, the company and all key employees moved to Boulder, Colorado, where it remains today.

As a result of the Consulting Service, other products have been developed to meet the expanding market demand, sparking a fast growth rate for LEC. LEC now offers many specialized products. LEC has demonstrated that it can solve all lightning related problem with its line of products. The products have been guaranteed functionally for over 25 years.

The list of customers is extensive and involves at least 38 foreign countries. The firms include over hundreds of broadcasters, all of the military services, and many utilities. Some of LEC's customers include: Chevron, Mobil, Texaco, Elf Autochem, Conoco, PPG Industries, Pemex, Corpoven, Arab Petroleum Pipelines, and Exxon.

Credibility Considerations

Some of the products offered by LEC represent a significant departure from the conventional approach. This was necessary in order to solve problems that had not been previously resolved. The most prominent is the Dissipation Array® System (DAS®). It offers the capability of preventing direct strikes, independent of the facility size or height. As of this date, with over 25 years of history, the DAS has proven reliability in excess of 99.7%.

Some have challenged the validity of the statistics as proof of performance. However, such challenges are unfounded. The discipline of Reliability Engineering analysis is founded on the validity of statistical data, most of which must be collected from operation records. Individual data points may be of questionable accuracy, however, many data points collected by LEC to eliminate inaccuracies.

In summary, over 25 years in the field of lightning strike prevention and well over 2000 systems in service throughout the world in mostly high Isokeraunic areas, and providing over 15,000 systems years of history leave no reasonable doubt as to LEC's ability to eliminate any lightning related problem.

Key Personnel and Structure of LEC

Roy B. Carpenter is both Chief Executive Officer and Chief Consultant (where his 50 years of experience pays off). Most of his time is occupied in Research and Development activities with a significant amount of consultation in many parts of the world.

Mr. Miles Snyder is President and Chief Operating Officer. He is supported by a staff of six engineers using Computer-Aided Design (CAD) equipment, plus several engineering subcontractors. In addition, he is supported by a model shop, a production group, and many production subcontractors.

Dr. Mark Drabkin is LEC's Chief Scientist, responsible for the development of new products related to the LEC mission. Also, the improvement of performance of existing products. He is supported by two lab technicians. Future products include a Surge Impedance Grounding Tester for grounding systems and special products for specific applications.

Darwin Sletten functions as Chief Engineer and is responsible for the physical design of all LEC Systems.

Peter A. Carpenter is Executive Vice President and Special Consultant.

In summary, LEC has 34 personnel with 1/3 engineers, plus a large supporting group of subcontractors locally and in primary working areas inside and outside the USA.

Achievements in Lightning Prevention

The following is a partial listing of Relevant LEC protected facilities and projects:

1. Exxon Gas Processing Plant, Mobile Bay, Alabama

   Lightning Eliminators & Consultants Inc. was specified at the construction phase of the Exxon Gas Plant in Alabama to prevent direct strikes to the facility. Dissipation Arrays were installed to protect the vertical vessels, pipe racks, stacks, and major buildings. To this date, no direct strikes to the plant.

2. Texaco Canada, Edmonton/Calgary

   In 1975 LEC installed Hemisphere Arrays and Conic Arrays to protect an Oil storage site in Canada.

3. Six Gas Compressor / Metering Stations, Mexico

   Three Gas Compressing and three Metering Stations in Pemex suffered damaged from direct strikes terminating in the stations. LEC installed Dissipation Arrays® to protect the pipe racks, separators, compressor buildings, metering buildings, control room, substations, water towers, and light poles. To date, Pemex has experienced no problems due to lightning.

4. Three Gas Compressor Stations, USA

   LEC protected three Noram Gas Transmission sites in 1995. The protection system included Dissipation Arrays, Spline Ball Ionizers, and transient voltage surge suppressors.

5. Two Gas Distribution Stations, Petronas, Malaysia

   In 1992, LEC installed two Dissipation Array Systems for the Malaysian National Gas Metering and Regulating Stations.

6. Shell Forcados, Nigeria

In 1995, LEC was hired to provide a lightning prevention system for 14 tanks, power hose, power control building, main control building, and a high pressure gas vent. Currently, this project is active. Additionally, Lightning Eliminators and Consultants was specified as the sole supplier for a lightning prevention system for Shell Bonny LNG Terminal. This project is currently active.

The Lightning Problem

Lightning activity can create a number of problems for gas handling facilities and their related activities. These problems are associated with the direct strike and lightning's secondary effects. Most often these potential problems are ignored by the successful systems contractor in order to provide a competitive bid. As a result, the customer is the loser and suffers frequent lightning induced damage.

A Lightning Protection System must isolate the site from harmful direct strikes, and those secondary effects. The following describe the threat related to each of these phenomena.

Mechanics of the Strike

Thunderheads are electrically charged bodies suspended in an atmosphere that may be considered at best a poor conductor. During a storm, charge separation builds up within the cloud. The potential at the base of the cloud is generally assumed to be about one hundred million volts and the resulting electrostatic field about 10 Kv per meter of elevation above earth. The charging action (or charge separation) within the storm cell usually leaves the base of the cloud with a negative charge, but in a rare case the opposite seems true.

This resulting charge induces a similar charge of opposite polarity on the earth concentrated at its surface just under the cloud and of about the same size and shape as the cloud.

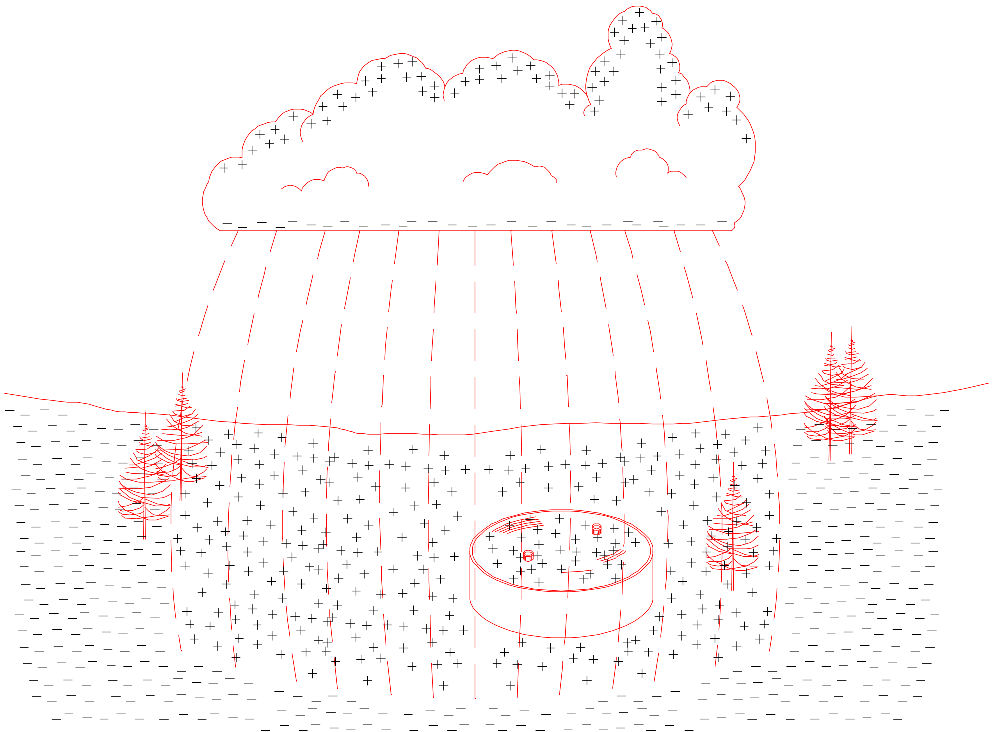

Figure 1: Charge Induction

As a storm builds in intensity, charge separation continues within the cloud until the air between the cloud and earth can no longer act as an insulator. The specific breakdown point varies with atmospheric conditions.

Low intensity sparks called “step leaders” form, moving from the base of the cloud toward earth. These steps are of about equal length, and that length is related to the charge in the cell and the peak current in the strike. These steps vary in length from about 10 meters to over 160 meters for a negative stroke. As the leaders approach earth, the electric field between them increases with each step. Finally, at about one step distance from earth (or an earth bound facility) a “Strike Zone” is established, as illustrated by Figure 2. That strike zone is approximately hemispherical in shape, with the radius equal to one step length. The electric field within that zone is so high that it creates upward moving streamers from earthbound objects. The first streamer that reaches the step leader closes the circuit and starts the charge neutralization process.

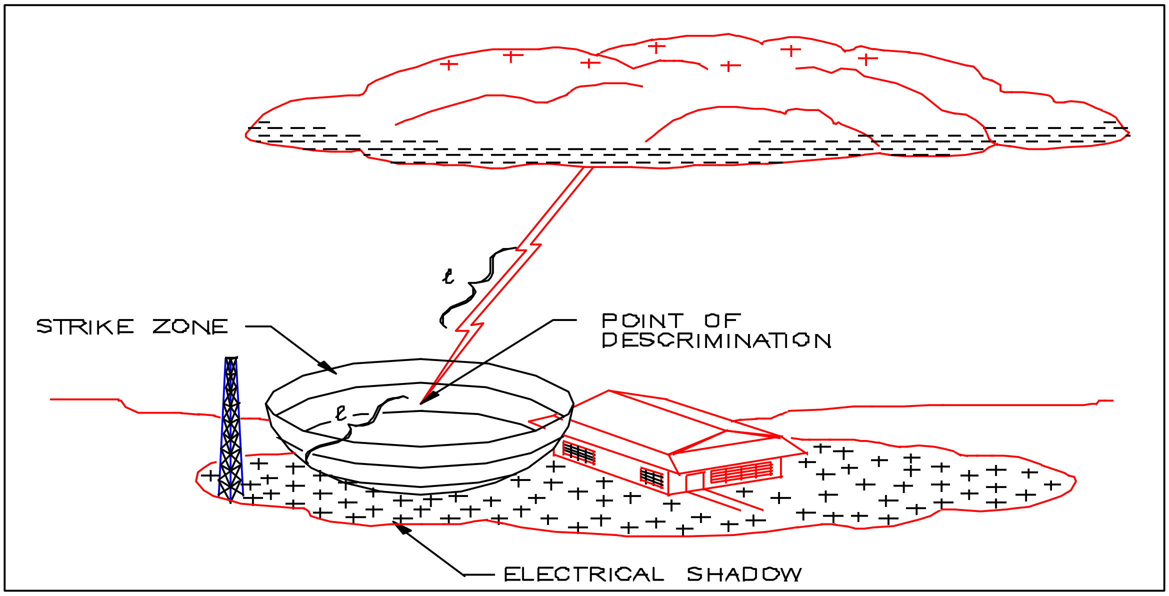

Figure 2: The Strike Zone

When structures intervene between the earth and the cells, they are likewise charged. Since they short out a portion of the separating air space, they can trigger a strike because the structure reduces a significant portion of the intervening air space.

Charge neutralization (the “strike”) is caused by the flow of electrons from one body to the other such that there is no resulting difference of potential between the two bodies (see Figure 3). The process creates the same result as shorting out the terminals of a battery.

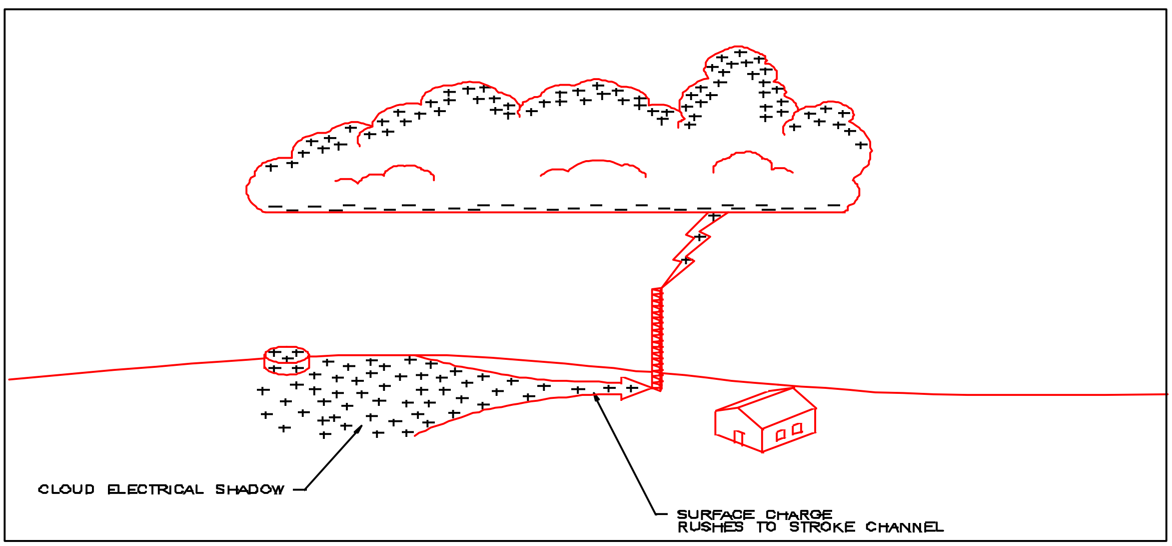

Figure 3: Charge Neutralization (Strike)

Direct Strike Effects

Once the stroke terminates, a series of events, called "secondary effects" takes place. The character of the stroke itself can vary in a number of parameters over several orders of magnitude as listed in Table 1. The data for that table was taken from Dr. Martin Uman's book, "The Lightning Discharge", published by Academic Press.

Storm Cell Charge	40 Amp-Sec
Peak Current	2 kA to 500 kA
Time to Peak Current	50 Nanoseconds - 10 microseconds
Peak Energy	Up to 10^{10} Joules
Stroke Duration	10 to 1000 microseconds
Propagation Speed	2 to 25 x 10^{7} m/s
Number of Current Surges per Lightning Flash	1 to 26

Table 1, Typical Lightning Discharge Parameters

Secondary Effects

There are at least five secondary effects that result from lightning terminating on some earthbound system. Any or all of these have caused damage to gas and LNG facilities. These effects may be categorized as:

1. Those that cause fires and explosions
2. Those that cause loss of instrumentation and control.

Some can cause both. These secondary effects are as follows:

- Electromagnetic Pulse (EMP)
- Electrostatic Pulse
- Earth Current Transients
- Bound Charge

Electromagnetic Pulse

The Electromagnetic Pulse is the result of the transient magnetic field that forms from the flow of current through the lightning stroke channel. After the lightning stroke channel is established between the cloud and earth, it then becomes a conductive path like a wire. The neutralization current commences to flow very rapidly, with the rate dependent on the channel path impedance and the charge within the cloud. The rate of rise of these current pulses varies by orders of magnitude. They have been measured at levels of up to 510 Ka per microsecond. A practical average would be 100 Ka per microsecond.

That transient currents flowing through a conductor produce a related magnetic field. Since these discharge currents rise at such a rapid rate, and achieve peak currents in the hundreds of thousands of amperes, the related magnetic pulse they create can be quite significant. The resulting induced voltage (EMP) within any mutually coupled wiring can also be significant.

As the charges build up in the clouds, a downward step leader is initiated at the bottom of the thunderclouds. As the downward step leader approaches the ground, an upward step leader meets it, and the return stroke happens. A huge amount of charge accompanies this return stroke, which could be transferred to the clouds. A return stroke acts like a giant traveling wave antenna generating strong electromagnetic pulse waves. Therefore, lightning EMP can propagate a long distance and affect large areas.

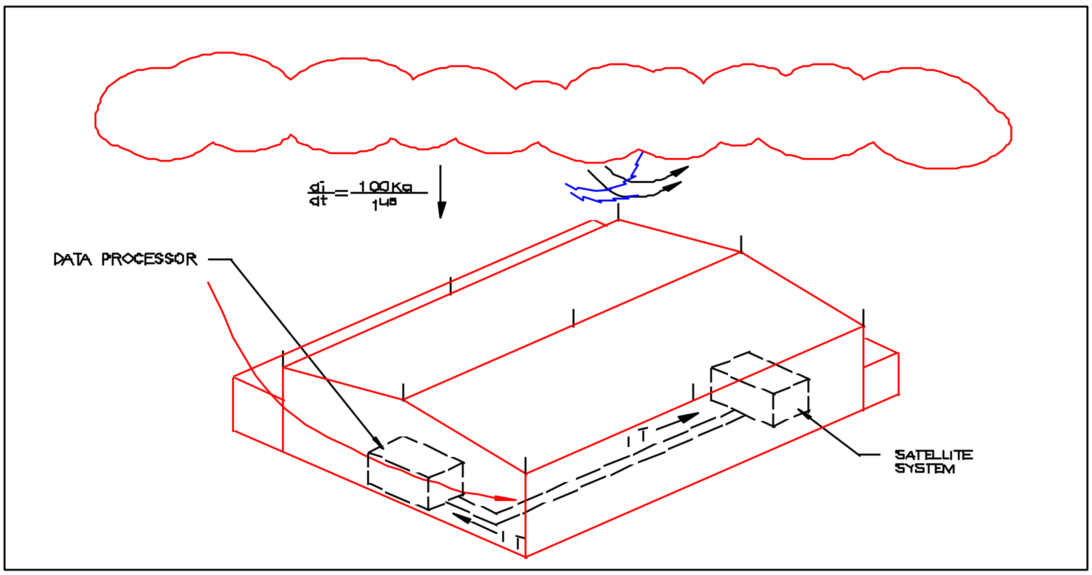

Figure 4: Stroke Channel EMP

Return Current I	5 kA - 200 kA
dI/dt	7.5 kA/µs to 500 kA/µs
Velocity	1/3 Speed of Light
Length (height of thunderclouds)	3-5 km above grade

Table 2, Lightning Return Stroke Data

Any elevated transmission/data line will also suffer from lightning EMP interference, regardless of usual shielding. The lightning EMP has a very wide spectrum and most of its energy is in the low frequency portion. Therefore, lightning EMP could penetrate the shielding and interfere with the system.

The EMP also has a related secondary effect, and as a result of the current flowing into the grounding system. In this situation, the fast changing current with time (di/dt) creates the magnetic field which now is mutually coupled to any underground (within ground) wiring that passes nearby, over or parallel to any part of that grounding system. Again, the mutual coupling results in the transfer of energy (EMP) into the underground wiring. That energy may not always be harmful to the entering electrical service. However, it will most likely be high enough to damage data circuits.

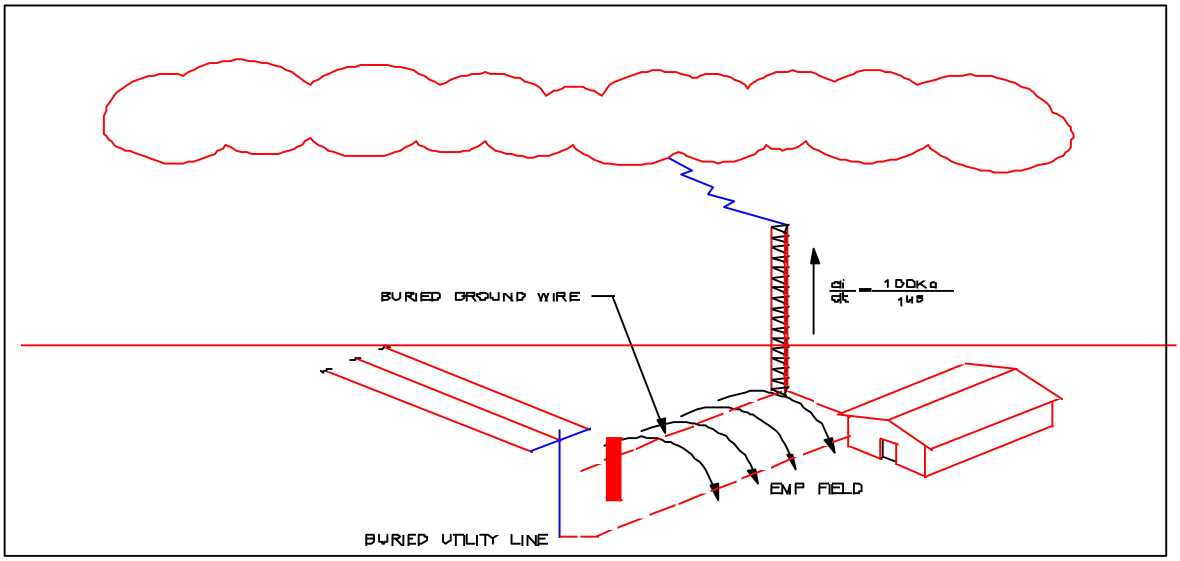

Figure 5: Grounding Current EMP

Electrostatic Pulse

Atmospheric transients or electrostatic pulses are the direct result of the varying electrostatic field that accompanies an electrical storm. Any wire suspended above the earth is immersed within an electrostatic field and will be charged to that potential related to its height (i.e. height times the field strength) above local grade. For example, a distribution or telephone line suspended at an average of 10 meters above earth in an average electrostatic field during a storm will take on a potential of between 100 Kv and 300 Kv with respect to earth. When the discharge (stroke) occurs, that charge must move down the line searching for a path to earth. Any equipment connected to that line will provide the required path to earth. Unless that path is properly protected, it will be destroyed in the process of providing the neutralization path. This phenomenon is known as the Atmospherically Induced Transient. The rising and falling electrostatic voltage is also referred to as the Electrostatic Pulse (ESP).

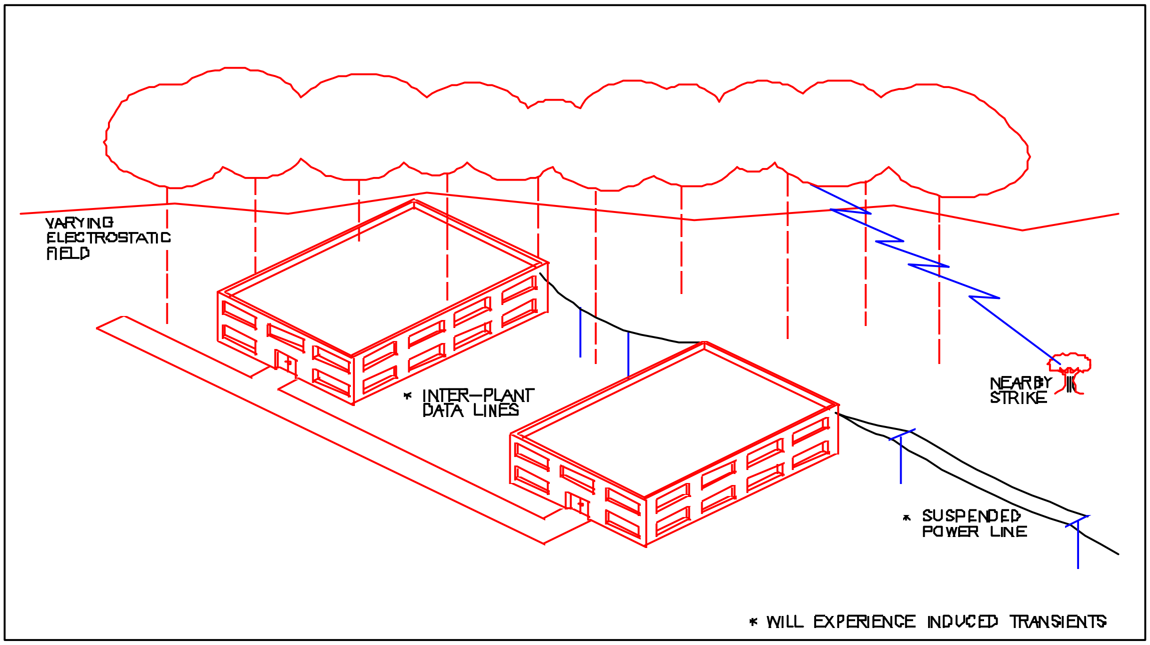

Figure 6: Electrostatic Pulses

According to electromagnetic theory, static charges will build up on the surface of any objects on the ground and the charge density is proportional to the magnitude of these static electrical fields. The higher the charge density, the higher the risk of a termination of the downward step leader.

A vertically erected metallic object, especially those having a sharp point, immersed in these fields have a considerable potential difference with respect to ground. If the object is not grounded, it can cause sparks. In some hazardous locations, it can ignite fire or upset sensitive electronic equipment.

Earth Currents

The earth current transient is the direct result of the neutralization process that follows stroke termination. The process of neutralization is accomplished by the movement of the charge along or near the earth's surface from the location where the charge was induced to the point where the stroke terminated. Any conductors buried in the earth within or near the charge will provide a more conductive path from where it was induced to the point nearest the stroke terminus. This induces a voltage on those conductors that is related to the charge, which is in turn related to the proximity of the stroke terminus.

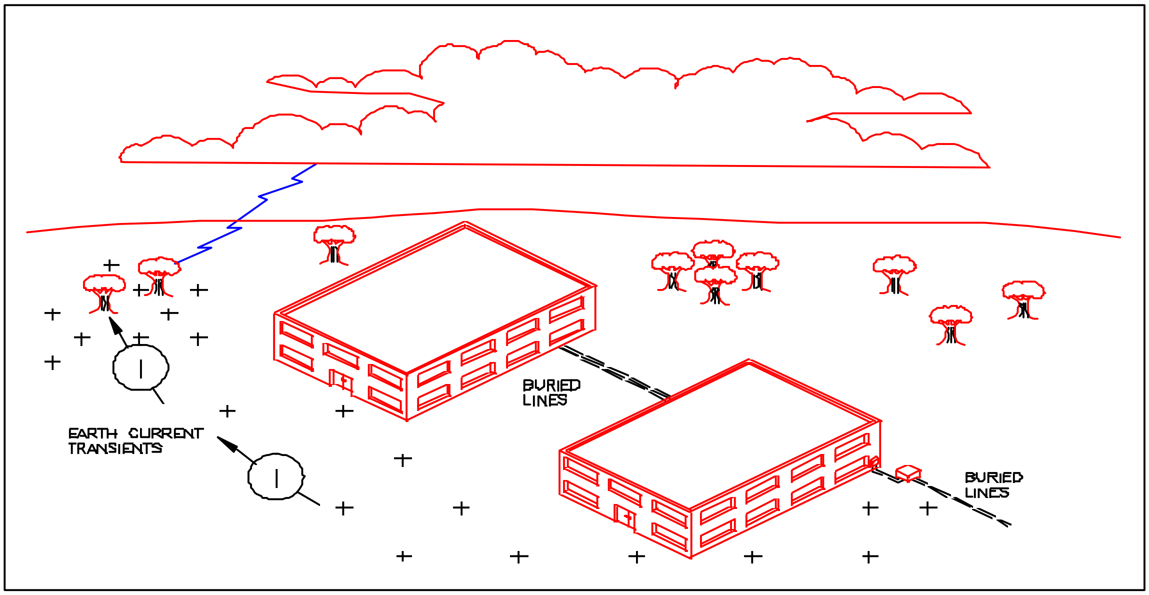

Figure 7: Earth Current Transients

This induced voltage is called an "earth current transient". It will be found on wires, pipes or other forms of conducts. If the wires are shielded, the internal wires will experience the first derivative of the shield current flow. Since the discharge process is fast (20 microseconds) and the rate of rise to peak is as little as 50 nanoseconds, the induced voltage will be very high.

The termination of a return stroke on ground may cause the following effects:

1. It may cause arcing through the soil to an adjacent gas pipeline cable and grounding system. A 50 kv/m breakdown gradient is usually assumed. For example, the foot resistance of a power tower is 10 ohms, return stroke current is 200 kA, and the minimum separation distance is 40 meters.
2. Surge current may be coupled by soil to the existing grounding system for the electronic equipment which causes a non-uniform GPR distribution in the ground system. For example, two buried 10 meter ground wires with a grounding resistance of 31.8 ohms are separated by 5 meters. As a 75 Ampere current is injected into one of the rods, the other will have a voltage rise of approximately 188 volts.

Bound Charge

The most common cause of lightning related petroleum product fires is the phenomena known as the “Bound Charge and resulting Secondary Arc” (BC/SA).

To understand the risk of the BC/SA, it is necessary to understand how the Bound Charge is formed and how the Secondary Arc results in a fire. The storm cell induces the charge on *everything* under it. That charge (ampere-seconds) is related to the charge in the storm cell. Since petroleum products are usually in a conducting metallic container, that container and everything in it takes on the charge and related potential of the local earth. Since the charging rate is slow, the product will take on the charge as well as the tank.

The earth is normally negative with respect to the ionosphere. When a storm cell intervenes between it and earth, the induced positive charge replaces that normally negative charge with a much higher positive charge. The container (tank) is at earth potential, which is the same as the surroundings, positive before the strike, but instantly negative after the strike.

The Secondary Arc results from the sudden change in charge (20 microseconds) of the tank wall and the unchanged state of the contained product’s charge.

Any form of grounding can exert no significant influence on the potential Bound Charge/Secondary Arc phenomena and any form of conventional protection cannot prevent that phenomena because there is no discharge path available. The tank and local earth are at the same potential, *before* the strike.

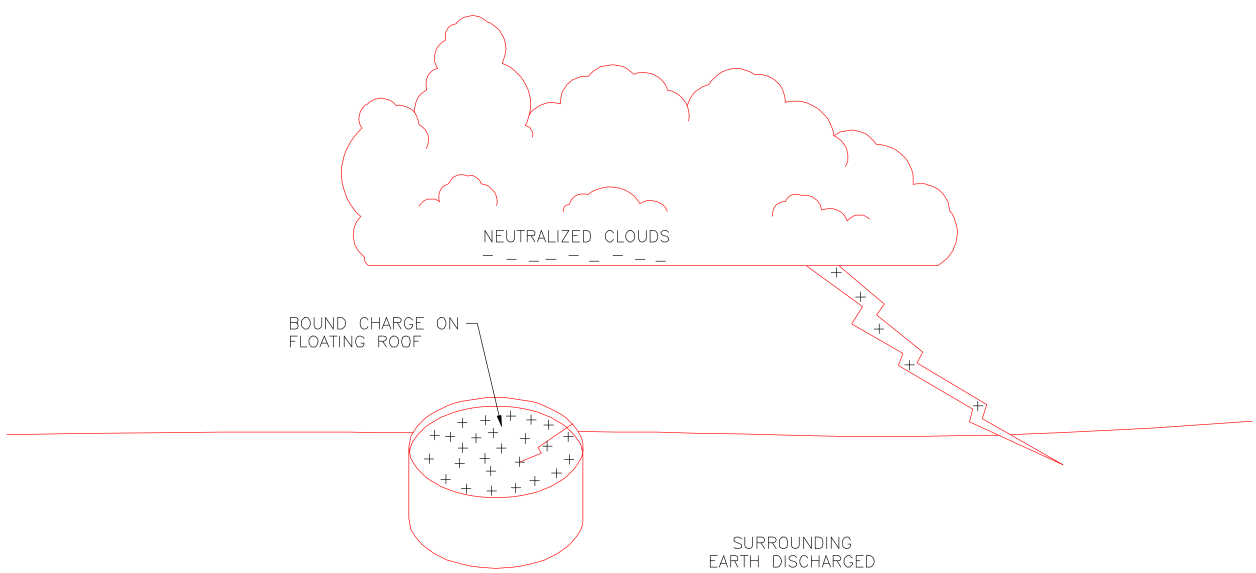

FIGURE 8, BOUND CHARGE HAZARD

Problem Conclusions

The foregoing **induced transients** have been measured and found to be manageable with the application of appropriate technology. These transients are known to be described as worst case, listed in Table 3.

Peak Surge Current	10,000 Amperes
Peak Energy	500 Joules
Shortest Time to Peak	100 Nanoseconds
Peak Voltage	5 kV

Table 3, Worst Case Secondary Effects

The secondary arc parameters are less definitive. They have not been measured. However, that is not as significant as is the statistics. It appears that it is the most common cause of flammable storage fires because lightning does not have to terminate on the container to ignite the fire. A strike within one hundred meters or so can initiate a secondary arc, if the situation is "right", a fire or explosion will result.

Preventing the Problems

Criteria to Prevent Lightning Related Problems

Preventing the foregoing problems requires three steps.

1. Identification of the exact nature of each problem source, and where it may manifest itself.
2. Selecting the most cost-effective protection **system concept.**
3. Determining the technological options available to deal with them and selecting the best or most appropriate of these options.

Selecting the Protection System Concept

There are three generic protection system concepts. These are:

1. Total elimination of all lightning activity from the area of concern.
2. The use of circuit protectors at every conceivable point of vulnerability, ineffective against fires.
3. A cost-optimized combination of the foregoing, a hybrid system.

LEC has studied these options as an applied automated process control systems, comparing both cost and risk (of not providing 100% effective protection). These studies involved refineries, gas processing plants, petrochemical plants, gas compressor stations and controlled storage facilities. The analytical results always favored the implementation of some form of hybrid system. They cost less and are far more effective. The Hybrid System actually seems to provide a certain amount of redundancy. The concept is applied by first selecting those areas and structures where the implementing of strike prevention system components would exercise the most influence on the strike prevention objective. These usually involve the tallest structures in the facility. having completed this, it is then necessary to identify any vulnerable areas that the foregoing may not prevent all forms of lightning-related damage. These will require secondary protection.

Those areas requiring secondary protection are usually remote areas and those around the fringes of the facility. They also include the electrical power distribution system, to and inside the facility. These components are usually referred to as Transient Voltage Surge Suppressors (TVSS). These TVSS are in two classifications:

1. Power Conditioners or Line Voltage Surge Suppressors (TVSS)
2. Data Line Protectors (DLP's)

Selecting the Protection System Components

The Keraunic number (lightning days per year), or isokeraunic level, is a measure of exposure rate. The higher the Kernauic number, the greater the stroke activity encountered in that area. In the United States this number varies from a low of 1 to over 100. In other parts of the world, it is as high as 300.

Structural characteristics such as height, shapes, size, and orientation, also influence this risk. For example, higher structures tend to collect the strokes from the surrounding area. The higher the structure, the more strokes it will collect. High structures will also trigger strokes that would not have otherwise occurred. Further, since storm clouds tend to travel at specific heights with their base from five to ten thousand feet, structures in mountainous areas tend to trigger lightning even more readily.

The system exposure factor for a transmission line provides an example. Consider a 50-mile stretch of transmission line in central Florida. According to data from the IEEE Subcommittee on Lightning, there should be about 1500 strokes to the line (total to the static wire and phase conductors). Two hundred twenty-five of these will exceed 80,000 amperes, all in just one average year.

Since different facilities have different kinds of problems with lighting, it is important to understand the capabilities and limitations of each type of protection system. In most cases, one or more of LEC's products can be adapted to solve the lightning protection problems. The following discussion briefly outlines features of the Dissipation Array® System (DAS®) and various types of transient voltage surge suppression (TVSS).

Dealing with the Direct Strike

Protection of the facility or area against direct strikes implies dealing directly with the strike itself, or with the mechanism that creates the strike. If the lightning protection concept is to deal with the strike, it must be capable of handling the parameters as defined without permitting any of the potentially harmful side effects of the lightning strike. If the lightning protection system deals with the mechanism that creates the strike, it eliminates the strike and as a result, also eliminates the secondary effects.

LEC recommends the use of a Dissipation Array® System (DAS®) because it has been proven to prevent direct strikes, thereby eliminating the hazards related to dealing with high energy lightning strikes. The DAS® is a patented lightning protection system based on the point discharge principle and the premise that a significant portion of the energy induced on the earth's surface by a storm cell can be leaked off slowly using what is known as the "point discharge" phenomenon. The 25 years of DAS® history accumulated to date proves this premise to be true and practical.

Preventing the direct strike to or near the critical facilities significantly reduces the need for protecting every potential point of transient induction and limits other protection requirement to those facilities entering, paralleling, or leaving the protected area.

It must be emphasized that the standard lightning rod will not resolve the problems encountered at any type of electronic based facility; instead, it can actually cause the problems. A stroke to the site brings too much energy, too close to sensitive equipment. The Dissipation Array® System is the only system that can be designed to prevent strikes and related losses. Use of a Dissipation Array® System throughout site will provide a safe environment for the facility, its operation and the operational staff.

The Dissipation Array® System is very sensitive to a multitude of design parameters. A compromise in any of these parameters will result in failure, particularly under high atmospheric stress conditions. These design parameters are incorporated into each lightning protection system recommended by LEC.

Dissipation Array® System (DAS®)

Lightning is the process of neutralizing the potential between the cloud base and earth. Any strike *prevention* system must facilitate this process slowly and continuously. The Dissipation Array® System (DAS®) has been designed to prevent a lightning strike to both the protected area and the array itself. The primary system components are the DAS® Ionizer, the Spline Ball Diverter System, and the Chem-Rod® Grounding Electrode. Some or all of these may be used in designing a particular protection system.

The DAS or Charge Transfer System is the only lightning protection system recommended by the American Petroleum Institute (API) to protect against direct strikes and the secondary effects, which includes the bound charge/secondary arc.

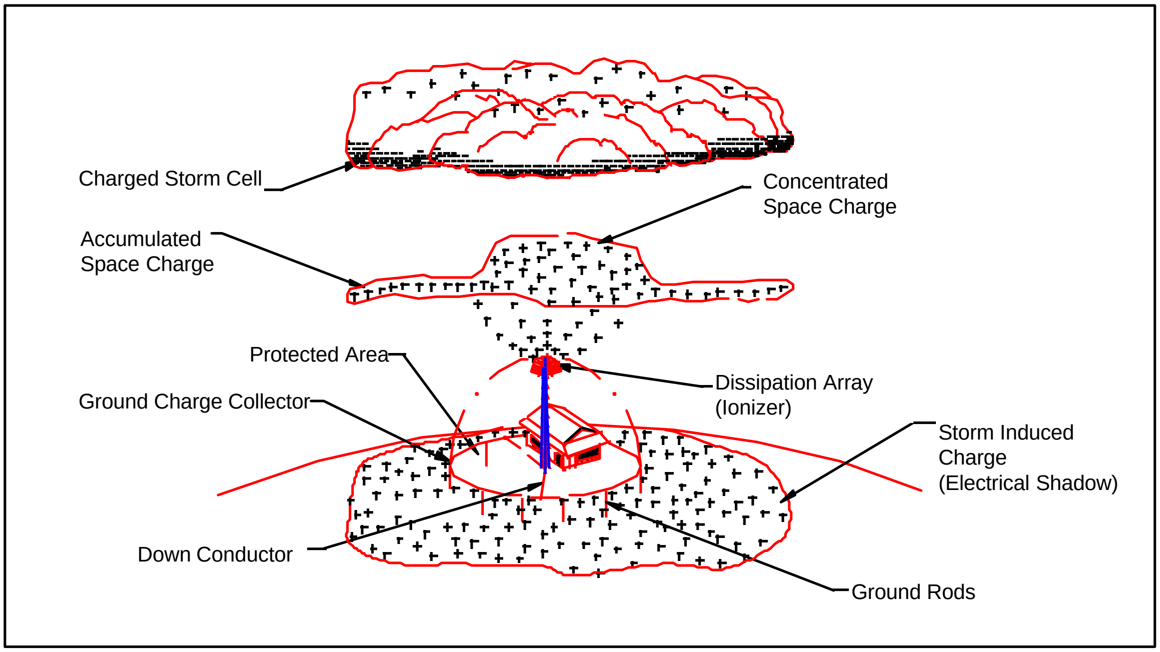

Figure 9: LEC's Dissipation Array® Concept

To prevent a lightning strike to a given area, a system must be able to reduce the potential between that site and the cloud cell, so that it is not high enough for a stroke to terminate within the area. That is, the protective system must release, or leak off, the charge induced in the area of concern to a level where a lightning stroke is impractical. (Charge induction comes about because of the strong electric field created by the storm and the insulating quality of the intervening air space.)

Atmospheric scientists have found that much of the storm's energy is dissipated through what is called natural dissipation, which is ionization produced by trees, grass, fences and other similar natural or manmade pointed objects that are earth bound and exposed to the field created by a storm cell. For example, a storm cell over the ocean will produce more lightning than the same cell over land, because the natural dissipation of the land will reduce the storm's energy. Consequently, a multipoint ionizer is simply a more effective dissipation device, duplicating nature more efficiently.

The point discharge phenomenon was identified over one hundred years ago. It was found that a sharp point immersed in an electrostatic field where the potential was elevated above 10,000 volts would transfer a charge by ionizing the adjacent air molecules.

The Dissipation Array® System is based on using the point discharge phenomenon as a charge transfer mechanism from the protected site to the surrounding air. The electrostatic field created by the storm cell will draw that charge away from the protected site, leaving that site at a lower potential than its surroundings.

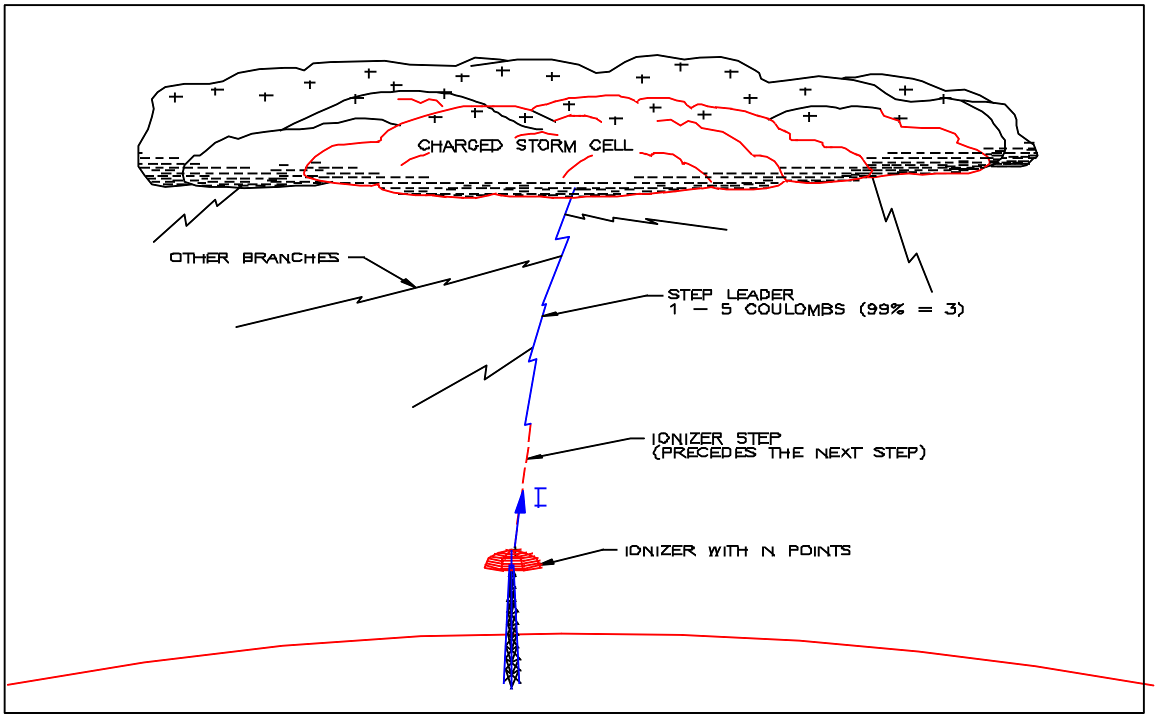

Figure 10: Point Discharge as a Transfer Mechanism

A second phenomenon that adds to the protection provided by the DAS® is the presence of a "space charge". This charge develops between the protected site and the storm cell and forms what may be considered a Faraday Shield. The ionized air molecules formed by point discharge are drawn above the ionizer where they slow down and tend to form a cloud of these ionized air molecules.

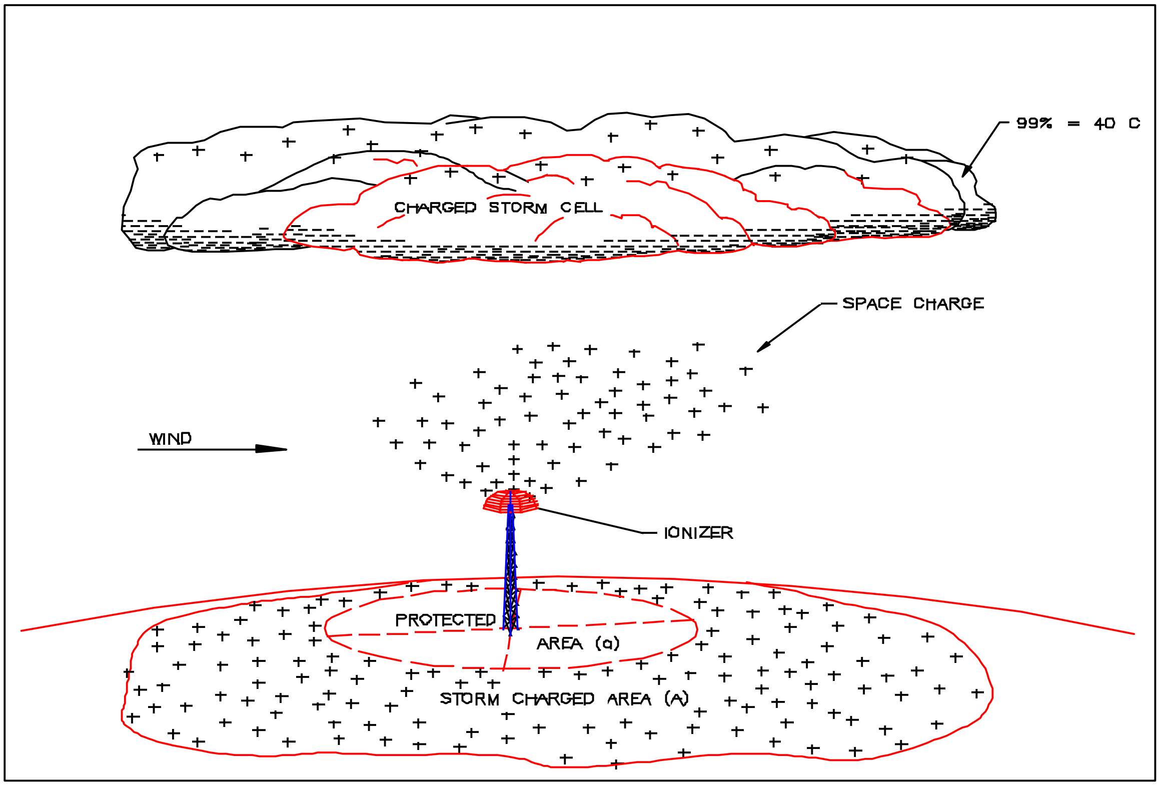

Figure 11: The "Space Charge" Effect

The DAS® Ionizer

The DAS® Ionizer is a multipoint device. It is designed to efficiently produce ions from many points simultaneously. A single point is usually a more efficient ionizer than the high point density ionizer at *low* electrostatic potentials. This is caused by the interference phenomenon that occurs between adjacent points that are close together. However, as the electrostatic field increases, the single point will create streamers and encourage a strike. In contrast, the multipoint ionizer starts the ionization process at a somewhat higher potential, but as the potential increases, the ionization current increases exponentially. Since these ions are spread over a large area, no streamers are generated. In extreme situations a luminous cloud of ions is produced, causing a momentary glow around the array and a sudden burst of current flow.

The ionizer assembly is very sensitive to a number of design parameters, some of which can be reduced to formulation, others can not. These factors include size, shape, elevation, point shape, point height above the array face, point spacing, range in wind velocity, plus the character and relationship of the surroundings. Thus effective system design remains as much an art as a science.

Spline Ball Diverter System (SBDS)

LEC has also addressed the market for hybrid ionizers, which combine the features of the ionizers with those of air terminals. This had led to the development of two new products:

The Spline Ball Ionizer® (SBI-48) Module

The Spline Ball Terminal® (SBT®) Module

Both of these units are UL® listed as "Air Terminals", and both qualify as ionizer modules. The multiple points make them an ionizer. The proper spacing of points assures optimum ionization current before it switches to the "collector mode". They also qualify as air terminals under UL96A, and therefore are usable as such in any NFPA78 based system. Both Spline Ball assemblies are made up of about 100 points each, which when deployed, present point sets in all 360 degrees in azimuth and about 200 degrees in elevation. As a result, regardless of the orientation of the storm related electric field or an incoming leader, many ionizer points will be oriented directly toward it and ready to transfer the charge rapidly.

These forms of ionizer modules support a wide variety of applications. When enough of these modules are used to replace conventional air terminals, this converts a conventional collector system to a preventor system.

Grounding System

The ionizer assembly alone is, of course, not sufficient. The system must be grounded. The Ground Current Collector (GCC) provides the source of charge to keep the ion current flowing through the array and discharge the site. The GCC is designed to provide an electrically isolated or floating ground subsystem for the protected area with respect to the earth. Since the induced charge created by the storm is at the earth's surface, that portion of the earth's surface containing the facilities to be usually protected is surrounded with the GCC. The GCC is normally composed of the Ground Current Collector wire or copper tubing buried to a depth of about 25 centimeters and short ground electrodes along the GCC at intervals of about ten meters. The enclosed area may be integrated by a net of cross conductors which also connect surface structures and grounding system.

LEC's Chem-Rod® Grounding Electrode is an ultra-efficient low surge impedance grounding system. It provides the perfect low resistance interface with true earth by continuously conditioning the surrounding soil, using specially formulated mineral salts evenly distributed along the entire length of the electrode. It is so efficient that one Chem-Rod® can replace up to ten conventional grounding rods.

The design of the Chem-Rod® insures a stable, efficient system that is virtually maintenance free.

As the charge moves into the area, it first interfaces with the GCC which provides a preferred path for the charge from this point of interface to the dissipater or ionizer assembly by means of the service wires, thus essentially bypassing the protected area. The current flow thus created through the surrounding surface soil causes a small voltage drop across that soil resistance such that the electrically integrated, isolated island established by the GCC is reduced to a lower potential than its surroundings. The short ground electrodes give the island enough depth to assure collection of any charge induced within the area of concern.

The Charge Conductor function provides a direct, low impedance path from the GCC to the ionizer. In contrast to a lightning rod system, these wires carry low current levels over the shortest path possible and are selected more for structural integrity than for current carrying capacity. The maximum current flow is in the milliampere range and measurements indicate less than ½ ampere at maximum (except on rare occasions).

Transient Voltage Surge Suppression (TVSS)

AC Power Lines

Power line voltage anomalies are the greatest source of destructive and disruptive phenomena that electrical and electronic equipment experience in day-to-day operations. The causes may vary significantly with location, but the results are the same. Either the equipment will fail immediately or degrade over a period of time. The failures may be catastrophic, result in reduced Mean Time Before Failure (MTBF), or in some form of momentary or long term "lockup."

These anomalous events can result in a need for replacement, repair, reprogramming or rerun of the program in progress. Any of these events can result in lost time and money. All of these events can be totally eliminated with the appropriate power conditioning equipment, properly installed and maintained. Most of these events can be eliminated through the correct use of relatively inexpensive protection equipment.

Transient Voltage Surge Suppressors (TVSS) must perform three functions:

1. Prevent immediate damage from any overvoltage
2. Protect the reliability of the protected system
3. Be reliable itself.

LEC has studied the character of voltage line anomalies and protective components available on the market today. The results indicate some significant deficiencies within the TVSS industry. The current TVSS units are designed to deal with the potentially destructive anomalies, but are not; and in their present state, cannot protect the reliability of the protected system.

As a result, LEC developed the Sandwich Block Technology.

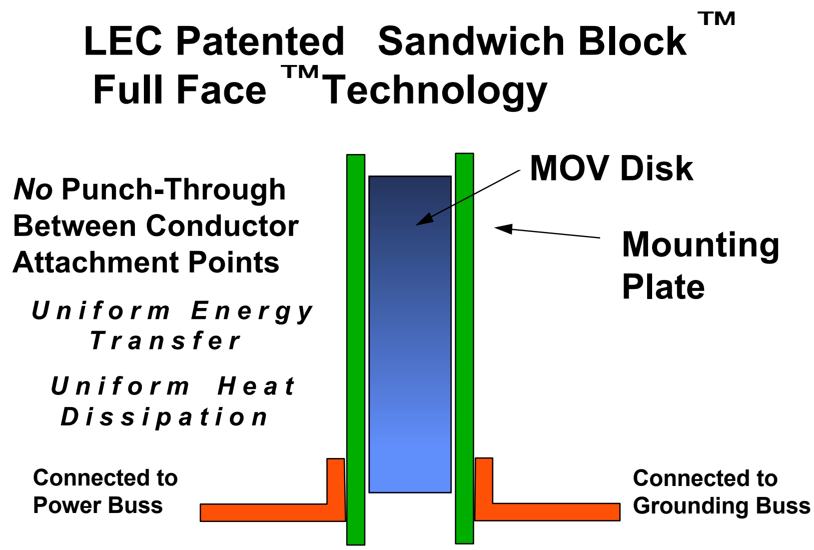

Figure 12, Sandwich Block

The Sandwich Block Surge Suppressor (SBSS) can dissipate up to 560,000 amperes of surge current and respond to that peak current in less than 50 nanoseconds. No other concept can handle one tenth of that with a 50 nanosecond response. Further, because of the large heat sinks, the SBSS can handle repeated high current surges without damage.

Although the 560,000 ampere protection is seldom if ever used, the high current handling capability provides a very low Clamping Ratio. That is, the E/I slope is very flat, resulting in both protection of the protected system reliability and protector system (SBSS) reliability.

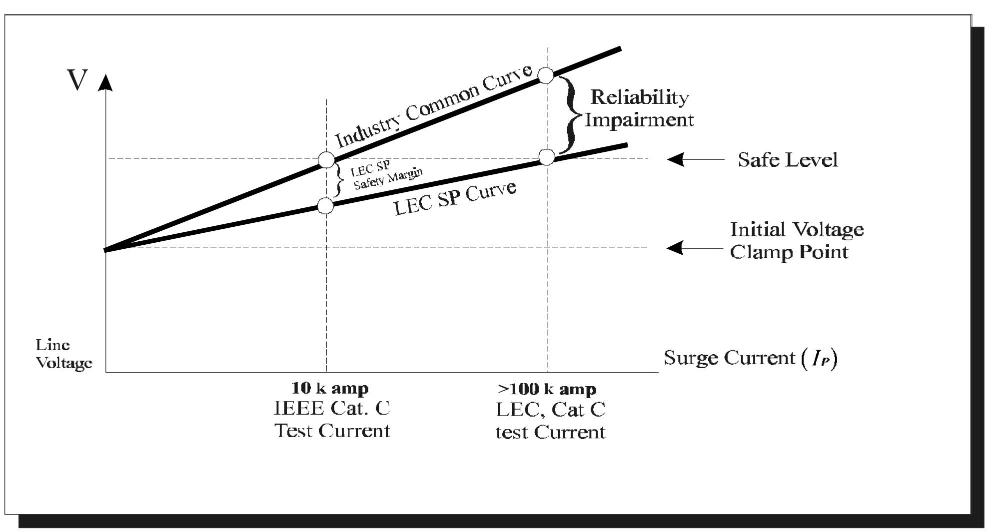

Figure 13, V/I Curve

LEC offers the SBSS as the most effective TVSS on the market today, a patented product with 21 claims approved.

Telephone, Data and Control Lines

Telephone, Data and Control lines are the most sensitive circuits within a process controlled facility. A very small (low energy) “high voltage” spike can wipe out an Input/Output circuit and often make it impractical to repair it. These circuits have various voltages, currents and data rates on the lines. Each one must be matched to a specific protector, designed for those circuits. There is no universal protector that can satisfy all the circuit requirements. However, there is only one circuit configuration that can be used for protecting these circuits. These are the Series Hybrid DLP’s.

The packaging concept is equally important. The protection circuit **cannot** be on the same card as the protected circuit. Further, it must be serial in both circuit configuration and physical layout. Both are to prevent arcs from bypassing the protection. The DLP manufactured by LEC satisfies these requirement; and can be used as terminations for field wires within what is usually referred to as “Marshaling Cabinets”.

Prevention Conclusions

The risk from lightning is real, and traditional lightning protection devices do not adequately cover all the risks. The secondary effects which cause much of the damage are in fact increased by collecting strikes.

LEC has developed proven technologies which can eliminate lightning strikes from a protected area and protect against the secondary effects of lightning where the facility is not completely protected. If a lightning strike could put your facility out of business, or even out of action for a few hours, consider whether the cost of preventing all future risks from lightning would not easily offset the cost of installing one of LEC’s lightning elimination systems. It is cheap insurance.

Customer List

DAS PETROLEUM & CHEMICAL APPLICATIONS

(As of 12/31/96, 2 Pages)

DATE	CLIENT (SUBCONTRACTOR)	Location	DESCRIPTION
12/10/96	Arab Petroleum Pipelines	Egypt	6 hemi, 35 SBI, 120 SBT, 25 CR, TVSS
12/6/96	PDVSA/Corpoven (LEC de Ven.), Musipan & Muri	Venezuela	10200' DA wire
12/6/96	PDVSA/Corpoven (LEC de Venezuela), Amana	Venezuela	14 hemi, 2 stack, refinery
12/6/96	PDVSA/Corpoven (LEC de Venezuela), Carito	Venezuela	8 hemi, 2 stack, refinery
12/6/96	PDVSA/Corpoven (LEC de Venezuela), Tejero	Venezuela	10 hemi, 2 stack, 16800' DA wire, refinery
12/6/96	PDVSA/Corpoven (LEC de Venezuela), Muri	Venezuela	8 hemi, 2 stack, refinery
12/5/96	PDVSA/Corpoven (LEC de Venezuela), Musipan	Venezuela	2 rim, 4 hemi, 1 paragon, 2 stack, refinery
11/20/96	PDVSA/Corpoven (LEC de Ven.), Musipan & Muri	Venezuela	6800' DA Wire for hemis
10/16/96	Mobil Oil Corp.	Beaumont	hemi, 4 SBI, 4 CR, supv
10/2/96	DOPCO (Procon System Co. Ltd.)	Korea	2 flat roof, 27 SBI, 3 parapet, 33 SBT, tank farm
8/12/96	PDVSA/Corpoven (LEC de Ven.), El Palito	Venezuela	6800 DA Wire, replacing old DAS wire
7/11/96	Pemex (LEC de Mexico)	Mexico	2 paragon, 84 sbi, 2 parapet, 2 roof, tvss
7/11/96	Pemex (LEC de Mexico)	Mexico	paragon, 38 sbi, 8 sbt, compressor station
7/9/96	Pemex (LEC de Mexico)	Mexico	2 roof pk, 54 sbi, 3 paragon, 20 sbt, 2 hemi, tvss
6/24/96	PDVSA/Bariven, El Chaure Refinery	Venezuela	5 rim arrays
4/19/96	Phillips 66 Co.	Sweeney	1000' DA wire for DDS
4/1/96	AGIP (Balton CP Ltd.)	Nigeria	Multiple DA, CRs, tvss, SBI systems
3/14/96	PDVSA/Corpoven (LEC de Venezuela)	Venezuela	3400' DA Wire for hemis
3/5/96	PDVSA/Corpoven (LEC de Venezuela)	Venezuela	3400' DA Wire for hemis
2/27/96	PDVSA/Corpoven (LEC de Venezuela)	Venezuela	3400' DA Wire for hemis
11/20/95	GE Plastics, IDB City of Montgomery	Burkville	2 DA stack, 2 CR
10/9/95	Pemex	Mexico	13 DA, 110 SBI, 20 SBT, TVSS
	Shell, Forcados	Nigeria	2 DA rim arrays
9/5/95	Noram Gas Transmission, was Arkla	3 sites	DA, 38 SB, TVSS (1 Arkansas, 2 OK)
8/28/95	Chevron, Cabinda Gulf Oil Co.	Nigeria	DA, 10 SBI, 4 CR, TVSS
8/25/95	MG Industries	Malvern	DA, TVSS, Grnding, Vertical vessel
8/25/95	MG Industries	Malvern	DA, TVSS, 18 SBI, Grnding, vertical vessel
7/25/95	AGIP, Port Harcourt (Balton CP Ltd.)	Uganda	2 DA on twrs, 18 SBI, 6 CR, TVSS, total of 4 twrs
5/30/95	PDVSA/Lagoven (Ingenieria Y Applicaciones)	Venezuela	3 tanks, trap-stack, 4 parag., parapet, 32 SB, TVSS
5/18/95	Mobil Oil Corp.	Beaumont	Paragon DA, 6 SBI
4/19/95	Chevron Niugini Pty	Papua New Guin.	7 DA, 49 SBI, TVSS, 7 sites
3/29/95	Amoco Oil Co.	Mandan	DDS, 13 Brackets, 2000' Wire
12/9/94	Mobil Oil	Beaumont	PTR-4 area of refinery, 2 stack DA, 3 hemi DA
11/15/94	General Electric Plastics	Mt. Vernon	Stack DA, 1 CR
11/4/94	Chemical Waste Mgmt	Port Arthur	Stack DA
10/7/94	Pemex (Construcciones Protexa)	Mexico	20 low profile DA for tanks
8/9/94	Exxon (Turner Supply)	Mobile	500' DA Wire, 6 arms
8/3/94	Mobil Oil Co.	Beaumont	3 hemi DA, TVSS
5/20/94	ELF Atochem	Axis	1 paragon DA, 12 CR, TVSS, 40 SBI, 15 SBT
5/6/94	Conoco	Westlake	1 stack DA, 4 hemi DA, 9 SBI
4/28/94	PPG Industries	Lake Charles	12 SS arms, 750' DA Wire
4/5/94	General Electric Plastics	Burkville	2 DA Grids [Burkeville is near Selma.]
3/31/94	Texaco Offshore Facilities (Index Brook)	Nigeria	5 sites+tanker, 14 DA, 62 SBI, 10 SBT
3/14/94	Lodinsa	Costa Rica	Parapet DA, 38 SBT, explosives mfr warehouse
1/11/94	Mobil Oil Co.	Beaumont	stack DAS
12/14/93	Chevron Overseas Petroleum (LEC Nigeria)	Nigeria	Conic DAS for 220' tank
12/6/93	Star Enterprise (Texaco/Saudi Joint Venture)	Port Arthur	DDS with 100,000' DAS wire, 415 T-bars
10/4/93	Encon Petroleum and Industrial	Egypt	hemi DA, 4 CR, 1 SBI
10/4/93	ARKLA Energy Resources Co.	Malvern	gas metering station, paragon DA, 12 CR, TVSS
8/19/93	Chevron Overseas Petroleum	Nigeria	DAS, 100' tower
7/2/93	Chevron Overseas Petroleum	Nigeria	2 hemi DAS, 14 SBI, 10 CR, TVSS, 6 SBT
4/16/93	Augusta Services/Columbia Nitrogen	Augusta	DAS Replacement
3/5/93	EI Dupont, Sabine River Works (J. Brown Const.)	Orange	DAS, LWS
1/27/93	Chevron Nigeria Ltd., 3 sites	Nigeria	4 hemi DAS, 21 SBI, 9 SBT, 5 CR
12/18/92	Pemex, Dept. De Compras	Mexico	2 hemi, 4 CR, 12 SBI, TVSS

DATE	CLIENT (SUBCONTRACTOR)	Location	DESCRIPTION
10/19/92	Augusta Services/Columbia Nitrogen	Augusta	3 hemi, 24 SBT, fertilizer mfr
10/6/92	Exxon USA, Mobile Bay (H.B. Zachry)	Mobile	24 DASs, 15 SBT bldgs (350 SBT), 50 SBI

5/29/92	Amoco Oil Co. (Fluor Daniel)	Mandan	4160' DAS wire, hardware
2/28/92	PDVSA/Bariven, Amuay Refinery, Judibana	Venezuela	11 conic DAS, 2 floating roof DAS
2/13/92	Mobil Producing, Qua Iboe Terminal	Nigeria	22 DAS, LWS, TVSS
12/17/91	Malaysian Gov't (LEC Inc. - Malaysia)	Malaysia	2 DAS, nat'l gas metering/regulating
11/19/91	PDVSA/Bariven, Amuay Refinery, Judibana	Venezuela	57 conic roof tanks
11/14/91	Amoco Chemical	Alvin	1 DA stack, 8 SBI
10/28/91	Chevron Overseas Petroleum (Cabinda), Malongo	Angola	1 hemi, 4 CR, 6 SBI
10/21/91	Mobil Oil Co.	Beaumont	2 hemi
10/18/91	Zaire Gulf Oil Co. (Chevron O'seas Petroleum)	Zaire	2 hemi: earth sta. & tower, TVSS
6/24/91	Phillips (Brown and Root, USA)	Old Ocean	2 Cone Roof tanks
5/20/91	PPG Industries Inc.	Lake Charles	Substations, DDS, hemi
4/24/91	PDVSA/Bariven, El Palito Refinery, Puerto Cabello	Venezuela	27 DAS: 8 stack, 18 hemi, 1 panel, 14 SBI
2/1/91	PPG Industries	Lake Charles	450' wire and arms, DDS
1/18/91	ARKLA Energy Resources	Malvern	6 hemi, TVSS, Malvern Compressor Sta.
10/26/90	PPG Industries	Lake Charles	2 7500' 69kV DDS, substation hemi
9/21/90	Exxon Company USA	Baytown	9 SBI, 3 hemi, gnding, refinery, power
8/28/90	US West (Dynalectric)	Omaha	office bldg, data center, parapet DA, 7 SBI
8/9/90	PDVSA/Bariven, Amuay Refinery, Judibana	Venezuela	55 rim, 11 conic, 20 paragons for oil reservoir
6/29/90	Mobil Oil (Motorola)	Paulsboro	Paulsboro Refinery, hemi, 4 CR
9/8/89	General Electric Plastics	Mt. Vernon	vent stack, 1 CR
7/25/89	Arab Petroleum Pipeline	Egypt	Met. Tower, 2 DA, 8 CR
3/22/89	Amoco Oil Co, Whiting Refinery (Fluor Daniel)	Whiting	computer bldg, DA, TVSS
3/14/89	Penzoil Sulphur	Pecos	bldg, anten, 3 DA (2 conic, 1 roof), 8 CR
1/20/89	Mobil Oil	Beaumont	Catalytic crack refinery, DA, 2 CR
7/15/88	Interprovincial Pipeline, Edmonton	Canada	6 oil storage tanks, rim DA
5/25/88	Amoco Oil, Mandan Refinery	Mandan	DDS for 3 4160v lines, DDS 480v line
4/29/88	Texaco Canada Resources, Edmonton	Canada	oil storage tanks, 15 hemis, 2 traps, 23 CR
3/7/88	Interprovincial Pipeline, Sarnia	Canada	oil storage tank
2/17/88	Mobil Oil (Motorola)	Beaumont	commun tower, DAS, 3 CR
12/14/87	Arab Petroleum Pipeline Co., Alexandria	Egypt	hemi, 4 CR
12/14/87	Federal Express	Memphis	Fuel Farm pkg lot, 10 hemi, 10 CR
3/13/87	PPG Industries	Lake Charles	hydrogen contact cool pole, hemi
11/24/86	Tennessee Gas Pipeline	Pritkin	DA (trap), 3 CR
10/10/86	Texaco Services Inc.	Castleberry	gas plant, trap, stack, hemi, 11 CR, TVSS
1/3/86	Phillips Petroleum Co.	Old Ocean	storage tanks, 2 trap, 8 perimeter, 260' tower
12/3/84	Augusta Services/Columbia Nitrogen	Augusta	hemis
1/4/84	Ethyl Corp.	Pasadena	9 cooling towers, rim arrays
8/4/83	PPG Industries (Fogarty Eng. Sales)	Lake Charles	chlorine plant, 4 DAS
7/18/83	Conoco, Grand Chenier Separation Sta.	Grand Chenier	Microwave site/tower
6/17/83	Texaco, Inc.	Snyder	18 oil storage tanks, TVSS
3/10/83	Conoco, Inc.	Lake Charles	Microwave site, 170'
10/18/82	Texaco Canada Resources Ltd., Edmonton	Canada	Oil processing & storage, 10 DAS
7/23/82	Augusta Services/Columbia Nitrogen	Augusta	Processing plant, 3 hemi, 400' hot gas stack, TVSS
3/19/82	Hydrocarbon Transportation (UPG Inc.)	Lorraine	2 hemi kits
3/30/81	Texas Pipeline Co.	Terrebonne Parish	Microwave, 170' tower, tank
3/3/81	Cloro de Tehuantepec	Mexico	chlorine plant, 2 DAS
11/25/80	Warren Petroleum Co. (Digital Systems)	Mont Belvieu	170' distillation tower
1/6/80	Phillips Petroleum	Freeport	Oil storage tanks, 22 conic DAS
10/12/79	Hydrocarbon Transportation Co.	Des Moines	small hemi
9/27/79	Mobil Oil Corp.	Beaumont	Refinery Area, stack, hemi, conic
9/20/78	Dow Chemical Co.	Freeport	ammonia plant
9/15/78	Industrial Gases Ltd. (Stabell Svcs & Co.), Ibadan	Nigeria	Oxygen & acetylene plant, trap
9/5/78	PDVSA/Bariven, El Palito Refinery, Puerto Cabello	Venezuela	Large Oil Reservoir, 8 hemis
6/15/78	Ethyl Corp.	Pasadena	4 cooling towers
6/8/78	Shell Oil Co. (Ball Brothers), Thomasville Plant	Brandon	Met. tower
6/15/77	Texaco of Canada, Edmonton	Canada	oil storage and processing plant
4/19/77	Northern Petro-Chemical	Morris	hemi, 140' tower
4/12/76	Northern Petro-Chemical	Morris	cooling tower, hemi, roof
3/2/76	PPG Ind. (Fluor Corp, Blount Bros.)	Lake Charles	Chlorine plant, 3 paragons
5/9/75	Texaco of Canada, Calgary	Canada	Oil storage site, hemis, tanks, conic
10/15/72	Unocal, Union Oil Co.	Indonesia	420 acre tank farm, hemi, tower, conic

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