Packaging Waste and Hitting Home Runs: How Education and Lightning Strike Detection Technology Supports Company and Community Activities

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ABSTRACT

The weather is the most significant and unmanageable variable when performing environmental remediation activities. This variable can contribute to the failure of a project in two ways: 1) severe injury to an employee or employees following a cloud-to-ground lightning strike without prior visual or audible warnings; and 2) excessive "down time" associated with mobilization and demobilization activities after a false alarm (e.g., lightning was seen in the distance but was actually moving away from the site). Therefore, in order for a project to be successful from both safety and financial viewpoints, the uncertainties associated with inclement weather, specifically lightning, need to be understood to eliminate the element of surprise. This paper discusses educational information related to the history and research of lightning, how lightning storms develop, types of lightning, the mechanisms of lightning injuries and fatalities, and follow-up medical treatment. Fortunately, lightning storm monitoring does not have to be either costly or elaborate. WESKEM, LLC selected the Boltek StormTracker Lightning Detection System with the Aninoquisi Lightning 2000^{TM} software. This fixed system, used in combination with online weather web pages, monitors and alarms WESKEM, LLC field personnel in the event of an approaching lightning storm. This application was expanded to justify the purchase of the hand-held Sky Scan Lightning/Storm Detector Model P5 used by the Heath Youth Athletic Association (HYAA) which is a non-profit, charitable organization offering sports programs for the youth and young adults in the local community. Fortunately, a lightning injury or fatality has never occurred on a WESKEM Paducah project or an HYAA-sponsored event. Using these fixed and hand-held systems will continue to prevent such injuries from occurring in the foreseeable future.

INTRODUCTION - MYTHS AND LEGENDS OF LIGHTNING

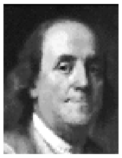
During an earlier time, lightning was considered to be a magic fire from the sky that man captured in order to stay warm at night and keep savage animals away. As primitive man sought answers about the natural world, lightning became a part of superstitions (i.e., observed as cause and effect), myths and early religions. Even Santa Claus had reindeer named Donner (thunder) and Blitzen (lightning). Thales, the Greek philosopher, in 600 BC, rubbed a piece of amber with a dry cloth and noted that it would then attract feathers and straw. William Gilbert, court healer to Queen Elizabeth in the late 1500s, also used amber to duplicate these earlier experiments. He named this *via electrica*, after *electra* which is Greek for amber. Although these experimentalists may not have understood the process at the time, they were demonstrating the phenomenon of static electricity (1).

THE LEYDEN JAR – AN EARLY "LIGHTNING" CONTAINER

In 1746, electrical science had developed to the point where positive and negative charges could be separated. Machines were invented, such as the Leyden jar, that was used like a thermos bottle for storing "volts". Pieter van Musschenbroek of the University of Leiden, Netherlands, made the storage jar known to the scientific world. Hence, the jar was named after Leiden, the home town of the university. A Leyden jar is a device that early experimenters used to help build and store electric energy. It was also referred to as a "condenser" because many people thought of electricity as fluid or matter that could be condensed. Today, this device would be called a capacitor. Basically, the Leyden jar is a cylindrical container made of a dielectric (i.e., an insulator, like plastic or glass) with a layer of metal foil on the inside and on the outside. With the outside surface grounded, a charge is given to the inside surface. This gives the outside an equal but opposite charge. A spark is created when a conductor connects the outside and inside surfaces. Friction machines could charge the jars and electricity could be carried around and demonstrated. "Electric magic" was in great demand at the royal courts of Europe as entertainment. Fig. 1. shows various types of Leyden jars (2, 3).

Fig. 1. Various types of Leyden jars

LIGHTNING RESEARCH – FROM FRANKLIN'S KITE THROUGH TODAY



Lightning is static electricity on a giant scale, generated from thunderstorms, including snowstorms and volcanoes. Benjamin Franklin performed the first systematic, scientific study of lightning during the second half of the 18th century. During a Pennsylvania thunderstorm in 1752, the most famous kite in history flew with sparks jumping from a key tied to the bottom of a damp kite string to an insulating silk ribbon tied to the knuckles of Franklin's hand. Franklin's grounded body provided a conducting path for the electrical currents responding to the strong electric field buildup in the storm clouds. In addition to showing that thunderstorms contained electricity by measuring the sign of the charge delivered through the kite apparatus, Franklin was able to infer that while the clouds were overhead, the lower part of the thunderstorm was generally negatively charged.

Little progress was made in understanding the properties of lightning until the late 19th century, when photography and spectroscopic tools became available for lightning research. In Germany, Pockels (ca. 1897-1900) analyzed magnetic fields induced by lightning to estimate electric currents. Also, many experimenters used time-resolved photography during the late 19th century to identify individual lightning strokes that make up a lightning discharge to the ground (1).

In modern times, C.T.R. Wilson (1869-1959) was the first to use electric field measurements to estimate the structure of thunderstorm charges involved in lightning discharges. Wilson, who won the Nobel Prize in 1927 for the invention of the Cloud Chamber, made major contributions to our present understanding of lightning (4).

Research continued at a steady pace until the late 1960s when lightning research became particularly active by the improved measurement and observational capabilities that were made possible by advancing technology. This increased interest was motivated by the danger of lightning to aerospace vehicles and solid-state electronics used in computers. The National Aeronautics and Space Administration (NASA) has documented various lightning strike events to spacecraft. One major incident occurred during the 1969 launch of Apollo 12 when lightning briefly knocked out vital electronic systems. Fortunately, the astronauts regained control of the spacecraft. During another launch in 1987, an unmanned Atlas Centaur 67 carrying a Naval communications satellite was determined to be struck by lightning. The lightning current apparently altered the memory in the digital flight control computer causing an excessive angle of attack that eventually caused a breakup of the vehicle (5).

WHAT IS LIGHTING AND THUNDER? (5, 6, 7)

The Global Electric Circuit

In nature, a potential difference of 200,000 to 500,000 Volts exists between the Earth's surface and the ionosphere with a fair weather current of about 2×10^{-12} amperes/meter^2 (2 pA/m^2). It is believed that this potential difference is due to the world-wide distribution of thunderstorms. Present measurements indicate that an average of almost 1 ampere of current flows into the stratosphere during the active phase of a typical thunderstorm. Therefore, to maintain the fair weather global electric current flowing to the surface, 1,000 to 2,000 thunderstorms must be active at any given time producing approximately 100 lightning strikes to Earth per second. In the United States (U.S.), there are about 15-20 million ground strikes per year. While present theory suggests that thunderstorms are responsible for the ionospheric potential and atmospheric current for fair weather, the details are not fully understood. Fig. 2. shows the global electric circuit between the Earth and the ionosphere.

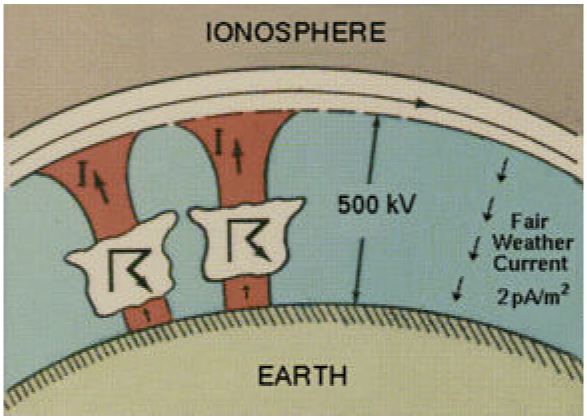


Fig. 2. The Earth and Ionosphere global electric circuit

Characteristics of a Beginning Lightning Storm – Clouds and Rain

When moisture-laden warm air is heated, it begins to rise. As these currents or bubbles of warm moist air rise higher in the atmosphere, both the surrounding air pressure and temperature decrease. The air bubbles expand, causing cooling of the moisture which eventually condenses to form clouds. As the cloud cools further, more moisture condenses and the water droplets making up the cloud grow and merge until some become so large and heavy that the air currents within the cloud can no longer support them. These water droplets begin to fall as rain.

Ice is a Critical Component to the Lightning Process

Three basic components are needed to create a thunderstorm: 1) moisture, 2) atmospheric turbulence, and 3) a cold front that causes the air to rise. Continued rising motions within the storm may build the cloud to a height of 10 to 16 km (6 to 10 miles) above sea level. These towering Cumulus clouds may be the first indications of a developing thunderstorm.

Lightning originates around 5 to 8 km (15,000 to 25,000 feet) above sea level. Since upper atmospheric temperatures are colder, rain drops are carried upward until some of them convert to ice particles, called hydrometeors. Therefore, ice forming in the higher parts of the cloud is a critical component for generating lightning. The ice particles can vary in size from small ice crystals to larger hailstones, and the rising and sinking motions within the storm result in numerous collisions between these particles. This causes a separation of electrical charges (i.e., electrical differential). The exact mechanisms by which this charging happens remain unknown. Positively charged ice crystals rise to the top of the thunderstorm, and negatively charged ice particles and hailstones drop to the middle and lower parts of the storm. The electrical charges build up until they are strong enough to overcome the resistance of the surrounding atmosphere.

A storm that fails to produce ice may also fail to produce lightning. However, even when lightning is not produced, pellets of ice may grow by the accumulation of liquid droplets. When the updrafts are very strong, the growing ice pellets can be suspended for long periods, allowing them to grow larger. Eventually some may become too large for a given updraft and begin to fall as hail. Diameters are typically 5 to 10 mm (0.2 to 0.4 inches).

How Lightning Develops Between the Cloud and the Ground

A moving thunderstorm gathers another pool of positively charged particles along the ground that travel with the storm. As the differences in charges continue to increase, positively charged particles rise up objects such as trees, houses, telephone poles and even people. A person’s hair standing on end is a result of the positively charged particles and is one of nature's warning signs that the person could become a lightning target. The negatively charged area in the storm will deposit charges that move toward the ground in less than a second and are called stepped leaders. The stepped leader is invisible to the human eye and, as it grows, it creates an ionized path depositing a charge along the channel. As the stepped leader nears the Earth, a large potential difference is generated between the end of the leader and the Earth. Typically, a streamer is launched from the Earth and intercepts the descending stepped leader just before it reaches the ground. Once a connecting path is achieved to complete the circuit, the return stroke, which is a flow of charge (i.e., current), flies up the already ionized path at close to the speed of light. This return stroke releases tremendous energy and bright light appearing as lightning. There may be several return strokes of electricity within the established channel that you will see as flickering lightning. This entire event takes less than half a second to occur.

Many cloud-to-ground lightning flashes have forked or multiple attachment points striking the Earth. Tests carried out in the U.S. and Japan verified this finding in at least 50% of the negative flashes and in more than 70% of the positive flashes (8).

Thunder

Lightning causes thunder. Lightning can travel 144,846 km/s (90,000 miles/second), and the average width of a lightning bolt is 2.5 – 5.0 cm (1-2 inches). Therefore, the bright light of the flash caused by the return stroke represents a great deal of energy. For perspective, an average flash of lightning will light a 100-watt bulb for more than 3 months. The energy rapidly heats the air in the lightning channel to 27,760 degrees C (50,000 degrees F), or three times hotter than the surface of the sun, in a few millionths of a second. The air that is now heated to such a high temperature has no time to expand, so it is now at a very high pressure. The high pressure air then expands outward into the surrounding air compressing it and causing a disturbance that propagates in all directions away from the lightning stroke. The disturbance is a shock wave for the first 9 m (30 feet), after which it becomes an ordinary sound wave or thunder. Thunder can sound continuous because each point along the channel produces a shock wave and accompanying sound wave.

Although the lightning flash and resulting thunder occur at essentially the same time, sound travels one-fifth of a mile in the same time. Therefore, by counting the seconds between the flash and the thunder and dividing by 5, one can estimate distance to the storm. This method is referred to the *flash-to-bang method*. (Refer to Section: How Weather Affects Outdoor Waste Management Activities for a description on the *flash-to-bang method*).

Negative Lightning And Positive Lightning

Not all lightning forms in the low, negatively charged area in the thunderstorm cloud. Some lightning originates in the “Cirrus Anvil” at the top of the thunderstorm. This area carries a large positive charge. Lightning from this area is called positive lightning. This type is particularly dangerous for several reasons. It frequently strikes away from the rain core, either ahead or behind the thunderstorm, and can strike as far as 8 to 16 km (5 to 10 miles) from the storm in areas that most people do not consider to be a lightning risk area. Previously, 3 to 5 km (2 to 3 miles) was used in lightning safety education (8). The other problem with positive lightning is that it typically has a longer duration, and thus can easily ignite a fire. Positive lightning usually carries a high peak electrical current, which increases the lightning risk to an individual.

COMMON TYPES OF LIGHTNING (5, 7)

Fig. 3. shows the positive/negative charges that can develop and the various types of lightning that can be discharged during a storm.

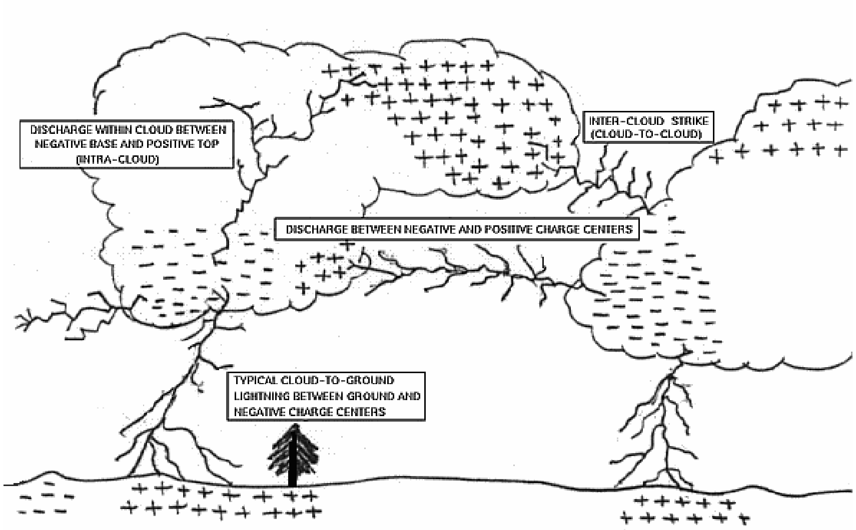


Fig. 3. The positive/negative charges that can develop and the various types of lightning that can be discharged during a storm

Fig. 4. provides an example of **cloud-to-ground** lightning. Although this type of lightning is not the most common, it is the most understood, damaging and dangerous form of lightning.

Fig. 4. Cloud-to-ground lightning

Most flashes originate near the lower-negative charge center of the cloud, thus delivering a negative charge to Earth. However, a minority of flashes carry a positive charge to Earth. These positive flashes often occur during the dissipating stage of a thunderstorm's life. Positive flashes are also more common as a percentage of total ground strikes during the winter months.

Fig. 5. provides an example of **intra-cloud** lightning which is the most common type of discharge.

Fig. 5. Intra-cloud lightning

This occurs between oppositely charged centers within the same cloud. Usually the process takes place within the cloud and looks like a diffuse brightening or flickering from the outside of the cloud. The flash may even exit the boundary of the cloud and a bright channel, similar to a cloud-to-ground flash, can be visible for many miles.

The ratio of cloud-to-ground and intra-cloud lightning can vary significantly from storm to storm. Storms with the greatest vertical development may produce intra-cloud lightning almost exclusively. Some suggest that the variations are latitude-dependent, with a greater percentage of cloud-to-ground strikes occurring at higher latitudes, while others suggest that cloud-top height is a more important variable than latitude. Still, the specific details of why a discharge stays within a cloud or comes to Earth are not well understood. Depending upon cloud height above the Earth and changes in electric field strength between cloud and Earth, the discharge stays within the cloud or makes direct contact with the Earth. If the field strength is highest in the lower regions of the cloud, a downward flash may occur from cloud to Earth.

Inter-cloud lightning, as the name implies, occurs between charge centers in two different clouds with the discharge bridging a gap of clear air between them.

Flashes that do not strike the Earth are called **cloud flashes**. They may be inside a cloud, travel from one part of a cloud to another, or from cloud to air.

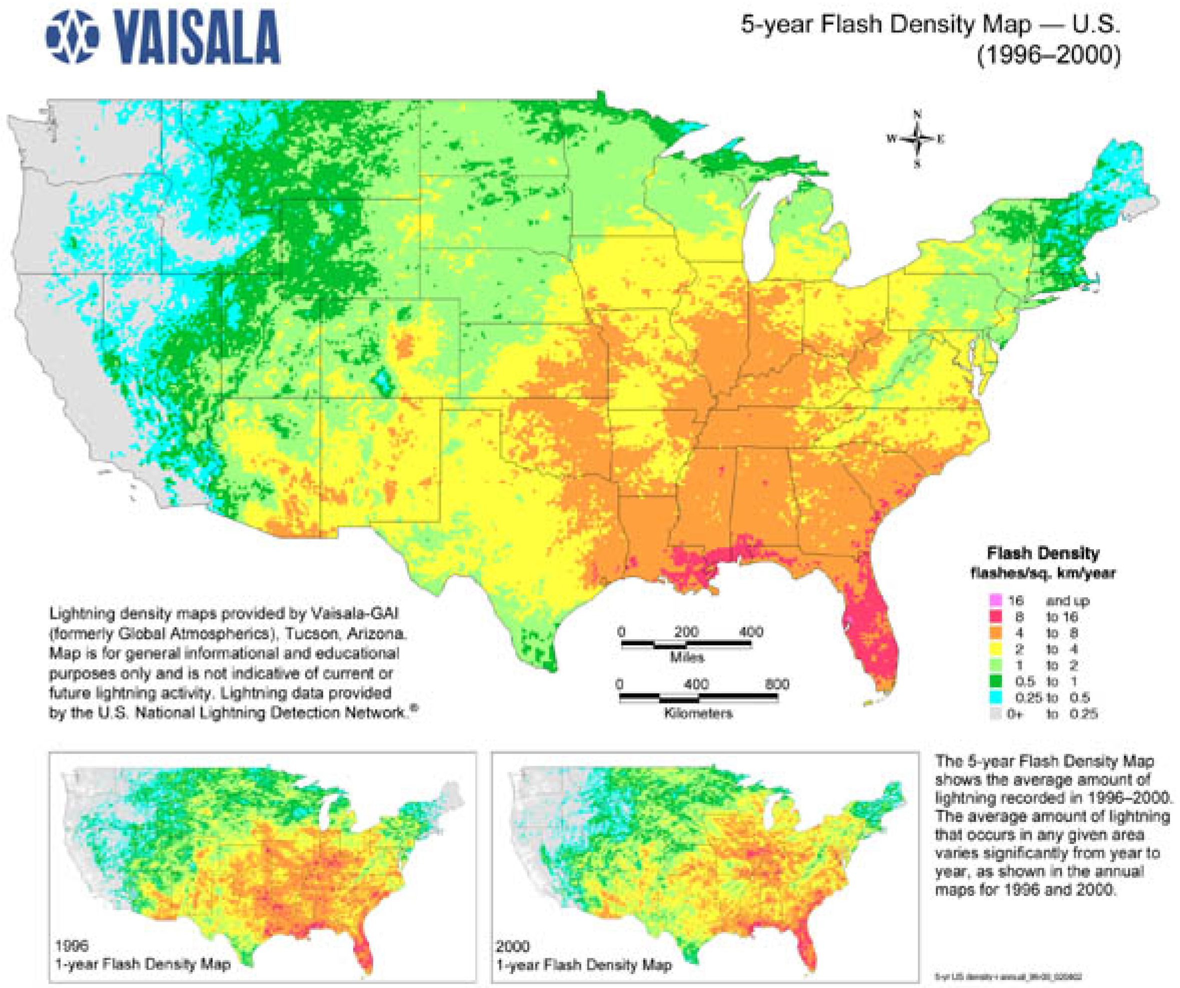
Even with these categories, numerous names and descriptions have been developed for lightning. Some identify subcategories and others may arise from optical illusions, appearances, or myths. Some popular terms include: ball lightning, heat lightning, bead lightning, sheet lightning, silent lightning, black lightning, ribbon lightning, colored lightning, tubular lightning, meandering lightning, cloud-to-air lightning, stratospheric lightning, red sprites, blue jets, and elves.

Thundersnow

Lightning occurs less frequently in the winter because there is not as much instability and moisture in the atmosphere as there is in the summer. Also, without warm surface temperatures, the near-surface air would not rise very far into the upper atmosphere. However, lightning can occur within snowstorms. Called thundersnow, relatively strong instability and abundant moisture may be found above the surface, such as above a warm front, rather than at the surface where it may be below freezing. Thundersnow is sometimes observed downstream of the Great Salt Lake and the Great Lakes during lake-effect snowstorms.

Where does Lightning Strike?

Lightning comes from a parent Cumulonimbus cloud. These thunderstorm clouds are formed wherever there is enough upward motion of air, atmospheric turbulence, and moisture to produce a deep cloud that reaches up to levels somewhat colder than freezing. These conditions are most often achieved during summer. In general, the U.S. mainland has a decreasing amount of lightning toward the northwest. Over the entire year, the highest frequency of cloud-to-ground lightning is in Florida between Tampa and Orlando. This is due to the presence of a large moisture content in the atmosphere at low levels below 1,524 m (5,000 feet), as well as high surface temperatures that produce strong sea breezes along the Florida coasts. The western U.S. mountain ranges produce strong upward motions of air creating atmospheric turbulence that contribute to frequent cloud-to-ground lightning strikes. Also, there are high frequencies of strikes along the Gulf of Mexico coast westward to Texas, the Atlantic coast in the southeast U.S. and inland from the Gulf. Regions along the Pacific west coast have the least cloud-to-ground lightning strikes. Fig. 6. shows a 5-year flash density map for the U.S. (9)



Lightning density maps provided by Vaisala-GAI (formerly Global Atmospherics), Tucson, Arizona. Map is for general informational and educational purposes only and is not indicative of current or future lightning activity. Lightning data provided by the U.S. National Lightning Detection Network.®

The 5-year Flash Density Map shows the average amount of lightning recorded in 1996–2000. The average amount of lightning that occurs in any given area varies significantly from year to year, as shown in the annual maps for 1996 and 2000.

Fig. 6. A 5-year flash density map for the U.S.

LIGHTNING INJURIES AND FATALITIES (9-14)

In the U.S., lightning causes more than $2 billion in damages annually and, on average, results in more fatalities than any other weather event. Over the last 40 years, lightning has been the second largest storm killer, exceeded only by floods. During the last 30 years, an average of 67 deaths per year have occurred in the U.S. from lightning strikes. This is more than the average of 65 deaths per year caused by tornadoes and the average of 16 deaths per year caused by hurricanes. However, because lightning usually claims only one or two victims at a time, and because lightning does not cause the mass destruction left in the wake of tornadoes or hurricanes, it generally receives much less attention than the more destructive weather-related killers. While documented lightning injuries in the U.S. average about 300 per year, undocumented injuries caused by lightning are likely much higher. As of October 6, 2005, there were 33 lightning fatalities in the U.S.

In 2004, there were 32 lightning fatalities, down from 44 in 2003 thanks in part to increased education and safety. The 2004 number falls significantly below the 10-year average of 49 fatalities. For the 6th consecutive year, Florida was hardest hit with 5 fatalities; Georgia also lost

5 citizens to lightning; Texas and Colorado each lost 3 lives to lightning. As in past years, the most dangerous place to be in 2004 was in the open, with 13 deaths or 41%, and under a tree, 6 deaths or 19%. In 2004, as in 2003, almost four times as many men, 26 or 81%, as woman, 6 or 19%, were killed by lightning. The 30-49 age range accounted for 53% of the fatalities with 17 deaths.

Although the risk of being struck by lightning based on an 80-year lifetime is 1:3,000 per exposed individual, and the odds that you will be affected by someone being struck (10 people affected for every one person struck) is 1/300, the best defense is being prepared and taking action with the onset of inclement weather.

There are no government agencies that require the reporting of lightning injuries. Although statistics like these are available, the true incidence and frequency of injuries and fatalities from lightning are still difficult to determine because of failure to seek medical treatment at the time of the injury.

MECHANISMS OF LIGHTNING INJURIES AND FATALITIES (15-16)

Lightning injury may occur by five mechanisms – 1) direct strike, 2) contact, 3) side flash or “splash” (i.e., lightning jumps from its pathway to a nearby person and adopts the person as its pathway), 4) ground current or step voltage (i.e., lightning current spreads radically through the ground), and 5) blunt trauma (i.e., the person is thrown by the opisthotonic contraction) caused by current passing through the body and from the explosive/implosive force caused as the lightning pathway is instantaneously superheated, which is seldom long enough to cause severe burns but does cause rapid expansion of air followed by rapid implosion of the cooled air as it rushes back into the void.

Although farmers used to be the primary victims of lightning, recreation-related injuries are now more frequent. Nine out of 10 people struck by lightning survive the event, but nearly 25% of these survivors suffer long-term psychological or physiological trauma. Furthermore, lightning incidents may involve more than one victim when the current "splashes" to other individuals or, as ground current, spreads the electrical power throughout the area where a group may be sheltered in a storm. Radial horizontal arcing has been measured at least 20 m (66 feet) from the point where lightning came in contact with the ground (8).

Resistance is the tendency of a material to resist the flow of current. The higher the resistance of a tissue to the flow of current, the greater its potential to transform electrical energy to thermal energy at any given current. Bone, tendon, and fat have a very high resistance and tend to heat up and coagulate rather than transmit current. The other tissues of the body are intermediate in resistance. Skin is the primary resistor to the flow of current into the body. Much of the energy may be dissipated at the skin surface, causing significant surface burns in a heavily calloused area, sometimes resulting in less deep internal damage than would be expected if the current were delivered undiminished to the deep tissues. Sweating can decrease the skin's resistance. Immersion in water can reduce this further and thus allow more energy to flow through the body resulting in electrocution with cardiac arrest but no surface burns, such as in a bathtub injury.

Nerves, designed to carry electrical signals, along with muscle and blood vessels, due to their high electrolyte and water content, are good conductors.

Voltage is a measure of potential difference between two points and is determined by the electrical source. In general, longer contact with high voltage current results in the greatest degree of tissue destruction. Although there is an extraordinarily high voltage and **current**, expressed in amperes which is a measure of the amount of energy that flows through an object with lightning, the extremely short duration and the physics of lightning result in a very short flow of current internally. There is little, if any, skin breakdown and almost immediate flashover of current around the body. This usually results in little, if any, burning of tissues. As the tissue breaks down under the energy of the current flow, its resistance may change markedly, making it impossible to predict the amperage for any given injury.

The pathway that a current takes determines the tissues at risk, the type of injury observed, and the degree of conversion of electrical energy to heat. Lightning current may flow internally for an incredibly short time and cause short-circuiting of the body's electrical systems. As current density increases, it eventually flows through tissues indiscriminately, treating the body as a volume conductor, with the potential for irregular destruction of tissue, e.g., areas of normal-appearing tissue next to burned tissue.

Diagnosis, Treatment and Aftereffects

Diagnosing a lightning injury can be very complex since the evidence of a thunderstorm and the incident itself is often not observed directly. Although a burn pattern may be present, obtaining information at the scene may be difficult due to the condition of the patient, e.g., being unconscious, experiencing paralysis, and/or disorientation. There may even be damage to structures that are distant from the apparent contact and ground points of the patient.

In the past, patients with lightning injuries were often treated like occupational high-voltage injuries. However, these injuries are distinctly different. Probably the most important difference between lightning and high-voltage electrical injuries is the duration of exposure to the current. The rapid rise and decay of lightning energy makes predicting lightning injuries even more complicated than predicting man-made electrical injuries. The study of such massive discharges of such short duration is not well advanced, particularly with regard to effects on the human body. Lightning injuries tend to cause few external or internal burns, little tissue loss, and rarely causes myoglobinuria, but may certainly result in permanent functional impairment. Treatment for lightning patients is based primarily on routine common-sense assessment of their presenting injuries with attention and follow-up for the long-term issues, such as pain and cognitive dysfunction, without requiring massive fluid resuscitation or large repeated debridements. Occupational high-voltage injuries tend to cause deep internal injuries, myoglobinurea renal failure, shock and massive loss of tissue and function.

Therefore, once the accident scene is controlled, a quick initial assessment of the patient needs to be performed with attention to the airway, breathing, and circulation. Cardiac monitoring is essential and, if the patient is in cardiac arrest, standard advanced life support protocols should be initiated. Primarily, the major cause of death in lightning injuries is cardiac arrest. Current passing through the heart or thorax can cause cardiac arrhythmias and direct myocardial damage. Although automaticity may lead to the heart restarting on its own, the respiratory arrest, which often lasts longer than the cardiac arrest, may cause secondary deterioration of the rhythm to ventricular fibrillation from hypoxia and asystole. This condition is more resistant to therapy than the first cardiac arrest. If the patient is properly ventilated during the time between the two arrests, the second arrest can possibly be avoided, thus saving the patient. Current passing through the brain can result in respiratory arrest seizures, direct brain injury, and paralysis. Hypothermia should also be assessed if the patient is soaked with rainwater from the passing storm.

Predicting the impairment of a patient after surviving a lightning strike is imprecise. Some patients have returned to premorbid status (i.e., before the present illness or condition) while others will continue to experience persistent impairments. This dilemma of etiologic specificity is illustrated in Table I. Questionnaires consisting of more than 70 "yes/no" items about symptom occurrence were collected retrospectively from 100 lightning strike survivors and 65 electric shock survivors two or more years after the event (mean interval, 4.5 years). The information reveals a wide range of symptoms, suggesting diffuse, nonspecific neurobehavioral dysfunction and varying degrees of potential debilitation. In both sample groups, nearly all of the most frequently reported complaints may be psychologic in nature or often reflect a psychologic component. Five of the top 10 symptoms for both groups are classic symptoms of depression. The asterisk (*) identifies the 10 most common symptoms for each sample group. Symptoms in *italics* are most likely to have an organic basis (i.e., secondary effects). Etiology for other symptoms may be organic, psychologic or both.

Table I: Frequencies of Common Aftereffects Reported by 65 Electrical Injury and 100 Lightning Injury Survivors

Symptom	Electrical Injury Sample (%)	Lightning Injury Sample (%)
Neurobehavioral		
Sleep disturbance	74*	44*
Memory deficit	71*	52*
Attention deficit	68*	41*
Headaches	65*	30
Irritability	60*	34*
Inability to cope	60*	29
Dizziness	48	38*
Easily fatigued	48	38*
Sensory		
Numbness	63*	36*
Paresthesias (Tingling, numbness, burning sensation)	60*	40*
Photophobia (Eye discomfort in bright light)	46	34*
Emotional		
Depression	63*	32
Other		
Muscle spasms	63*	34
Stiff joints	48	35*

HOW WEATHER AFFECTS OUTDOOR WASTE MANAGEMENT ACTIVITIES

The time-tested method for estimating the distance from a lightning storm is called the *flash-to-bang method*. This method consists of counting the time in seconds between seeing (i.e., visual verification) the lightning and then hearing (i.e., audible verification) the “clap” of thunder. For every five seconds, lightning is approximately 1.6 km (one mile) away. For 10 seconds, the lightning would be 3.2 km (two miles) away. Depending on the storm, lightning can strike as far as 16 km (10 miles) away from the rain area in the thunderstorm.

Since WESKEM, LLC waste management activities are conducted outdoors throughout the year (17), it is important to perform a daily check of the weather. The Activity Hazard Analysis process includes identifying and mitigating hazards associated with inclement weather, specifically on lightning (18). Fig. 7. shows clouds associated with a potential lightning storm developing in the distance.

Fig. 7. Clouds associated with a potential lightning storm developing in the distance

It is apparent that the abundance of weather-forecasting resources has never been greater. The local weather and extended forecasts can be accessed from a variety of generic weather web pages via the World Wide Web (WWW) by simply typing in the local 4-digit Zone Improvement Plan (ZIP) Code. Table II provides an example of the type of information that can be obtained from these web pages.

Table II: Generic Weather Web Page Information Available on the WWW

Current, high and low temperatures
Dew point and heat index
Hour-by-hour, five-day and 10-day forecasts
Barometric pressure, humidity and chance of precipitation
Wind speed
Visibility
Sunrise and sunset

Having online access to the national weather services, radar and satellite images and other free outlets is a very good start (19-23). However, using satellite images to predict the travel path of inclement weather may neither be available in "real time" nor provide adequate resolution to determine a storm's exact location relative to the site (i.e., you can only zoom in so far on a satellite image or map). For all field personnel, and even members of the local community, the main concern is to provide the best weather information possible so that everyone can respond appropriately to severe weather conditions in the immediate vicinity.

If a daily weather report and radar check indicated a storm was expected to move into the area, the practice was to assign a dedicated employee to survey the sky for a lightning strike. If a strike was observed in the distance, a 30-minute shutdown process was started. Although the storm’s direction could be estimated based on checking a generic weather web page, this method was not always accurate. Furthermore, since lightning can strike as far as 16 km (10 miles) away from the rain area in the thunderstorm, having the work area fall within the “lightning strike zone” did not provide an adequate safety margin for the field employees.

LIGHTNING DETECTION SYSTEM

Although the Leyden jar was viewed as a scientific marvel, today, the application of modern technology provides WESKEM, LLC a better understanding of the weather, and thus protect its field employees, and minimize unnecessary project delays. Furthermore, this modern technology does not have to be either costly or elaborate. WESKEM, LLC selected the Boltek StormTracker Lightning Detection System, with the Aninoquisi Lightning 2000^{TM} software (24, 25). Fig. 8. shows the lightning detection antenna of the StormTracker system installed on a building used to support WESKEM, LLC outdoor field activities.

Fig. 8. Lightning detection antenna of the StormTracker system

The system and software are add-ons to any existing project desktop computer and can be connected through a company’s intranet to multiple PCs throughout the site. Although the system does not detect precipitation, it does allow WESKEM, LLCs’ Environmental, Safety and Health (ES&H) personnel to monitor the first lightning strike of a developing storm through the last strike from a decaying storm.

Boltek's StormTracker system uses state-of-the-art technology to make real-time lightning detection affordable (<$700 for the entire package) and a direction-finding antenna to receive and locate the radio signals produced by lightning. These are the same signals, often heard in the form of static, that are transmitted through an AM radio during a thunderstorm. StormTracker, in connection with the Lightning/2000™ system, detects cloud-to-cloud, cloud-to-ground, positive, and negative lightning strikes up to a 483-km (300-mile) radius around the Paducah, Kentucky area. Additionally, two special stroke types, the "intercloud discharge" and the "stepped leader", are detected from nearby storms. Intense storms are capable of being detected over 966 km (600 miles) away, but are dependent on the intensity of the storm and the kind of terrain between the detector and the storm. The storm's actual distance is calculated from signal strength. Special software reduces the effects of strike-to-strike energy variations providing accurate distance information.

The combination of direction and distance allows the strike to be plotted onto a radar-like screen, with the receiver location being the center of the screen with distance increasing outwards from the center. Fig. 9. shows a typical PC display of the StormTracker information. The storm is highlighted in real time on a map based on latitude and longitude of the Paducah/Kevil, Kentucky area. Lighting strikes (e.g., cloud-to-ground) and storm activity are differentiated and marked as they occur within 5-to-20 minute periods and are color coded according to their intensities. Shaded wedges indicate storms having a majority of positive cloud-to-ground strokes.

Fig. 9. PC screen display of StormTracker information

Fig. 10. shows the “zoom feature” allowing the user to isolate localized areas.

Fig. 10. PC screen display of zoom capability

Fig. 11. shows the early warning and threat assessment notifications of approaching storms. The ***Close*** *Storm Alarm* will activate a “yellow alert” for storms at 40 km (25 miles) identified by the yellow-colored ring, and a “red alert” for storms at 16 km (10 miles) identified by the red-colored ring. The ***Severe*** *Storm Alarm* activates if the number of lightning strikes per minute exceeds a preset limit.

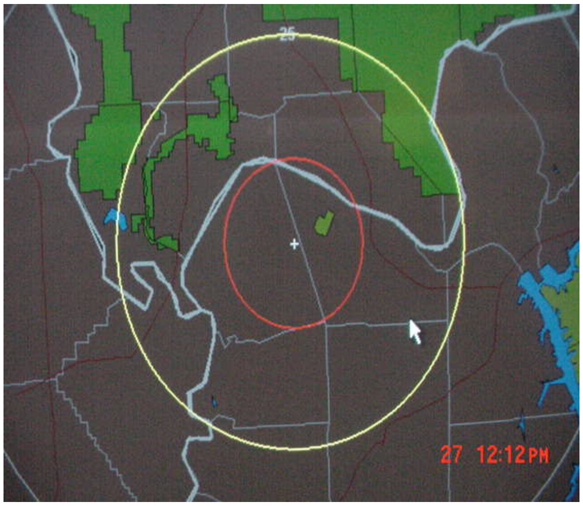


Fig. 11. Color-coded threat assessment boundaries

Fig. 12. shows the storms that are traveling in the same direction for longer than 1 minute and are color coded by intensity.

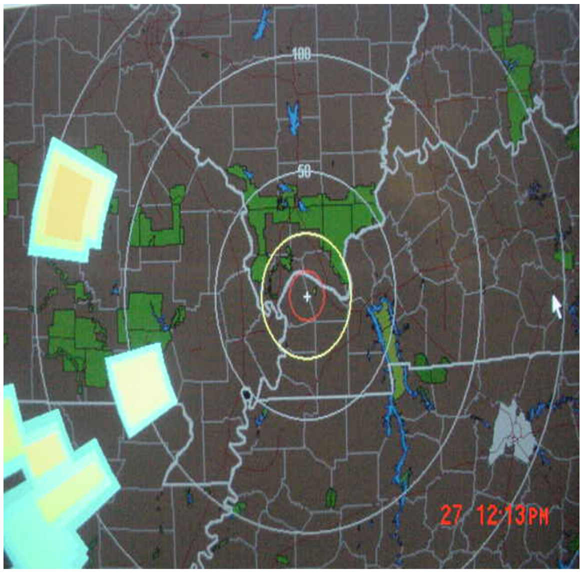


Fig. 12. Color-coded storms traveling in the same direction for longer than one minute

StormTracker keeps received data on the computer's hard drive. This allows the ES&H personnel to replay the previous few hours of storm activity in accelerated time. This feature provides continuous looping of the data from a user-selected starting point through current time. Watching historical data in accelerated time highlights the direction of the current storm. Compared to the previous *flash-to-bang method*, field employees do not have to guess if the storm is heading in their direction. The ES&H personnel can see instantly the storm's location and direction relative to the project site and take appropriate action.

APPLICATION TO THE SURROUNDING COMMUNITY

The Heath Youth Athletic Association (HYAA), located next to the Paducah Gaseous Diffusion Plant (PGDP), is a non-profit, charitable organization offering sports programs for the youth and young adults in the local community and proudly supports the local recreational T-ball (4-6 years old), baseball (boys, 7-14 years old), and fast-pitch softball (girls, 7-14 years) teams. The program's aim is to provide education and instruction in the fundamentals of baseball and softball (26).

As shown in Fig. 13., the HYAA sports complex is designed for hosting concurrent day-or-night games that are played on any one of the three main baseball/softball fields.

Fig. 13. A typical day at the HYAA sports complex

The complex also includes a T-ball field, a practice field, batting cages, a nearby tennis court, community center, parking lots, and a concession stand that sells excellent hot dogs and Gator-Aid®. Over 200 people, consisting of organizers, umpires, grounds keepers, parents, players, children and infants from the Western Kentucky area, are typically on hand to watch baseball and/or softball games played on weekday evenings. Day-and-night weekend tournament games can usually attract crowds of over 400 people, both locally and from the bordering states – Illinois, Missouri and Tennessee. The sudden onset of a storm developing without any prior visual (e.g., lightning) or audible (e.g., thunder) warnings would create a very unsafe and dangerous situation.

A member of the HYAA board of directors, also employed by WESKEM, LLC, was working on a project that was using the StormTracker system. Taking a proactive approach, the employee received approval from the HYAA to purchase a hand-held model, the SkyScan P5 Portable Lightning Detector, to be used at the sports complex. This hand-held unit detects electromagnetic emissions from individual lightning strokes within a 64 km (40 mile) radius and in all directions as storms travel either toward or away from the area. The detector reports the level of activity of lightning in a storm and emits an audible warning tone each time it detects a lightning stroke. The distance of each stroke is registered on its range indicator. The indicator reports distances of 0-4.8 km (0-3 miles), 4.8-12.9 km (3-8 miles), 12.9-32 km (8-20 miles) and 32-64 km (20-40 miles). Each detection of a lightning stroke stays lit for approximately 3 seconds, allowing the user to see the distance of that stroke, and then compare it to the closest detected stroke which is retained in the memory for 15 seconds (27).

The hand-held model was put to immediate use when it detected a storm approaching the area prior to any significant visual or audible warnings, as shown in Fig. 14.

Fig. 14. Quiet before the storm

The organizers were able to stop the games and close down the complex so the attendees could return to their vehicles and drive home in an orderly manner before the first raindrops fell.

The HYAA's goal is to instill a sense of teamwork and sportsmanship in the lives of the local youth. This goal of teamwork and sportsmanship was clearly displayed based on the exchange of information between WESKEM, LLC and the HYAA regarding the purchase and use of the hand-held model. Both fixed and hand-held systems are designed to enhance employee safety associated with field activities, but moreover, have contributed significantly to the overall safety of the general public participating in local community activities at the HYAA's sports complex.

CONCLUSION – THE ONLY THING PREDICTABLE ABOUT THE WEATHER IS THAT WEATHER IS NOT PREDICTABLE

Based on this successful application involving WESKEM, LLC and the local community, information obtained from online weather web pages used in concert with the real-time fixed and hand-held detection systems takes the guesswork out of making decisions to "stop work" or resume outdoor activities. This combination accounts for local geographical and topographical conditions, as compared to relying on a competent weather forecaster that may actually be reporting the weather 3,219 km (2,000 miles) away or relying on a web page weather map. Since the installation of this system, WESKEM, LLC's ES&H personnel can respond to inclement weather conditions in real time. This ensures the safety of their field employees and maintains project efficiencies by minimizing mobilization/demobilization downtime from false alarms. Furthermore, there are subsequent benefits to WESKEM, LLC employees during off-work hours and to the local community when similar technologies, such as the Sky Scan Lightning/Storm Detector Model P5 having a 64-km (40-mile) range, are used to monitor severe weather approaching the HYAA sports complex. Fortunately, a lightning strike event (e.g., injury or fatality) has never occurred on a WESKEM Paducah project or an HYAA-sponsored event. Using these fixed and hand-held systems will continue to prevent such injuries from occurring in the foreseeable future.

However, in addition to relying on just technology, it is just as important to educate employees and community representatives on the conditions required to create lighting and thunder, the mechanisms of lighting injuries and fatalities, as well as diagnosis, treatment and aftereffects. In the event that local support agencies (e.g., medical and rehabilitation facilities) are called upon as a result of a lightning strike, both employees and community representatives will know how to respond in the interim, potentially reducing the severity of the injury of a lightning strike patient.

The primary cause of death from a lightning strike is from cardiac arrest. Seizures or severe brain damage from hypoxia during cardiac arrest, spinal artery syndrome, and vascular spasms are indirect results of a lightning injury. Therapy involves cardiac resuscitation for those seriously injured and supportive care for those less severely injured. For example, burns, if any, tend to be superficial, and injuries are what one would expect from short-circuiting or overloading the body's electrical systems (e.g., tinnitus, blindness, confusion, amnesia, cardiac arrhythmias, and vascular instability). The neuropsychologic deficits tend to be nonspecific and resemble those of traumatic brain injury. While disturbances of language, awareness, or visuospatial functions seem to be rare, impairments of attention, concentration, verbal memory, and new learning are frequently identified. Survivors may thus experience a reduced capacity to function, both occupationally and socially, and may complain of forgetfulness, inefficiency, and inability to handle even mildly stressful situations. These new obstacles and sense of loss may contribute to psychologic disorders, which in turn affect cognition.

Although behavioral effects have been described in numerous case reports, research on predicting what the combination or duration of behavioral sequelae will be among lightning strike survivors has been relatively scant and subject to a number of shortcomings. However, as these shortcomings are remedied, knowledge of the prevalence and nature of morbidity will permit more effective clinical care. Nevertheless, collective medical experience suggests that the first 12 months following injury are crucial in the recovery process, with the most substantial gains being observed during that time. Subsequent recovery is possible up to 36 months post injury which eventually plateaus. Patients that fail to recover from the initial effects, even after three months of rehabilitation, are at risk for long-term sequelae and disability. Evaluation will be interdisciplinary consisting of psychotherapy, pharmacotherapy, and neuropsychologic intervention.

REFERENCES

1. “History and Mystery of Lightning”. National Oceanic and Atmospheric Administration's National Weather Service (NOAA-NWS), Silver Spring, MD. <http://www.lightningsafety.noaa.gov/myths.htm>.
2. “Leyden Jar”. Wikipedia, The Free Encyclopedia. <http://en.wikipedia.org/wiki/Leyden_jar>.
3. Electrochemical and Electronic Instruments. <http://chem.ch.huji.ac.il/~eugeniik/instruments/>.

4. "C.T.R. Wilson–Biography". Nobelprize.org. <http://nobelprize.org/physics/laureates/1927/wilson-bio.html>.
5. "A Lightning Primer from the GHCC". Global Hydrology and Climate Center (GHCC), Huntsville, AL. <http://thunder.msfc.nasa.gov/primer/index.html>.
6. "Lightning Safety". National Oceanic and Atmospheric Administration's National Weather Service (NOAA-NWS), Silver Spring, MD. <http://www.lightningsafety.noaa.gov/science.htm>.
7. "Questions and Answers about Lightning". National Severe Storms Laboratory. <http://www.nssl.noaa.gov/edu/ltg>.
8. "Little Known Lightning Facts". National Oceanic and Atmospheric Administration's National Weather Service (NOAA-NWS), Silver Spring, MD. <http://www.lightningsafety.noaa.gov/little_known_facts.htm>.
9. "5-Year Flash Density Map – U.S. (1996-2000)". National Oceanic and Atmospheric Administration's National Weather Service (NOAA-NWS), Silver Spring, MD. <http://www.lightningsafety.noaa.gov/lightning_map.htm>.
10. "Lightning Safety – Fact Sheets and Publications". National Oceanic and Atmospheric Administration's National Weather Service (NOAA-NWS), Silver Spring, MD. <http://www.lightningsafety.noaa.gov/more.htm>.
11. "Lightning – The Underrated Killer". National Oceanic and Atmospheric Administration's National Weather Service (NOAA-NWS), Silver Spring, MD. <http://www.lightningsafety.noaa.gov/overview.htm>.
12. "2004 Lightning Fatalities". National Oceanic and Atmospheric Administration's National Weather Service (NOAA-NWS), Silver Spring, MD. <http://www.nws.noaa.gov/om/severe_weather/light04.pdf>.
13. "Lightning Kills, Play It Safe". National Oceanic and Atmospheric Administration's National Weather Service (NOAA-NWS), Silver Spring, MD. <http://www.lightningsafety.noaa.gov/>.
14. "Medical Aspects of Lightning – Odds of Becoming a Lightning Victim". National Oceanic and Atmospheric Administration's National Weather Service (NOAA-NWS), Silver Spring, MD. <http://www.lightningsafety.noaa.gov/medical.htm>.
15. M.A. Cooper, "Emergent Care of Lightning and Electrical Injuries". Seminars in Neurology, 15(3), September 1995. <http://www.uic.edu/labs/lightninginjury/treatment.html>.
16. M. Primeau, G.H. Engelstatter, K.K. Bares, "Behavioral Consequences of Lightning and Electrical Injury". Seminars in Neurology, 15(3), September 1995. <http://www.uic.edu/labs/lightninginjury/psycho.html>.
17. D.D. Watson, J. Eyman, and J.M. Hylko, "Changing the Landscape - Low Tech Solutions to the Paducah Scrap Metal Removal Project are Providing Safe, Cost Effective Remediation of Contaminated Scrap Yards". Waste Management '03, Tucson, AZ. February 25, 2003.

18. T.T. Potts, J.M. Hylko, and T.A. Douglas, "An Interactive Database Tool for Applying Integrated Safety Management in a Streamlined and Consistent Manner". Presented at the 9th International Conference on Environmental Remediation and Radioactive Waste Management (ICEM '03), Examination Schools, Oxford, England. September 23, 2003.
19. Memphis, Tennessee Radar Loop by Intellicast, <http://www.intellicast.com/Local/USLocalWide.asp?loc=kmem&seg=LocalWeather&prodgrp=RadarImagery&product=RadarLoop&prodnav=none>.
20. Paducah Weather Forecasts on Yahoo! Weather, <http://weather.yahoo.com/forecast/USKY1215.html>.
21. Weather.com – Local Weather Page (ZIP: 42001), <http://www.weather.com/weather/local/42001?lswe=42001&lwsa=WeatherLocalUndeclared&from=whatwhere>.
22. Weather Underground: Nexrad Mixed Composite Radar Map, <http://www.wunderground.com/radar/mixedcomposite.asp?region=c4&size=2x&type=loop>.
23. WPSD Regional 3-D radar, <http://cache1.intelliweather.net/imagery/WPSD/3drad_reg_640x480_img.htm>.
24. Boltek's StormTracker Lightning Detection System, <http://www.boltek.com/stracker.htm>.
25. Aninoquisi Lightning 2000™ software, <http://www.aninoquisi.com/lightning2000.htm>.
26. Heath Youth Athletic Association (HYAA), <http://www.heathyouthaa.com/>.
27. SkyScan Portable Lightning Detector, <http://www.skyscancanada.com/P5main.html>.

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