LIGHTNING STRIKE REPORT -
ESCANABA GENERATING PLANT AND DISTRIBUTION SYSTEM
MAY 14, 2007, AND AUGUST 28, 2007

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Prepared and Submitted by:
Michael A. Furmanski
Electric Superintendent
City of Escanaba
December 7, 2007

BACKGROUND OF EVENTS

May 14, 2007 LIGHTNING STRIKE

On May 14, 2007 at 1:19:44 am the #1 generator was damaged by a lightning strike hitting on or near the plant. The generator shut itself down and the plant operators were able to get the boiler backed down under control and shut down. A short time later, they noticed a fire under the #1 generator. When the operators tried to call Escanaba Public Safety, they discovered that the phone landlines were not operational. One of the operators used a cell phone to call Escanaba Public Safety while the other operators started to work on extinguishing the fire. An Escanaba Public Safety Patrolman was the first responder to the incident. Upon arrival to the Generating Station, the officer observed the security gate was disabled as its controls had also been damaged by the lightning strike. Prior to the Escanaba Public Safety Fire Truck arrived on scene, the operators were successful in extinguishing the fire. Station support staff arrived a short time later and manually opened the gate. The #2 generator stayed on line and did not show any signs of damage from the lightning strike.

Later that same day, a piece of an antenna was found lying on the ground near the plant. Further investigation found a damaged antenna on the top of the plant, near the bucket elevator housing. This antenna was approximately 20' long and was made up of sections of copper tubing with the sections all soldered together on the inside of the antenna with a fiberglass outer shell. The antenna was removed and disassembled by plant personnel. During disassembly, it was discovered that every solder joint had been burned clear. It was agreed on by all personnel that this was most likely the point of entry for the strike.

Within the first few days of the investigation, a burn mark was found on a piece of copper bus bar in the plant substation. This piece of bus bar was in the circuit that came from the #1 generator and terminated at the substation main bus. In looking at the burn mark, there was patina around the mark, suggesting that the mark had been there for some time. It was agreed on that this was a possible entry point, but not as likely due to the mark appearing to be somewhat aged.

On May 15, AIMS, Inc of Milwaukee, WI was brought on-site to assess the damage to the #1 generator. They found a dead short on the B phase and a partial short on the C phase. The generator's rotor was removed on May 22, 2007 and damaged turns were found in the stator. Attachment #1 is a picture of the damaged turns.

Requests for Proposals to repair the turns in the stator of #1 generator were sent to various repair shops a within days of May 22, 2007. Included in the scope of work was an order to rebuild or repair the rotor, which had had some shorted turns for a few years. The rotor's condition did not require immediate attention prior to the lightning strike and had been operating that way for quite some time. City staff along with the Plant Operator decided then that rotor repairs should be made in conjunction with the stator repairs so as to maximize down time repair opportunities.

Upon receipt of the Requests for Proposals, the Plant Operator and City Staff recommended the repair bid be awarded to ReGENco of Milwaukee, WI to repair both the rotor and the stator. The stator repair work totaled $703,804.86 and the rotor repair work totaled $250,176.30. There were some miscellaneous repairs that totaled $23,308.39. The total of all the repair work was $977,289.55. It is important to note that the $250,176.30 for the rotor repair should not be attributed to the lightning strike of May 14, 2007 as this was a good opportunity to have this work done.

The generator was reassembled and was placed back into service on August 20, 2007. Over the next 24 hours, generator #1 had to be taken out of service so that balancing shots could be added. Generator #1 was put back in service on August 21, 2007.

August 28, 2007 LIGHTNING STRIKE

On August 28, 2007, early morning thunderstorms caused power outages throughout the area. At 4:52:03am, both generators tripped at the plant, both transmission lines feeding into Escanaba from the Delta Sub tripped at the Delta Sub end and at the power plant substation end, leaving Escanaba without power. The #1 line was closed at 4:57:17am at the Delta Sub end. The #2 line was closed at 5:01:11am at the Delta Sub end. With the #2 line closed, the City's West Side Substation was energized. The plant was without power until 5:02:03am, when both of the transmission lines were closed at the power plant substation end. This energized the power plant substation and the plant. The #1 generator was brought back on line at 5:05am, but there were control problems with the unit so it was shut down at 5:13am. These problems were fixed and the #1 generator was put back into service at 9:00am. The #2 generator suffered a failed rupture disk which was replaced and the unit was put back in service at 10:50am.

Later in the evening of August 28, 2007, more severe storms moved through the area. I was contacted around 7:00 and informed that the entire City was without power. On my way into the office, I contacted the plant control room and was told the American Transmission Company (ATC) was experiencing system problems. Both transmission lines, both steam units, and the combustion turbine were all down. Three (3) City Linemen had been called out and were at the Electric Department when I arrived. Believing it to be an ATC problem, there wasn't much we could do, so the linemen ran the transmission lines looking for any problems. No problems were found and eventually the transmission lines were closed by ATC and the plant was brought back on line.

On August 29, there was a current imbalance identified on the #2 transmission line. Plant personnel were dispatched to look for problems in the power plant sub. All 6 bushing insulators on OCB 461 (the #2 line), along with the six (6) switches feeding into and out of OCB 461 were found to be broken and in very bad condition. These switches appeared to have been struck directly by lightning. This was verified by an eyewitness who saw lightning strike in the power plant substation and the plant go black early in the morning on August 28, 2007. Attachment #2 shows one of the damaged switches. It was decided to shut the #2 line down. City linemen opened switch #574 which is located near the Danforth Rd/Landfill Rd intersection. When this switch was opened, a very noticeable, sustained buzzing came from a switch located near OCB 461. UPPCO substation personnel were called in to do a thermal scan of this area. The arcing switch was not any hotter than the surrounding equipment. The 6 switches and OCB 461 were taken out of service on September 2. Three (3) new switches were installed during this outage.

On September 5, 2007, the #2 transformer was tested and found to be in good condition. Because of that, the #2 transmission line was energized and fed through the transfer breaker onto the transfer bus which was tied to the main bus to help carry the load.

In early November, the bushings for OCB 461 were replaced as well as the other 3 switches. Another shut down was required to tie OCB 461 back into the #2 transformer. This shutdown occurred on December 1 which put things back to normal with both transmission lines feeding into the main bus at the power plant sub.

LIGHTNING ANALYSIS – CAUSE AND FUTURE PROTECTION

After the lightning strike of May 14, City Staff contacted several lightning experts to determine the root cause of the strike and make recommendations to minimize our exposure to another strike. City Staff was referred to Mr. John Kuth of Marquette, MI. Staff spoke with Mr. Kuth, but determined that he did not have the desired education and background necessary for this type of study. Staff was then referred to Lightning Eliminators and Consultants (LEC) of Boulder, Colorado. They sent 2 representatives to Escanaba and they met with Plant and City Staff. They toured the plant, took ground resistance readings, took measurements, and took photos. City Staff checked on some of the references they provided and they came back favorable. In further researching LEC, Plant Superintendent Jerry Pirkola provided City Staff with an IEEE paper that disputed much of what LEC proposed. City Staff was suspicious of LEC findings due to the fact that the company specializes in the sale of product. Sensing a potential conflict of interest, City Staff felt LEC was not the best choice. City Staff was then referred to National Lightning Safety Institute (NLSI) of Louisville, Colorado. References were checked with positive results. The City of Escanaba hired NLSI to determine the root cause of the damage to the facility as well as provide recommendations to improve our lightning protection. By the time NLSI was contracted with, the power plant sub had been hit by lightning, so the substation was included in their scope of work.

Mr. Richard Kithil of NLSI was on site October 29-31. His written report is included as attachment #3. Included in his report are many recommendations on improving the plant lightning protection system using various pieces of equipment. He also made a number of recommendations for improving the lightning protection at both of the city substations. All of these recommendations will be looked at from a cost/benefit standpoint to prioritize them and complete them in a timely manner through the departmental Capital Improvement Program.

Mr. Richard Kithil's expert opinion of what occurred can be found in his written report. In summary, it is believed that the antenna on the roof of the plant was the point of entry for the lightning strike. Mr. Kithil does not believe that the antenna caused the event or that the event would have been avoided had the antenna not been there. Lightning is a random occurrence and basically the plant's number was up and lightning was going to hit there. Had the antenna not been there, the strike would have still occurred, just through a different point of entry. There are a number of steel exhaust pipes near the antenna's location that would have likely served as a point of entry. Once the strike contacted the antenna, the current followed the building's steel columns. This current continued down searching for a path to ground and got into the station grounding grid. Once the current was on the grounding grid, the ground potential was elevated, which initiated the sequence of events that led to the generator failure. It should be noted that most strikes (96%) are negative polarity, average 25,000 amps of current, with a duration of about 150 ms. The strike that hit the Escanaba Generating Station was a positive strike with 77,000 amps of current. We do not have an exact duration for this particular strike, but most positive strikes have a duration of 400 – 500 ms. Being that the current magnitude is much higher and is there for a much longer time, positive strikes cause considerably more damage than negative strikes.

ReGENco also supplied an explanation of what they found in the damaged generator. Their report is included as attachment #4.

CONCLUSION

Obviously, these lightning strikes caused many problems for the City of Escanaba. The strikes themselves caused damages to physical assets owned by the City. With the temporary loss of these assets, the City was forced to buy power from May 14 – August 21. Buying power during the summer is quite expensive as the electrical demand peaks typically occur during the summer. The monetary damages are found in attachment #5. Beyond the monetary damages, the plant personnel were put in a dangerous situation while putting the fire out with no way for additional help to get to them.

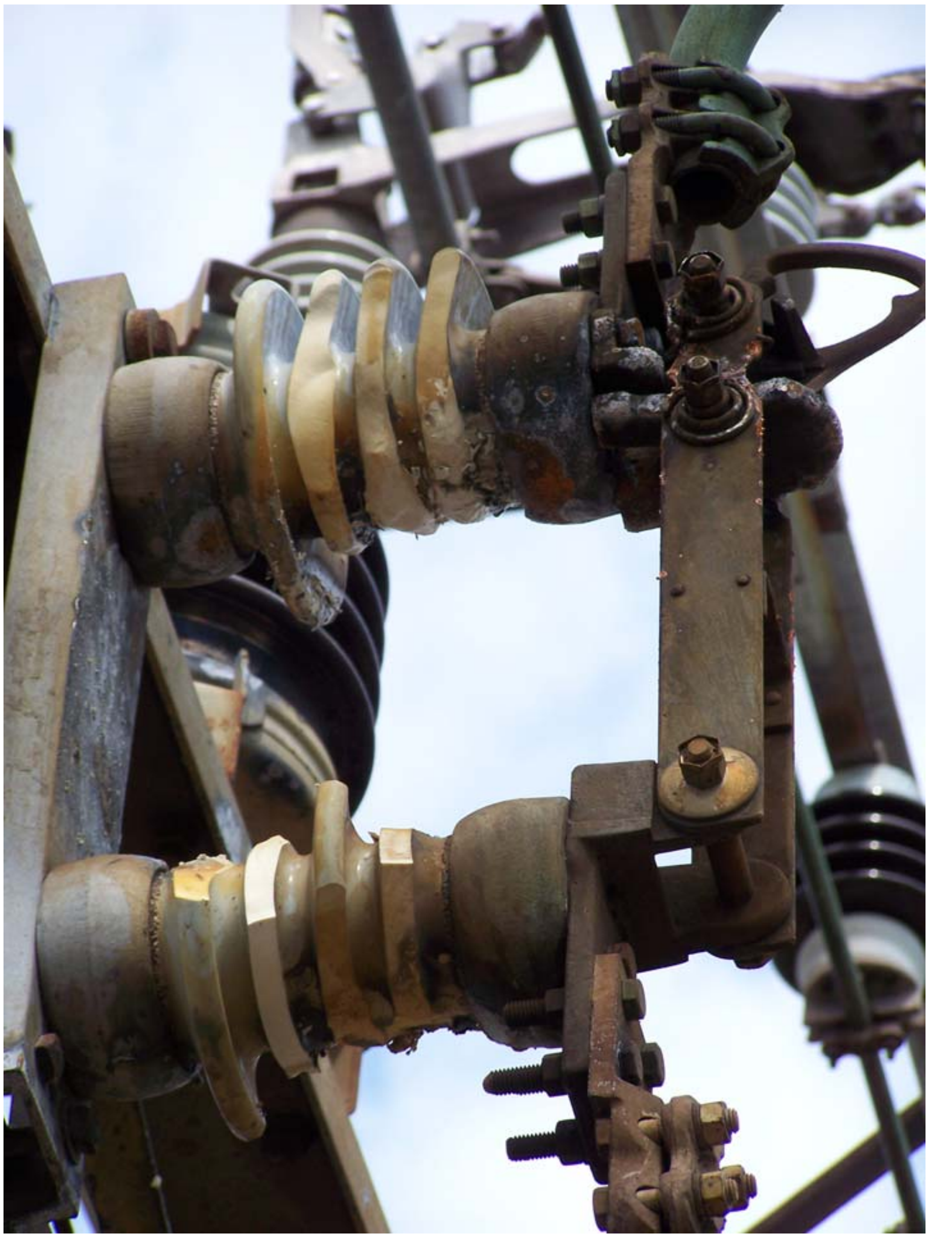
Benefits that can be taken away from these events include: 1) the stator on the #1 generator was rewound, which will serve the community for many years. 2) The rotor on the #1 generator was repaired without causing additional down time. 3) These events also triggered us to review our lightning protection system for the generating station as well as the distribution system. By taking the steps recommended by NLSI, we will lessen our chances for damage from another strike, which may have caused even more damage. 4) Emergency response procedures have been fine tuned and implemented throughout the plant. 5) Communication protocol has been improved. The outage of August 28 lasted much longer than it should have and with new procedures in place, future transmission outages will be addressed much quicker.

Respectfully Submitted,

Michael A. Furmanski
Electrical Superintendent
City of Escanaba

Attachment #1 – photo showing burnt windings on #1 generator stator

Attachment #2 – Switch damaged from the August 28, 2007 lightning strike



ReGENco's report and supplemental explanation from NLSI, as prepared by Gerald Pirkola.

December 3, 2007

Mike Furmanski
Electrical Superintendent
City of Escanaba
1711 Sheridan Road
Escanaba, MI 49829

Subject: Unit 1 Generator Winding Damage from Lightning Strike

Dear Mr. Furmanski:

We received an explanation from ReGENco as to what happened in Unit 1 Generator. This is a very good explanation but doesn't really explain why it happened. Remember that ReGENco is a Generator & Turbine repair company and not a lightning consultant. Here is ReGENco's response.

> "The failure occurred in slot 12, top coil half. The coil failure was at the TE core end. This coil is the B1 main phase coil (this unit has two parallel circuits). The observed damage is indicative of a turn failure. The coil has five turns (see attached photo). As the turn insulation fails current is routed through the shorted area cause severe overheating. As each turns fails it causes damage to the adjacent turn insulation creating a "cascading effect" of turn failures. The generated heat causes destruction of the ground wall insulation resulting in failure to ground, in this case the stator core.
>
> It is possible that a lighting strike in the yard caused current to feed back into B-phase damaging the turn insulation precipitating into a turn failure in the phase coil leading to severe overheating causing a ground wall insulation failure. Additionally, insulation and shorting damage was observed in the B-phase generator cable between the generator and the phase connection cabinets (see attached photo). This failure was probably simultaneous to the winding failure.
>
> With the available information, this is our best "guess" as to what happened.
>
> Sorry for the delayed response. Things have been extremely busy this outage season. "

With this response, I contacted Richard Kithil from National Lightning Safety Institute (NLSI) and asked for further clarification from a lightning standpoint. Richard contacted one of his generator colleagues and this is his response. The Two main questions I asked are italicized below in Richard's response.

> This stroke was about 3 to 4 times the average stroke experienced in that region. In addition, it was a positive stroke. Positive strokes whether Cloud to Ground (C-G) or Ground to Cloud (G-C) have longer energy transfer duration. This translates into more heat, damage, and a longer ground potential rise than the numerous negative C-G lightning activity we witness the majority of the time. Positive strokes are not only more damaging but they are also harder to protect.
>
> Addressing the questions: *'Could the generator core potential have risen*? And *'Would it have to strike the substation B Phase*? I think the answer to both of these questions is maybe for a couple off reasons.
>
> One, the event is very quick and while relay's react very quickly with respect to 60Hz fault systems that may be too long for the microsecond lightning event. An unknown is whether the relay senses bi-directional events. Ground Potential rises are extremely quick, attempt to distribute widely throughout the site and they disappear just as quickly.   Whether in the substation yard or right next to the plant, ground potential differences are experienced in varying level of magnitudes some distance from the point of the lightning event. One question that I did not ask: Was there a step up transformer in the circuit to the substation bus and did it have high and low side arresters? If it did, this may direct the investigation more to the grounding system as a conduit for the energy transfer. To continue: the voltage developed in the equipment may become high enough to cause internal arcing between internal parts as it tries to equalize. This is where the

damage would more than likely occur. The arcing would not necessarily result in serious damage, but if it breaks down the insulation (air or whatever), the power fault follow through following the arc will complete the damage. Transmission power lines often experience this type of event during lightning storms. In most cases, the only way to prevent a long outage or insulator damage is to interrupt the power, which in turn extinguishes the arc.

Two, a ground reactor is on the neutral. It is quite possible that the ground potential rise developed in the ground system caused the reactor to charge to a higher voltage and then discharge back into the generator. This is a scenario that I do not have any knowledge of happening, but I know that if you place a metallic conductor through a metal conduit with out grounding the conduit to the conductor on both ends, a choke effect occurs during a lightning event and the voltage that exits will be at least two times the input voltage. With a lightning strike with ground potential rises near the stroke exceeding 10 of thousands of volts, this type of event would be disastrous.

Third, in this age of monitoring equipment, you may wish to consider paths via conductors and equipment installed in and near the generator including oil pump feed piping and such that may be grounded near the direct stroke area and thus a path for lightning transients.

In addition, while an earlier event resulted in some cable damage, a lightning stroke of this magnitude would have no problem finding cables located in block wall, direct buried or non-metallic conduit and destroy it. I witnessed lightning triggered stroke tests in Florida where much smaller strokes did just that. In a couple of cases, they traveled over 3 feet deep and 3 feet horizontally to find and destroy a direct buried cable in non-metallic conduit. Where I am going with this is that you may with to consider a megger or hi-pot test on the power system cables (and maybe the transformer) to check for possible latent insulation damage.

Any one of these scenarios could have triggered the internal generator event.

Note that we replaced the burned conductors and performed hi-pot testing on the generator cables that go out to the substation. The hi-pot tests passed satisfactory. Also, a question asked early on in the response, we do not have a step-up transformer in the circuit; we connect directly to the substation.

Both ReGENco's and NLSI's responses discuss how insulation can break down and what happens as a result of the break down. What we know for sure is that the lightning strike that hit the powerhouse on May 14, 2007 was an unusually high magnitude strike (77KA positive). It hit the north side of the powerhouse as evident from the antenna and Unit 1 is on the north side of the building where the unit is grounded. Grounding tests show that the powerhouse grounding grid is in good condition.

Richard recommended surge protection in a number of places to protect sensitive electronic devices. I would also consider lightning surge arrestors on the generator leads where they enter the substation.

Please let me know if you would like any further follow up with ReGENco or NLSI. I look forward to hearing from you.

Thank you,

Gerald Pirkola
Superintendent Regional Generation – South MI
Upper Peninsula Power Company
Escanaba Generating Station
2000 Power Plant Road
PO Box 587
Escanaba, MI 49829

Ccost of the lightning strikes

May 14 Lightning Strike Net Energy Costs

Purchased Energy Costs to Replace Generator One

	Megawatts Purchased	Energy/ Capacity Charges	Unit Cost / Capacity
14-May	4044.5	$307,408.25	**$76.01**
June	5430	$405,783.95	**$74.73**
July	7388.1	$657,128.13	**$88.94**
Aug 20th	4685.9	$387,802.20	**$82.76**
Total	**21,548.50**	**$1,758,122.53**	**$81.59**

Calculated Coal Value Not Bunt and Land Fill Savings

1.68	2006/2007 Average Megawatt per Ton of Coal
12,797.09	Tons of Coal Not Burnt Based on Purchases (Total Megawatts Purchased /Average Mw / Ton)
$75.18	Coal Burn Costs Per Ton for May June July & August
$962,084.91	Total Dollar Value of Coal Not Burnt
$35,895.83	Ash Land Fill Savings(Based on 2006 22% of Coal ends up as Ash(12,797.09*.22)*12.75
$997,980.73	Total Dollar Value of Coal Not Burnt and Land Fill Savings

Net Energy Cost

$1,758,122.53	Total Purchase Cost of Energy and Capacity
$997,980.73	Total Dollar Value of Coal Not Burnt and Land Fill Savings
$760,141.80	Net Difference for Energy Costs Minus Coal and Ash Savings

Generator Work

Generator Stator Work	$703,804.86
Generator Rotor Work	$250,176.30
Miscellaneous Electrical Repairs	$23,308.39
Total All Work to Date	$977,289.55
Less Opportunity Work (Rotor)	($250,176.30)
Total Due to Lightning Strike	**$727,113.25**

Total Net Cost of Lightning Strike To Date

Net Energy	**$760,141.80**

	Repairs	**$727,113.25**
	Total Cost to Date	**$1,487,255.05**

August 28 OCB 461 Outage 1&2 Costs and Estimates

Equipment		**Costs**
Knife Switches (quantity 6)		$8,106
OCB Bushings (quantity 6)		$12,222
Fuses (quantity 5)		$1,820
Voltage Transformer (quantity 1)		$803
Insulators (quantity 4)		$244
	Total	**$23,194**

Labor & Expenses		
UPPCO S&C Labor		$11,000
Energis Service		$14,019
	Total	**$25,019**

Total Equipment & Labor	**$48,213**

Net Power Purchased the day of Aug 28 (On Peak)

Megawatts	Energy Costs	$$ Value Coal Saved	
206.1	$22,860.37	$9,201.83	$13,659

Total Estimated OCB 461 Repair & Net Power Purchase	**$61,872**
Total Cost May 14 & August 28	**$1,549,127.05**
Total CT Profit (Sales+Startup - Fuel+OM) May 14/Aug 19	**$215,215.32**

ESCANABA GENERATING STATION LIGHTNING PROTECTION SURVEY

by Richard Kithil Jr., Founder & CEO
National Lightning Safety Institute (NLSI)
www.lightningsafety.com
November 9, 2007

Escanaba Generating Station Lightning Protection Survey

by Richard Kithil Jr., Founder & CEO
National Lightning Safety Institute (NLSI)
www.lightningsafety.com
November 9, 2007

1.0 Executive Summary

1.1 The lightning strike damage to Escanaba Generating Station (EGS) Generator No. 1 would not have been prevented with lightning rods on the roofs or by the absence of the roof-mounted radio antenna. Most of the current traveled vertically on parallel paths to the Motor Control Center (MCC) and the generator location via structural steel beams. Internal arcing at generator windings was a consequence of one of the "paths of least resistance." Other damages resulted from radiated voltages through various vulnerable circuits.

1.2 The strike which damaged switchgear in the T&D Yard happened when strong sequential lightning strokes (three within less than one second) attacked the area. Switches failed due to overloading or overheating or both.

1.3 The physical plant is more than 50 years old. During that time, IEEE codes and recommended practices have been revised.

1.3.1 Surge protection devices (SPDs) at critical controls and at branch panels should be installed at the generating plant. They were not specified in original designs. Secondary damages in the building could have been contained or reduced with SPD application.

1.3.2 Some areas of the T&D Yard are not shielded/protected with the present overhead shield wires (OSW) configuration. The geometry of OSW at present calls for a maximum 30 degree "shadow" or protective angle. Fifty years ago, a 45 degree OSW design was considered satisfactory.

1.4 This Report contains details to bring lightning protection at the Generating Plant and the T&D Yard up to contemporary standards.

2.0 Overview of Lightning Behavior.

Lightning acts in an erratic, random and unpredictable manner. Its behavior is not fully understood by science. Absolute protection from its effects is not possible. However, it is possible to apply systematic defenses which can be effective to reduce consequential damage. A menu describing such defenses is contained in *Appendix 6.3, Matrix of Lightning Protection Defenses.*

Some generalizations about lightning activity are:

- Each strike is different and unique
- Has an average current 25,000 amps with hundreds of millions of volts
- Has temperatures up to 55,000 degrees F. and travels at 1/3 speed of light
- Is always accompanied by Thunder, which is caused by ruptured air molecules
- Is a RF (radio frequency) event, not AC or DC in behavior
- Has a general frequency range is 3-30 MHZ
- Causes $5-6 Billions in damage to the USA economy each year

A NLSI summary paper containing expanded lightning protection information is in *Appendix 6.4, 21st Century Lightning Safety for Environments Containing Sensitive Electronics, Explosives and Volatile Substances.*

While understanding the exact behavior of lightning remains elusive, there are modern tools to investigate its impact on facilities. The Vaisala Corp. *StrikeNet* is an archived database of past lightning strikes which can be searched to provide clues as to consequential damage for specific strikes. See: https://thunderstorm.vaisala.com We analyzed the *StrikeNet* databases for time periods of the two incidents at EGS and important information was learned about the two lightning events at EGS. Exact strikes were located by *StrikeNet* and were correlated with known times of the two outages. In each case, strikes were unusually strong, containing about three times the typical 25,000 Amps (current).

3.0 Lightning Incident to No. 1 Generator, May 14, 2007 at 1:19:44 AM EGS Clock Time.

3.1 Results of *StrikeNet* Report. A 77kA positive strike was recorded at 1:19:38 AM. It was within a 0.4 mile Circle of Confidence to the building NW corner. (*StrikeNet* reporting is not 100% exact, but for investigation purposes we consider this strike as conclusive due to small differences in reported times.) Positive strikes are of a longer duration - in fractions of a second - than negative strikes. Typically, they are responsible for more damages. See the full *StrikeNet* Report in Appendix 6.1.

3.2 Opinion as the Reasons for Damage.

3.2.1 A unusually strong 77 kA positive lightning event attached first to a roof-mounted antenna pole. Lightning then traveled via building steel columns seeking parallel paths to electrical earth. The nearby motor control center (MCC) was affected as were many downstream circuits. Generator windings were damaged during this "least impedance to ground" event. Had the antenna pole not been present, lightning probably would have attached to the same area of the building anyway.

3.3 Improved Defenses for Lightning Hazard Mitigation

3.3.1 Grounding is satisfactory. Massive building steel in concrete caissons with concrete and rebar building foundations comprise the overall Earth Electrode Subsystem. No evidence of corrosion was observed. The water table is high so good electrical conductivity can be assumed excepting during drought conditions when soils become resistive.

3.3.2 SPDs are absent from important locations. All branch panel SPDs should protect both load and line sides (bi-directional). (See the list of *NLSI-Approved Vendor Sources, Appendix 6.5*. We recommend Lightning Protection Corp., Goleta CA. Contact them for specification requirements.) We suggest branch panel SPDs be located at all sources which provide power to all outside-the-building sources:

3.3.2.1 Panel L8, Shop
3.3.2.2 Panel L6, Pump House
3.3.2.3 Panel L5, Substation Lighting
3.3.2.4 Panel L4, Coal Handling
3.3.2.5 Panel L2A, Gate & Ext. Floods
3.3.2.6 Panel L1, Lighting
3.3.2.7 Panel DC7, Battery Room

NLSI's inquiries to Emerson Electric (manufacturer of the Mobrey Hydrostat 2468) resulted in correspondence that SPDs for it are unavailable and instead should be installed at the respective sub-panels.

GAI-Tronics Corp. reported that SPDs for their telephones are available from Anixter, Graybar or distributor representative Al Harris at R.L. Balconi Company in Ishpeming, tel. 906-485-1051. We suggest the deployment of optical isolators (if available) for important telephone circuits.

The Motor Control Center (MCC) Class 8938, Type WK122MIL374 can be retro-fitted with internal Square D MCC Surgelogic Bucket Transient Voltage Surge Suppressors with peak ratings per phase of 120kA up to 240kA. Contact your Square D representative for availability. Also see Google Search under "Square D MCC lightning protection" for general information.

SPDs should be installed on important low voltage signal Programmable Logic Controllers (PLCs) at the Distribution Control Center (DCS). We suggest DIN rail mounted SPDs, suitable for specific voltages, be obtained from www.dehn-usa.com (See the Yellow Line Blitzductor product line.) Contact Dehn Factory Representative Glenn Levanti (Port St. Lucie FL) at tel. 1-772-340-7006 or glenn.levanti@dehn-usa.com for exact specifications and technical assistance.

SPDs should be installed as a redundant defense layer at important wall outlets. Select brands of these SPDs with a minimum rating of 3000 Joules. Do not confuse Uninterruptible Power Supplies (UPS) with SPDs. UPSs are batteries-in-boxes designed to provide momentary stand-by time. SPDs control overvoltage transients. The correct SPD installation sequence is: 1) Connect equipment to UPS; 2) UPS to SPD; 3) SPD to 120 VAC wall outlet.

4.0 Lightning Incident to T&D Yard, August 28, 2007 at 4:52:03 AM EGS Clock Time.

4.1 Results of *StrikeNet* Report. At 4:51:58 AM *StrikeNet* showed three negative strikes within the same second totaling 57kA as recorded within a one-half mile Circle of Confidence. See the full *StrikeNet Report, Appendix 6.2.*

4.2 Opinion as to Reason for Damage. There are several circumstances (or combinations thereof) responsible: A) power fault follow-though caused melting of (unopened) switches; B) flashover from ionized air caused breakdown voltage lasting two seconds or more, leading to steady state "thermal runaway" where equipment generates heat faster than it can be dissipated; C) aging and/or pollution (coal dust?) on the switches as a factor leading to deteriorating efficiency; D) arrestors not sized correctly for line voltages; D) OSWs not providing sufficient zones of protection. Exact reasons remain inconclusive.

4.3 Improved Defenses for Lightning Hazard Mitigation

4.3.1 Grounding is questionable due to a sandy (high resistance) soil which changes efficiency with seasonal moisture content. During our visit soils were moist. During summer droughts they are dry. More effective grounding can be obtained by using conductive cements in a shallow trench around the connected grounding fence line. See NLSI's *Lightning Protection for Engineers* book, Chapter 4, p. 52. Soils testing was inconclusive as to presence of acidity or corrosion, however the presence of corrosive sulphur and carbolic acid from fuel combustion should be assumed. At least one disconnected bonding wire from fence post to below-grade earthing was observed. Helpful design illustrations are contained in *IEEE 80, Reference 7.1* and in NLSI's *Lightning Protection for Engineers, Appendix 6.8.*

4.3.2 OSW geometries, by observation, appear to be inadequate to protect all T&D Yard equipment. At the time of plant construction IEEE 998 shielding angles were calculated to a 45 degrees "cone of protection." The most recent IEEE 998 standard is a more conservative 30 degrees angle or "shadow." The southern most side of the T&D Yard lacks protection. Some existing OSW should be elevated to achieve the 30 degrees angles.

4.3.3 West of the Yard are five tall wooden poles containing OSW and outgoing phase lines. The two southern-most poles' downconductors are not connected to OSWs and should be so terminated.

4.3.4 Arrestors in the Yard should be investigated and verified as to correct voltage sizing. (Oversized arrestors will not provide adequate protection. Example: 100 kV arrestors for 35 kV line?)

5.0 Other NLSI Activities for City of Escanaba

5.1 Oil Storage Tanks. The EGS diesel storage tanks meet the requirements for lightning protection as described by American Petroleum Institute *Recommended Practice API 2003 Protections Against Ignitions Arising Out of Static, Lightning, and Stray Currents.*

5.2 New West Substation.

5.2.1 Grounding within the fence is uniform and meets IEEE 80 requirements. Grounding at the OSW at the pole across the street was a satisfactory 2.0 ohms. Note: extreme dry conditions could change this.

5.2.2 The OSW configuration leaves some equipment unprotected. The transformer in the middle of the Yard is vulnerable. Additional OSW should be erected here with a thirty degree "shadow" configuration.

5.2.3 The equipment hut electrical system is not protected. AN SPD should be installed on the branch panel with short leads and no tight bends The incoming coaxial cable is protected with a small Polyphaser SPD, but it should be re-located to its' building entry area with a ground reference wire at that location in common with other grounds.

5.3 Parks & Recreation Department. NLSI met with Director Tom Penegor at lunchtime to discuss lightning personal safety for employees and for the general public at city facilities.

5.4 Public Safety Department. At the close of the final day, NLSI met with Lt. Mark Seymour to tour the Public Safety Department radio and communications facilities.

6.0 Appendices

6.1 May 14 *StrikeNet* Report
6.2 August 28 *StrikeNet* Report
6.3 NLSI *Matrix for Lightning Protection Defenses*
6.4 NLSI *21st Century Lightning Safety for Environments Containing Sensitive Electronics, Explosives and Volatile Substances*
6.5 NLSI *Approved SPD Vendors Sources*
6.6 NLSI DVD *Personal Lightning Safety 101* (already provided)
6.7 NLSI DVD *Case Study in Lightning Hazard Mitigation* (already provided)
6.8 NLSI book *Lightning Protection for Engineers* (already provided)

7.0 References

7.1 IEEE 80,Guide for Safety in AC Substation Grounding, IEEE, NY NY
7.2 IEEE 142, Grounding of Industrial and Commercial Power Systems, IEEE, NY NY
7.3 IEEE 1100, Powering and Grounding Electronic Equipment, IEEE, NY NY
7.4 IEEE 998, Guide for Direct Lightning Stroke Shielding of Substations, IEEE, NY NY

APPENDIX 6.1

May 14, 2007 *StrikeNet* Report

Oct 29, 2007 10:14:26 PM

Thank you for using Vaisala's STRIKEnet® to validate the referenced claim. Your report was generated using data from Vaisala's National Lightning Detection Network®, the most comprehensive archive database in North America.

STRIKEnet Report 195593

Report Title:	city escanaba 2
Claim Number:	102907a
Insured/Claimant Name:	esc
Approx. Claim/Loss Value:	$25,000.00
Items Damaged/Loss Type:	electrical
Search Period:	May 14, 2007 12:01:00 AM US/Eastern to May 14, 2007 03:59:00 AM US/Eastern
Search Radius:	5 mi/8 km around the given location.
Search Center Point:	45° 46.297000' N (Latitude), 87° 3.928000' W (Longitude)

Comments: 22 strikes were detected by the National Lightning Detection Network for the given time period and location.

Thank you again for selecting STRIKEnet. If you have any questions please contact us at 1 800 283 4557 or thunderstorm.support@vaisala.com.

Best Regards, The Vaisala STRIKEnet Team

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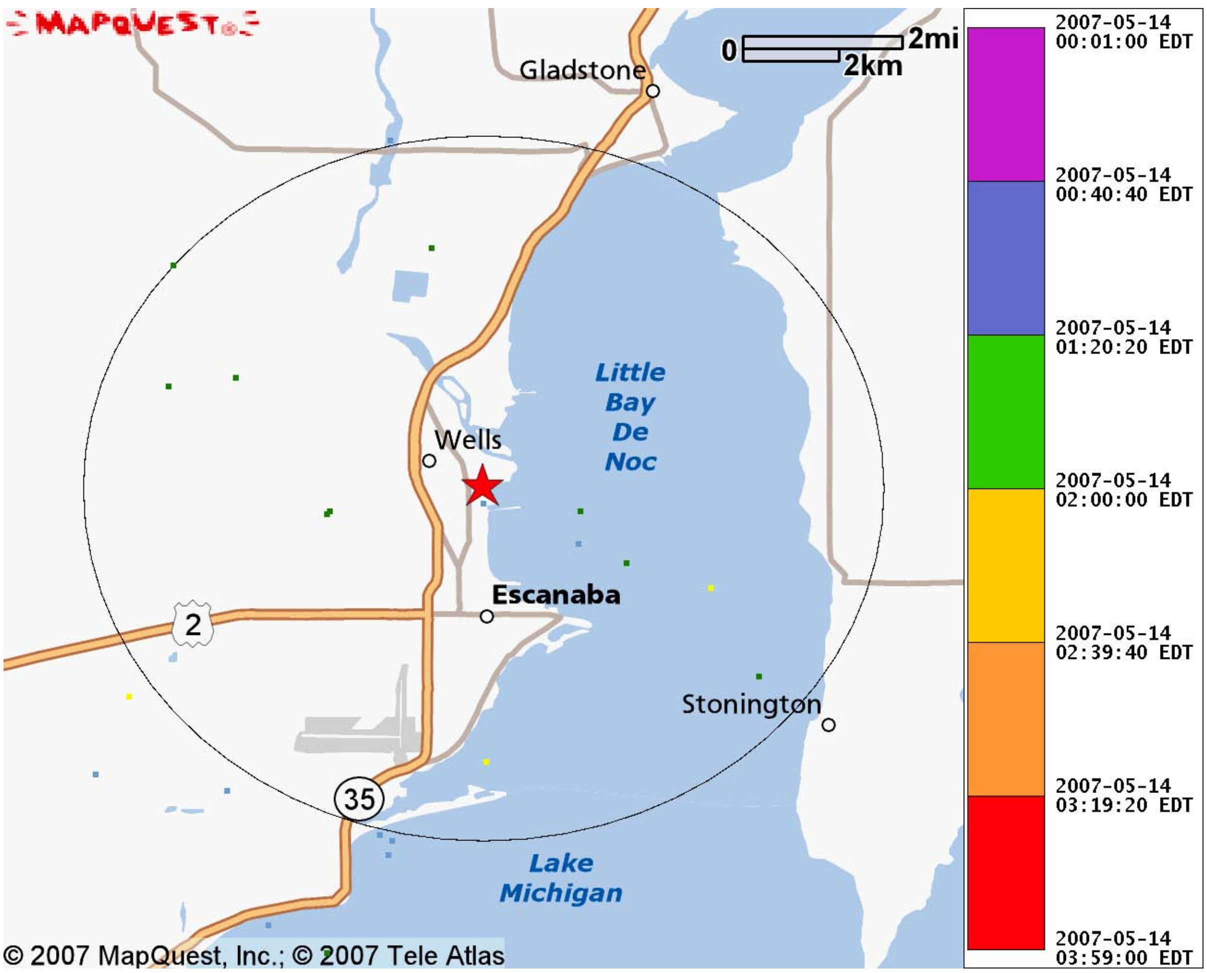
STRIKEnet Report 195593

Report Title: city escanaba 2 Total Lightning Strokes Detected: 22 Lightning Strokes Detected within 5 mi/8 km radius: 13 Lightning Strokes Detected beyond 5 mi/8 km whose confidence ellipse overlaps the radius: 9 Search Radius: 5 mi/8 km Time Span: May 14, 2007 12:01:00 AM US/Eastern to May 14, 2007 03:59:00 AM US/Eastern

Location Points For Lightning Strokes



Lightning data provided by Vaisala's NLDN® and/or Environment Canada's CLDN.

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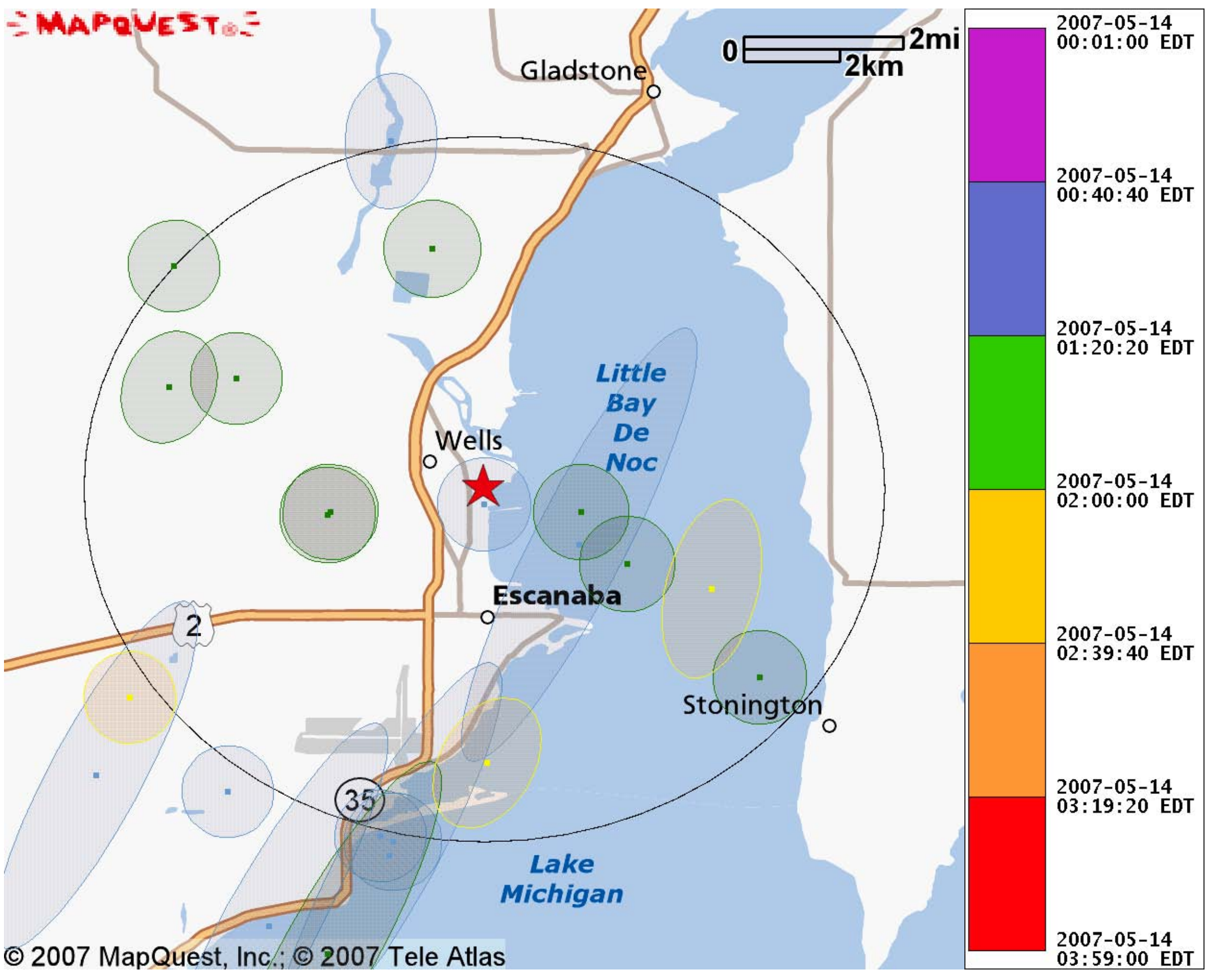
STRIKEnet Report 195593

Report Title: city escanaba 2 Total Lightning Strokes Detected: 22 Lightning Strokes Detected within 5 mi/8 km radius: 13 Lightning Strokes Detected beyond 5 mi/8 km whose confidence ellipse overlaps the radius: 9 Search Radius: 5 mi/8 km Time Span: May 14, 2007 12:01:00 AM US/Eastern to May 14, 2007 03:59:00 AM US/Eastern

Confidence Ellipses For Lightning Strokes



Lightning data provided by Vaisala's NLDN® and/or Environment Canada's CLDN. Note: These ellipses indicate a 99% certainty that the recorded lightning event contacted the ground within the bounds of the ellipse.

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STRIKEnet Report 195593

Area Of Study With Center Point

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STRIKEnet Report 195593

Report Title: city escanaba 2 Total Lightning Strokes Detected: 22 Lightning Strokes Detected within 5 mi/8 km radius: 13 Lightning Strokes Detected beyond 5 mi/8 km whose confidence ellipse overlaps the radius: 9 Search Radius: 5 mi/8 km Time Span: May 14, 2007 12:01:00 AM US/Eastern to May 14, 2007 03:59:00 AM US/Eastern

Lightning Stroke Table (Note: All events shown. Events ordered by time.)

Date	Time	Peak Current (kA)	Distance From Center (mi/km)	Latitude	Longitude
May 14, 2007	12:57:30 AM	-5.6	6.7/10.8	45.6822	-87.1208
May 14, 2007	12:57:31 AM	-10.6	5.1/8.2	45.7006	-87.0922
May 14, 2007	12:57:32 AM	-25.5	5.1/8.2	45.6994	-87.0887
May 14, 2007	12:57:32 AM	-7.2	5.3/8.6	45.6965	-87.0899
May 14, 2007	01:10:41 AM	-6.4	6.3/10.1	45.7130	-87.1653
May 14, 2007	01:13:28 AM	-5.9	5.0/8.1	45.8427	-87.0892
May 14, 2007	01:17:06 AM	108.3	5.3/8.6	45.7097	-87.1315
May 14, 2007	01:19:38 AM	77.8	0.2/0.4	45.7683	-87.0654
May 14, 2007	01:19:39 AM	-6.4	1.4/2.3	45.7601	-87.0408
May 14, 2007	01:21:42 AM	116.1	3.4/5.5	45.8206	-87.0787
May 14, 2007	01:25:07 AM	48.6	4.3/7.0	45.7330	-86.9942
May 14, 2007	01:25:38 AM	-6.6	4.2/6.7	45.7923	-87.1466
May 14, 2007	01:26:58 AM	73.9	2.1/3.3	45.7561	-87.0285
May 14, 2007	01:28:59 AM	67.8	5.0/8.0	45.8170	-87.1453
May 14, 2007	01:31:49 AM	198.6	3.4/5.5	45.7940	-87.1292
May 14, 2007	01:35:52 AM	48.9	2.0/3.2	45.7661	-87.1057
May 14, 2007	01:35:52 AM	23.5	1.9/3.1	45.7667	-87.1049
May 14, 2007	01:37:21 AM	-21.1	1.3/2.0	45.7668	-87.0403
May 14, 2007	01:37:22 AM	-6.3	6.8/11.0	45.6764	-87.1056
May 14, 2007	02:01:53 AM	-18.8	5.3/8.5	45.7289	-87.1567
May 14, 2007	02:06:42 AM	22.0	3.9/6.2	45.7155	-87.0647
May 14, 2007	02:10:09 AM	-29.4	3.2/5.1	45.7511	-87.0067

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STRIKEnet Report 195593

Report Title: city escanaba 2 Total Lightning Strokes Detected: 22 Lightning Strokes Detected within 5 mi/8 km radius: 13 Lightning Strokes Detected beyond 5 mi/8 km whose confidence ellipse overlaps the radius: 9 Search Radius: 5 mi/8 km Time Span: May 14, 2007 12:01:00 AM US/Eastern to May 14, 2007 03:59:00 AM US/Eastern

Lightning Stroke Table (Note: All events shown. Events ordered by distance.)

Date	Time	Peak Current (kA)	Distance From Center (mi/km)	Latitude	Longitude
May 14, 2007	01:19:38 AM	77.8	0.2/0.4	45.7683	-87.0654
May 14, 2007	01:37:21 AM	-21.1	1.3/2.0	45.7668	-87.0403
May 14, 2007	01:19:39 AM	-6.4	1.4/2.3	45.7601	-87.0408
May 14, 2007	01:35:52 AM	23.5	1.9/3.1	45.7667	-87.1049
May 14, 2007	01:35:52 AM	48.9	2.0/3.2	45.7661	-87.1057
May 14, 2007	01:26:58 AM	73.9	2.1/3.3	45.7561	-87.0285
May 14, 2007	02:10:09 AM	-29.4	3.2/5.1	45.7511	-87.0067
May 14, 2007	01:31:49 AM	198.6	3.4/5.5	45.7940	-87.1292
May 14, 2007	01:21:42 AM	116.1	3.4/5.5	45.8206	-87.0787
May 14, 2007	02:06:42 AM	22.0	3.9/6.2	45.7155	-87.0647
May 14, 2007	01:25:38 AM	-6.6	4.2/6.7	45.7923	-87.1466
May 14, 2007	01:25:07 AM	48.6	4.3/7.0	45.7330	-86.9942
May 14, 2007	01:28:59 AM	67.8	5.0/8.0	45.8170	-87.1453
May 14, 2007	01:13:28 AM	-5.9	5.0/8.1	45.8427	-87.0892
May 14, 2007	12:57:31 AM	-10.6	5.1/8.2	45.7006	-87.0922
May 14, 2007	12:57:32 AM	-25.5	5.1/8.2	45.6994	-87.0887
May 14, 2007	02:01:53 AM	-18.8	5.3/8.5	45.7289	-87.1567
May 14, 2007	12:57:32 AM	-7.2	5.3/8.6	45.6965	-87.0899
May 14, 2007	01:17:06 AM	108.3	5.3/8.6	45.7097	-87.1315
May 14, 2007	01:10:41 AM	-6.4	6.3/10.1	45.7130	-87.1653
May 14, 2007	12:57:30 AM	-5.6	6.7/10.8	45.6822	-87.1208
May 14, 2007	01:37:22 AM	-6.3	6.8/11.0	45.6764	-87.1056

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Oct 29, 2007 10:25:43 PM

Thank you for using Vaisala's STRIKEnet® to validate the referenced claim. Your report was generated using data from Vaisala's National Lightning Detection Network®, the most comprehensive archive database in North America.

STRIKEnet Report 195594 redo of 195592

Report Title: City Escanaba Claim Number: 102807 Insured/Claimant Name: esc Approx. Claim/Loss Value: $700,000.00 Items Damaged/Loss Type: electrical

Search Period: Aug 28, 2007 04:00:00 AM US/Eastern to Aug 28, 2007 05:01:00 PM US/Eastern Search Radius: 5 mi/8 km around the given location. Search Center Point: 45° 46.297000' N (Latitude), 87° 3.928000' W (Longitude)

Comments: 81 strikes were detected by the National Lightning Detection Network for the given time period and location.

Thank you again for selecting STRIKEnet. If you have any questions please contact us at 1 800 283 4557 or thunderstorm.support@vaisala.com.

Best Regards, The Vaisala STRIKEnet Team

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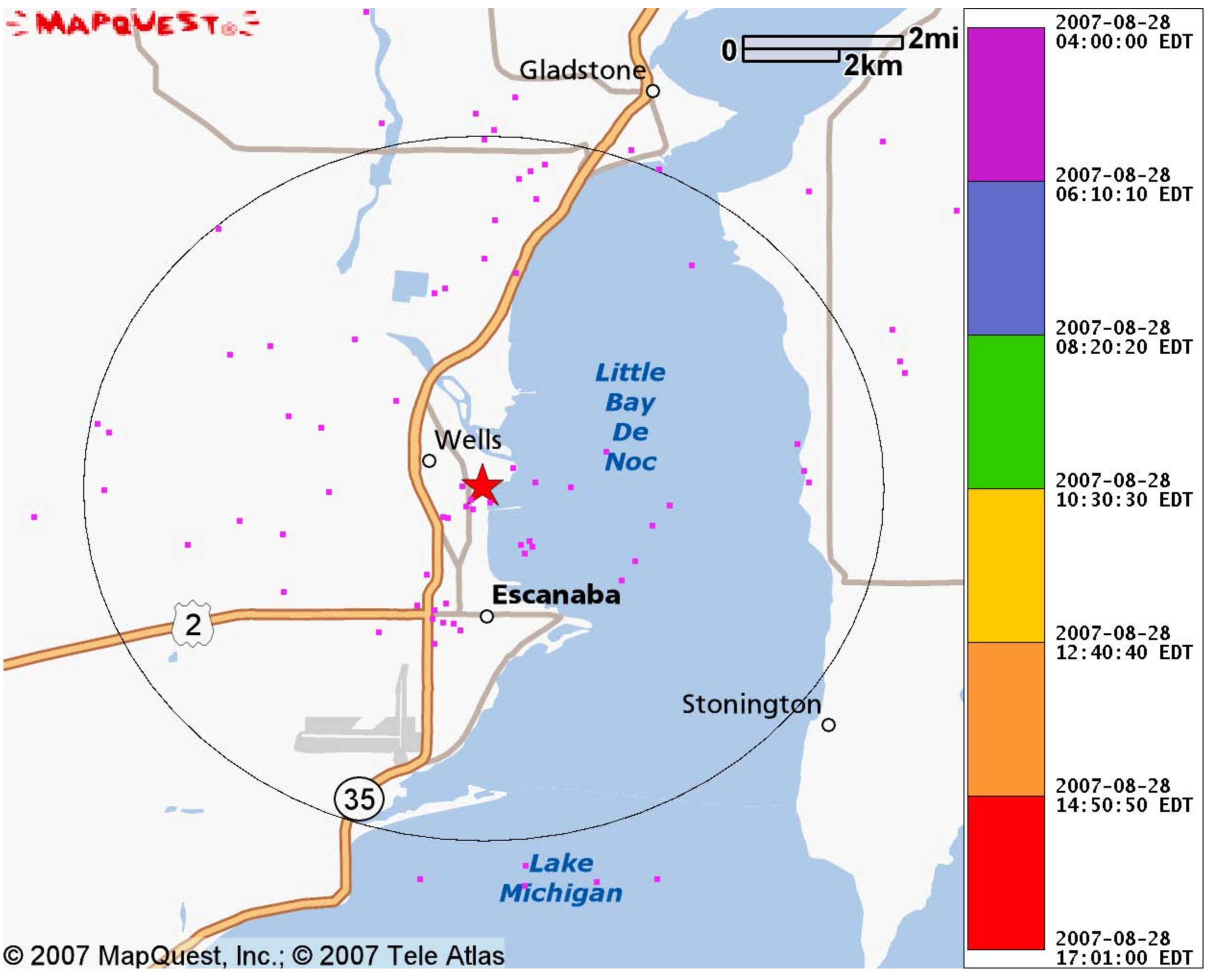
Report Title: City Escanaba Total Lightning Strokes Detected: 81 Lightning Strokes Detected within 5 mi/8 km radius: 58 Lightning Strokes Detected beyond 5 mi/8 km whose confidence ellipse overlaps the radius: 23 Search Radius: 5 mi/8 km Time Span: Aug 28, 2007 04:00:00 AM US/Eastern to Aug 28, 2007 05:01:00 PM US/Eastern

Location Points For Lightning Strokes



Lightning data provided by Vaisala's NLDN® and/or Environment Canada's CLDN.

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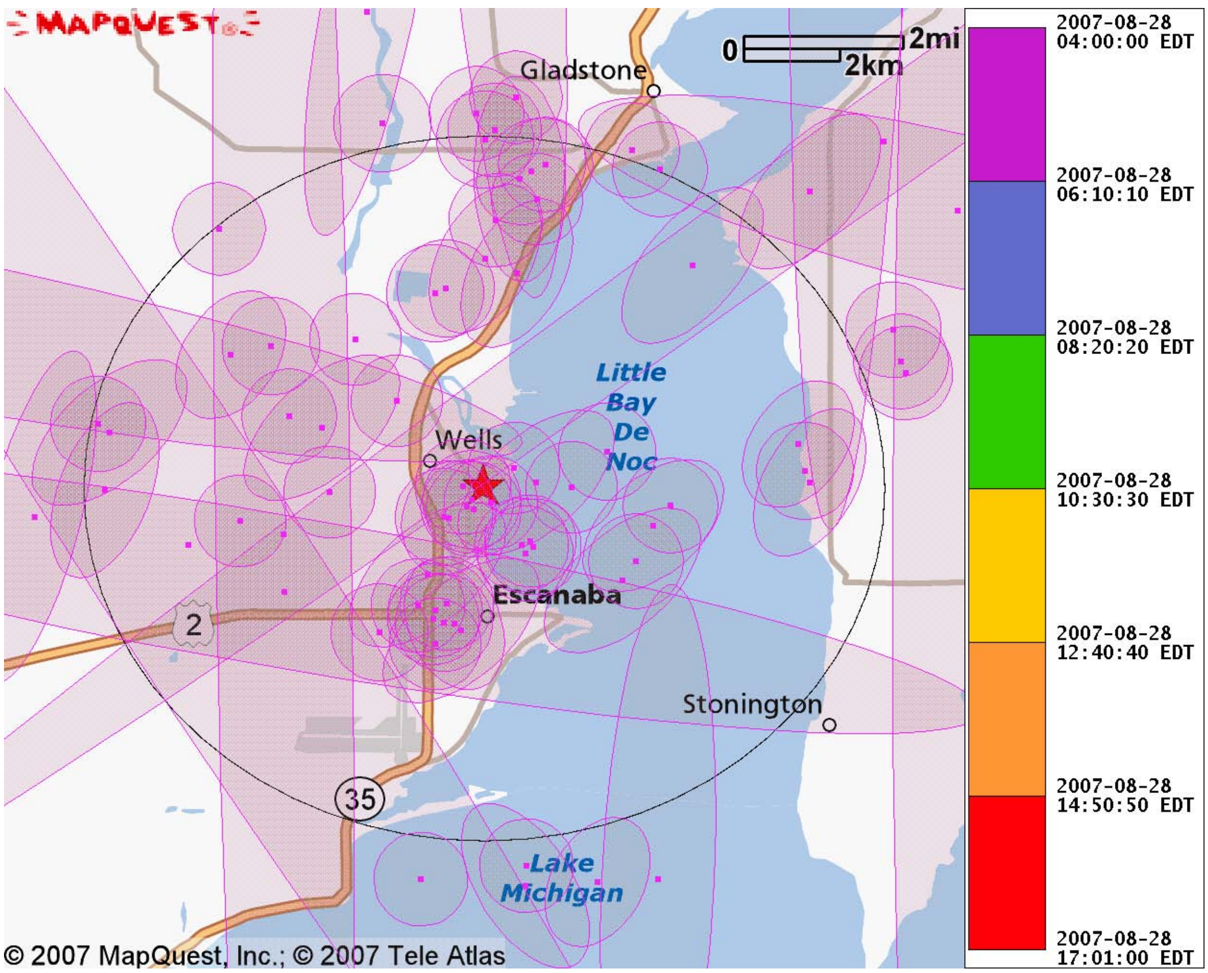
Report Title: City Escanaba Total Lightning Strokes Detected: 81 Lightning Strokes Detected within 5 mi/8 km radius: 58 Lightning Strokes Detected beyond 5 mi/8 km whose confidence ellipse overlaps the radius: 23 Search Radius: 5 mi/8 km Time Span: Aug 28, 2007 04:00:00 AM US/Eastern to Aug 28, 2007 05:01:00 PM US/Eastern

Confidence Ellipses For Lightning Strokes



Lightning data provided by Vaisala's NLDN® and/or Environment Canada's CLDN. Note: These ellipses indicate a 99% certainty that the recorded lightning event contacted the ground within the bounds of the ellipse.

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STRIKEnet Report 195594 redo of 195592

Report Title: City Escanaba Total Lightning Strokes Detected: 81 Lightning Strokes Detected within 5 mi/8 km radius: 58 Lightning Strokes Detected beyond 5 mi/8 km whose confidence ellipse overlaps the radius: 23 Search Radius: 5 mi/8 km Time Span: Aug 28, 2007 04:00:00 AM US/Eastern to Aug 28, 2007 05:01:00 PM US/Eastern

Lightning Stroke Table (Note: Earliest 50 events shown. Events ordered by time.)

Date	Time	Peak Current (kA)	Distance From Center (mi/km)	Latitude	Longitude
Aug 28, 2007	04:35:01 AM	-21.1	4.0/6.4	45.7751	-86.9827
Aug 28, 2007	04:39:00 AM	-12.5	9.1/14.6	45.9029	-87.0608
Aug 28, 2007	04:39:05 AM	-11.0	2.6/4.2	45.7620	-87.1171
Aug 28, 2007	04:42:02 AM	-9.0	6.9/11.1	45.8690	-87.0955
Aug 28, 2007	04:42:07 AM	-16.3	4.9/7.9	45.8246	-87.1336
Aug 28, 2007	04:42:40 AM	-22.1	5.3/8.5	45.8461	-87.0915
Aug 28, 2007	04:43:30 AM	-20.2	5.5/8.9	45.8514	-87.0571
Aug 28, 2007	04:44:37 AM	-14.5	16.7/26.9	46.0039	-86.9671
Aug 28, 2007	04:45:27 AM	-10.3	5.3/8.5	45.8482	-87.0674
Aug 28, 2007	04:46:45 AM	-15.8	5.0/8.1	45.8447	-87.0627
Aug 28, 2007	04:46:45 AM	-17.4	4.9/7.9	45.8428	-87.0650
Aug 28, 2007	04:47:49 AM	15.8	5.6/9.0	45.7656	-87.1812
Aug 28, 2007	04:48:04 AM	-23.0	2.8/4.6	45.8123	-87.0754
Aug 28, 2007	04:48:04 AM	-11.4	3.1/4.9	45.8155	-87.0569
Aug 28, 2007	04:48:04 AM	-19.4	2.8/4.5	45.8113	-87.0781
Aug 28, 2007	04:48:12 AM	-11.6	5.1/8.2	45.8406	-87.0272
Aug 28, 2007	04:48:54 AM	-12.7	4.1/6.6	45.8306	-87.0516
Aug 28, 2007	04:50:40 AM	-12.8	5.0/8.1	45.8368	-87.0199
Aug 28, 2007	04:51:42 AM	-6.5	7.0/11.2	45.8424	-86.9625
Aug 28, 2007	04:51:58 AM	-31.4	0.6/1.0	45.7657	-87.0759
Aug 28, 2007	04:51:58 AM	-18.5	0.3/0.5	45.7679	-87.0698
Aug 28, 2007	04:51:58 AM	-17.3	0.2/0.4	45.7691	-87.0686
Aug 28, 2007	04:51:58 AM	-21.1	0.3/0.5	45.7672	-87.0680
Aug 28, 2007	04:51:58 AM	-14.8	1.9/3.1	45.7708	-87.1053
Aug 28, 2007	04:52:05 AM	-16.7	4.6/7.5	45.8377	-87.0495
Aug 28, 2007	04:52:05 AM	-18.6	4.5/7.3	45.8363	-87.0533
Aug 28, 2007	04:52:12 AM	-13.0	4.1/6.6	45.8172	-87.0117
Aug 28, 2007	04:52:38 AM	-19.4	0.2/0.4	45.7686	-87.0636
Aug 28, 2007	04:52:55 AM	-27.4	0.6/1.0	45.7654	-87.0746
Aug 28, 2007	04:53:05 AM	27.7	4.7/7.6	45.7711	-87.1631
Aug 28, 2007	04:53:05 AM	-7.3	4.7/7.6	45.7829	-87.1618
Aug 28, 2007	04:53:05 AM	-11.9	4.9/7.8	45.7846	-87.1648
Aug 28, 2007	04:53:12 AM	-17.4	5.8/9.4	45.8322	-86.9814
Aug 28, 2007	04:53:31 AM	-8.9	0.6/1.0	45.7726	-87.0520
Aug 28, 2007	04:54:00 AM	-15.9	3.1/4.9	45.7649	-87.1283

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Date	Time	Peak Current (kA)	Distance From Center (mi/km)	Latitude	Longitude
Aug 28, 2007	04:54:05 AM	-12.8	0.5/0.8	45.7757	-87.0577
Aug 28, 2007	04:54:05 AM	-11.5	3.9/6.4	45.7806	-86.9844
Aug 28, 2007	04:54:17 AM	-12.2	5.5/8.8	45.7975	-86.9580
Aug 28, 2007	04:54:53 AM	-7.3	2.2/3.5	45.7840	-87.1071
Aug 28, 2007	04:55:09 AM	-18.6	3.7/5.9	45.7988	-87.1308
Aug 28, 2007	04:55:23 AM	-23.4	5.5/9.0	45.8040	-86.9598
Aug 28, 2007	04:55:35 AM	15.2	3.3/5.3	45.8006	-87.1203
Aug 28, 2007	04:55:42 AM	-13.1	2.6/4.2	45.7863	-87.1156
Aug 28, 2007	04:55:43 AM	-10.5	1.6/2.6	45.7894	-87.0879
Aug 28, 2007	04:56:50 AM	-17.1	2.6/4.2	45.8020	-87.0986
Aug 28, 2007	04:56:51 AM	-12.4	8.9/14.4	45.8094	-87.2435
Aug 28, 2007	04:57:17 AM	-9.7	5.5/8.8	45.7951	-86.9566
Aug 28, 2007	04:58:17 AM	-17.9	0.3/0.4	45.7718	-87.0707
Aug 28, 2007	04:58:17 AM	-21.0	1.1/1.8	45.7717	-87.0428
Aug 28, 2007	04:59:12 AM	-16.2	3.8/6.1	45.8262	-87.0623

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STRIKEnet Report 195594 redo of 195592

Report Title: City Escanaba Total Lightning Strokes Detected: 81 Lightning Strokes Detected within 5 mi/8 km radius: 58 Lightning Strokes Detected beyond 5 mi/8 km whose confidence ellipse overlaps the radius: 23 Search Radius: 5 mi/8 km Time Span: Aug 28, 2007 04:00:00 AM US/Eastern to Aug 28, 2007 05:01:00 PM US/Eastern

Lightning Stroke Table (Note: Closest 50 events shown. Events ordered by distance.)

Date	Time	Peak Current (kA)	Distance From Center (mi/km)	Latitude	Longitude
Aug 28, 2007	04:52:38 AM	-19.4	0.2/0.4	45.7686	-87.0636
Aug 28, 2007	04:51:58 AM	-17.3	0.2/0.4	45.7691	-87.0686
Aug 28, 2007	04:58:17 AM	-17.9	0.3/0.4	45.7718	-87.0707
Aug 28, 2007	04:51:58 AM	-21.1	0.3/0.5	45.7672	-87.0680
Aug 28, 2007	04:51:58 AM	-18.5	0.3/0.5	45.7679	-87.0698
Aug 28, 2007	04:54:05 AM	-12.8	0.5/0.8	45.7757	-87.0577
Aug 28, 2007	04:52:55 AM	-27.4	0.6/1.0	45.7654	-87.0746
Aug 28, 2007	04:51:58 AM	-31.4	0.6/1.0	45.7657	-87.0759
Aug 28, 2007	04:53:31 AM	-8.9	0.6/1.0	45.7726	-87.0520
Aug 28, 2007	05:03:06 AM	-18.6	0.9/1.5	45.7598	-87.0558
Aug 28, 2007	05:03:07 AM	-16.3	0.9/1.5	45.7608	-87.0535
Aug 28, 2007	05:03:06 AM	-14.8	1.0/1.7	45.7595	-87.0528
Aug 28, 2007	05:03:06 AM	-33.9	1.1/1.7	45.7582	-87.0547
Aug 28, 2007	04:58:17 AM	-21.0	1.1/1.8	45.7717	-87.0428
Aug 28, 2007	05:02:00 AM	-8.3	1.4/2.3	45.7539	-87.0800
Aug 28, 2007	05:01:28 AM	-26.9	1.6/2.6	45.7791	-87.0337
Aug 28, 2007	04:55:43 AM	-10.5	1.6/2.6	45.7894	-87.0879
Aug 28, 2007	05:01:48 AM	-14.7	1.7/2.7	45.7479	-87.0750
Aug 28, 2007	05:01:48 AM	-14.7	1.8/3.0	45.7465	-87.0779
Aug 28, 2007	05:02:00 AM	-27.8	1.8/3.0	45.7476	-87.0823
Aug 28, 2007	04:51:58 AM	-14.8	1.9/3.1	45.7708	-87.1053
Aug 28, 2007	05:01:48 AM	-10.8	2.0/3.2	45.7438	-87.0731
Aug 28, 2007	05:01:48 AM	-20.2	2.0/3.2	45.7448	-87.0785
Aug 28, 2007	05:01:48 AM	-34.1	2.0/3.2	45.7441	-87.0758
Aug 28, 2007	05:01:47 AM	-8.8	2.0/3.3	45.7425	-87.0713
Aug 28, 2007	05:03:54 AM	-11.0	2.2/3.5	45.7566	-87.0263
Aug 28, 2007	05:03:54 AM	-7.6	2.2/3.5	45.7528	-87.0297
Aug 28, 2007	05:03:53 AM	-8.1	2.2/3.5	45.7639	-87.0218
Aug 28, 2007	04:54:53 AM	-7.3	2.2/3.5	45.7840	-87.1071
Aug 28, 2007	05:01:48 AM	-19.8	2.3/3.7	45.7396	-87.0779
Aug 28, 2007	05:03:06 AM	-11.9	2.3/3.8	45.7680	-87.0173
Aug 28, 2007	05:02:00 AM	-19.3	2.4/3.9	45.7421	-87.0924
Aug 28, 2007	04:39:05 AM	-11.0	2.6/4.2	45.7620	-87.1171
Aug 28, 2007	04:55:42 AM	-13.1	2.6/4.2	45.7863	-87.1156
Aug 28, 2007	04:56:50 AM	-17.1	2.6/4.2	45.8020	-87.0986

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Date	Time	Peak Current (kA)	Distance From Center (mi/km)	Latitude	Longitude
Aug 28, 2007	04:48:04 AM	-19.4	2.8/4.5	45.8113	-87.0781
Aug 28, 2007	04:48:04 AM	-23.0	2.8/4.6	45.8123	-87.0754
Aug 28, 2007	05:01:48 AM	-10.3	2.9/4.6	45.7504	-87.1168
Aug 28, 2007	04:48:04 AM	-11.4	3.1/4.9	45.8155	-87.0569
Aug 28, 2007	04:54:00 AM	-15.9	3.1/4.9	45.7649	-87.1283
Aug 28, 2007	04:59:12 AM	-9.6	3.2/5.2	45.8184	-87.0651
Aug 28, 2007	04:55:35 AM	15.2	3.3/5.3	45.8006	-87.1203
Aug 28, 2007	04:55:09 AM	-18.6	3.7/5.9	45.7988	-87.1308
Aug 28, 2007	05:07:05 AM	15.8	3.8/6.0	45.7599	-87.1416
Aug 28, 2007	04:59:12 AM	-16.2	3.8/6.1	45.8262	-87.0623
Aug 28, 2007	04:54:05 AM	-11.5	3.9/6.4	45.7806	-86.9844
Aug 28, 2007	04:35:01 AM	-21.1	4.0/6.4	45.7751	-86.9827
Aug 28, 2007	05:02:34 AM	-11.3	4.0/6.5	45.7726	-86.9814
Aug 28, 2007	04:52:12 AM	-13.0	4.1/6.6	45.8172	-87.0117
Aug 28, 2007	04:48:54 AM	-12.7	4.1/6.6	45.8306	-87.0516

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STRIKEnet Report 195594 redo of 195592

Report Title: City Escanaba Total Lightning Strokes Detected: 81 Lightning Strokes Detected within 5 mi/8 km radius: 58 Lightning Strokes Detected beyond 5 mi/8 km whose confidence ellipse overlaps the radius: 23 Search Radius: 5 mi/8 km Time Span: Aug 28, 2007 04:00:00 AM US/Eastern to Aug 28, 2007 05:01:00 PM US/Eastern

Lightning Stroke Table (Note: All events shown. Events ordered by time.)

Date	Time	Peak Current (kA)	Distance From Center (mi/km)	Latitude	Longitude
Aug 28, 2007	04:35:01 AM	-21.1	4.0/6.4	45.7751	-86.9827
Aug 28, 2007	04:39:00 AM	-12.5	9.1/14.6	45.9029	-87.0608
Aug 28, 2007	04:39:05 AM	-11.0	2.6/4.2	45.7620	-87.1171
Aug 28, 2007	04:42:02 AM	-9.0	6.9/11.1	45.8690	-87.0955
Aug 28, 2007	04:42:07 AM	-16.3	4.9/7.9	45.8246	-87.1336
Aug 28, 2007	04:42:40 AM	-22.1	5.3/8.5	45.8461	-87.0915
Aug 28, 2007	04:43:30 AM	-20.2	5.5/8.9	45.8514	-87.0571
Aug 28, 2007	04:44:37 AM	-14.5	16.7/26.9	46.0039	-86.9671
Aug 28, 2007	04:45:27 AM	-10.3	5.3/8.5	45.8482	-87.0674
Aug 28, 2007	04:46:45 AM	-15.8	5.0/8.1	45.8447	-87.0627
Aug 28, 2007	04:46:45 AM	-17.4	4.9/7.9	45.8428	-87.0650
Aug 28, 2007	04:47:49 AM	15.8	5.6/9.0	45.7656	-87.1812
Aug 28, 2007	04:48:04 AM	-23.0	2.8/4.6	45.8123	-87.0754
Aug 28, 2007	04:48:04 AM	-11.4	3.1/4.9	45.8155	-87.0569
Aug 28, 2007	04:48:04 AM	-19.4	2.8/4.5	45.8113	-87.0781
Aug 28, 2007	04:48:12 AM	-11.6	5.1/8.2	45.8406	-87.0272
Aug 28, 2007	04:48:54 AM	-12.7	4.1/6.6	45.8306	-87.0516
Aug 28, 2007	04:50:40 AM	-12.8	5.0/8.1	45.8368	-87.0199
Aug 28, 2007	04:51:42 AM	-6.5	7.0/11.2	45.8424	-86.9625
Aug 28, 2007	04:51:58 AM	-31.4	0.6/1.0	45.7657	-87.0759
Aug 28, 2007	04:51:58 AM	-18.5	0.3/0.5	45.7679	-87.0698
Aug 28, 2007	04:51:58 AM	-17.3	0.2/0.4	45.7691	-87.0686
Aug 28, 2007	04:51:58 AM	-21.1	0.3/0.5	45.7672	-87.0680
Aug 28, 2007	04:51:58 AM	-14.8	1.9/3.1	45.7708	-87.1053
Aug 28, 2007	04:52:05 AM	-16.7	4.6/7.5	45.8377	-87.0495
Aug 28, 2007	04:52:05 AM	-18.6	4.5/7.3	45.8363	-87.0533
Aug 28, 2007	04:52:12 AM	-13.0	4.1/6.6	45.8172	-87.0117
Aug 28, 2007	04:52:38 AM	-19.4	0.2/0.4	45.7686	-87.0636
Aug 28, 2007	04:52:55 AM	-27.4	0.6/1.0	45.7654	-87.0746
Aug 28, 2007	04:53:05 AM	27.7	4.7/7.6	45.7711	-87.1631
Aug 28, 2007	04:53:05 AM	-7.3	4.7/7.6	45.7829	-87.1618
Aug 28, 2007	04:53:05 AM	-11.9	4.9/7.8	45.7846	-87.1648
Aug 28, 2007	04:53:12 AM	-17.4	5.8/9.4	45.8322	-86.9814
Aug 28, 2007	04:53:31 AM	-8.9	0.6/1.0	45.7726	-87.0520
Aug 28, 2007	04:54:00 AM	-15.9	3.1/4.9	45.7649	-87.1283

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Date	Time	Peak Current (kA)	Distance From Center (mi/km)	Latitude	Longitude
Aug 28, 2007	04:54:05 AM	-12.8	0.5/0.8	45.7757	-87.0577
Aug 28, 2007	04:54:05 AM	-11.5	3.9/6.4	45.7806	-86.9844
Aug 28, 2007	04:54:17 AM	-12.2	5.5/8.8	45.7975	-86.9580
Aug 28, 2007	04:54:53 AM	-7.3	2.2/3.5	45.7840	-87.1071
Aug 28, 2007	04:55:09 AM	-18.6	3.7/5.9	45.7988	-87.1308
Aug 28, 2007	04:55:23 AM	-23.4	5.5/9.0	45.8040	-86.9598
Aug 28, 2007	04:55:35 AM	15.2	3.3/5.3	45.8006	-87.1203
Aug 28, 2007	04:55:42 AM	-13.1	2.6/4.2	45.7863	-87.1156
Aug 28, 2007	04:55:43 AM	-10.5	1.6/2.6	45.7894	-87.0879
Aug 28, 2007	04:56:50 AM	-17.1	2.6/4.2	45.8020	-87.0986
Aug 28, 2007	04:56:51 AM	-12.4	8.9/14.4	45.8094	-87.2435
Aug 28, 2007	04:57:17 AM	-9.7	5.5/8.8	45.7951	-86.9566
Aug 28, 2007	04:58:17 AM	-17.9	0.3/0.4	45.7718	-87.0707
Aug 28, 2007	04:58:17 AM	-21.0	1.1/1.8	45.7717	-87.0428
Aug 28, 2007	04:59:12 AM	-16.2	3.8/6.1	45.8262	-87.0623
Aug 28, 2007	04:59:12 AM	-9.6	3.2/5.2	45.8184	-87.0651
Aug 28, 2007	04:59:56 AM	-12.0	7.1/11.4	45.8283	-86.9434
Aug 28, 2007	05:00:38 AM	-10.8	10.9/17.6	45.9032	-86.9392
Aug 28, 2007	05:01:28 AM	-26.9	1.6/2.6	45.7791	-87.0337
Aug 28, 2007	05:01:47 AM	-8.8	2.0/3.3	45.7425	-87.0713
Aug 28, 2007	05:01:48 AM	-34.1	2.0/3.2	45.7441	-87.0758
Aug 28, 2007	05:01:48 AM	-19.8	2.3/3.7	45.7396	-87.0779
Aug 28, 2007	05:01:48 AM	-20.2	2.0/3.2	45.7448	-87.0785
Aug 28, 2007	05:01:48 AM	-14.7	1.7/2.7	45.7479	-87.0750
Aug 28, 2007	05:01:48 AM	-14.7	1.8/3.0	45.7465	-87.0779
Aug 28, 2007	05:01:48 AM	-10.3	2.9/4.6	45.7504	-87.1168
Aug 28, 2007	05:01:48 AM	-10.8	2.0/3.2	45.7438	-87.0731
Aug 28, 2007	05:02:00 AM	-27.8	1.8/3.0	45.7476	-87.0823
Aug 28, 2007	05:02:00 AM	-8.3	1.4/2.3	45.7539	-87.0800
Aug 28, 2007	05:02:00 AM	-19.3	2.4/3.9	45.7421	-87.0924
Aug 28, 2007	05:02:34 AM	-11.3	4.0/6.5	45.7726	-86.9814
Aug 28, 2007	05:03:06 AM	-11.9	2.3/3.8	45.7680	-87.0173
Aug 28, 2007	05:03:06 AM	-14.8	1.0/1.7	45.7595	-87.0528
Aug 28, 2007	05:03:06 AM	-33.9	1.1/1.7	45.7582	-87.0547
Aug 28, 2007	05:03:06 AM	-18.6	0.9/1.5	45.7598	-87.0558
Aug 28, 2007	05:03:07 AM	-16.3	0.9/1.5	45.7608	-87.0535
Aug 28, 2007	05:03:53 AM	-8.1	2.2/3.5	45.7639	-87.0218
Aug 28, 2007	05:03:54 AM	-7.6	2.2/3.5	45.7528	-87.0297
Aug 28, 2007	05:03:54 AM	-11.0	2.2/3.5	45.7566	-87.0263
Aug 28, 2007	05:05:08 AM	-17.9	5.6/9.0	45.6917	-87.0817
Aug 28, 2007	05:07:05 AM	15.8	3.8/6.0	45.7599	-87.1416
Aug 28, 2007	05:07:06 AM	-18.9	5.3/8.6	45.6944	-87.0544
Aug 28, 2007	05:07:06 AM	-7.7	5.6/9.1	45.6902	-87.0548
Aug 28, 2007	05:08:29 AM	-23.6	5.7/9.2	45.6910	-87.0362
Aug 28, 2007	05:10:50 AM	-14.4	5.9/9.6	45.6915	-87.0206
Aug 28, 2007	05:12:13 AM	-25.1	4.4/7.0	45.8347	-87.0561

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Lightning Stroke Table (Note: All events shown. Events ordered by distance.)

Date	Time	Peak Current (kA)	Distance From Center (mi/km)	Latitude	Longitude
Aug 28, 2007	04:52:38 AM	-19.4	0.2/0.4	45.7686	-87.0636
Aug 28, 2007	04:51:58 AM	-17.3	0.2/0.4	45.7691	-87.0686
Aug 28, 2007	04:58:17 AM	-17.9	0.3/0.4	45.7718	-87.0707
Aug 28, 2007	04:51:58 AM	-21.1	0.3/0.5	45.7672	-87.0680
Aug 28, 2007	04:51:58 AM	-18.5	0.3/0.5	45.7679	-87.0698
Aug 28, 2007	04:54:05 AM	-12.8	0.5/0.8	45.7757	-87.0577
Aug 28, 2007	04:52:55 AM	-27.4	0.6/1.0	45.7654	-87.0746
Aug 28, 2007	04:51:58 AM	-31.4	0.6/1.0	45.7657	-87.0759
Aug 28, 2007	04:53:31 AM	-8.9	0.6/1.0	45.7726	-87.0520
Aug 28, 2007	05:03:06 AM	-18.6	0.9/1.5	45.7598	-87.0558
Aug 28, 2007	05:03:07 AM	-16.3	0.9/1.5	45.7608	-87.0535
Aug 28, 2007	05:03:06 AM	-14.8	1.0/1.7	45.7595	-87.0528
Aug 28, 2007	05:03:06 AM	-33.9	1.1/1.7	45.7582	-87.0547
Aug 28, 2007	04:58:17 AM	-21.0	1.1/1.8	45.7717	-87.0428
Aug 28, 2007	05:02:00 AM	-8.3	1.4/2.3	45.7539	-87.0800
Aug 28, 2007	05:01:28 AM	-26.9	1.6/2.6	45.7791	-87.0337
Aug 28, 2007	04:55:43 AM	-10.5	1.6/2.6	45.7894	-87.0879
Aug 28, 2007	05:01:48 AM	-14.7	1.7/2.7	45.7479	-87.0750
Aug 28, 2007	05:01:48 AM	-14.7	1.8/3.0	45.7465	-87.0779
Aug 28, 2007	05:02:00 AM	-27.8	1.8/3.0	45.7476	-87.0823
Aug 28, 2007	04:51:58 AM	-14.8	1.9/3.1	45.7708	-87.1053
Aug 28, 2007	05:01:48 AM	-10.8	2.0/3.2	45.7438	-87.0731
Aug 28, 2007	05:01:48 AM	-20.2	2.0/3.2	45.7448	-87.0785
Aug 28, 2007	05:01:48 AM	-34.1	2.0/3.2	45.7441	-87.0758
Aug 28, 2007	05:01:47 AM	-8.8	2.0/3.3	45.7425	-87.0713
Aug 28, 2007	05:03:54 AM	-11.0	2.2/3.5	45.7566	-87.0263
Aug 28, 2007	05:03:54 AM	-7.6	2.2/3.5	45.7528	-87.0297
Aug 28, 2007	05:03:53 AM	-8.1	2.2/3.5	45.7639	-87.0218
Aug 28, 2007	04:54:53 AM	-7.3	2.2/3.5	45.7840	-87.1071
Aug 28, 2007	05:01:48 AM	-19.8	2.3/3.7	45.7396	-87.0779
Aug 28, 2007	05:03:06 AM	-11.9	2.3/3.8	45.7680	-87.0173
Aug 28, 2007	05:02:00 AM	-19.3	2.4/3.9	45.7421	-87.0924
Aug 28, 2007	04:39:05 AM	-11.0	2.6/4.2	45.7620	-87.1171
Aug 28, 2007	04:55:42 AM	-13.1	2.6/4.2	45.7863	-87.1156
Aug 28, 2007	04:56:50 AM	-17.1	2.6/4.2	45.8020	-87.0986

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Aug 28, 2007	04:48:04 AM	-23.0	2.8/4.6	45.8123	-87.0754
Aug 28, 2007	05:01:48 AM	-10.3	2.9/4.6	45.7504	-87.1168
Aug 28, 2007	04:48:04 AM	-11.4	3.1/4.9	45.8155	-87.0569
Aug 28, 2007	04:54:00 AM	-15.9	3.1/4.9	45.7649	-87.1283
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Aug 28, 2007	04:55:09 AM	-18.6	3.7/5.9	45.7988	-87.1308
Aug 28, 2007	05:07:05 AM	15.8	3.8/6.0	45.7599	-87.1416
Aug 28, 2007	04:59:12 AM	-16.2	3.8/6.1	45.8262	-87.0623
Aug 28, 2007	04:54:05 AM	-11.5	3.9/6.4	45.7806	-86.9844
Aug 28, 2007	04:35:01 AM	-21.1	4.0/6.4	45.7751	-86.9827
Aug 28, 2007	05:02:34 AM	-11.3	4.0/6.5	45.7726	-86.9814
Aug 28, 2007	04:52:12 AM	-13.0	4.1/6.6	45.8172	-87.0117
Aug 28, 2007	04:48:54 AM	-12.7	4.1/6.6	45.8306	-87.0516
Aug 28, 2007	05:12:13 AM	-25.1	4.4/7.0	45.8347	-87.0561
Aug 28, 2007	04:52:05 AM	-18.6	4.5/7.3	45.8363	-87.0533
Aug 28, 2007	04:52:05 AM	-16.7	4.6/7.5	45.8377	-87.0495
Aug 28, 2007	04:53:05 AM	-7.3	4.7/7.6	45.7829	-87.1618
Aug 28, 2007	04:53:05 AM	27.7	4.7/7.6	45.7711	-87.1631
Aug 28, 2007	04:53:05 AM	-11.9	4.9/7.8	45.7846	-87.1648
Aug 28, 2007	04:42:07 AM	-16.3	4.9/7.9	45.8246	-87.1336
Aug 28, 2007	04:46:45 AM	-17.4	4.9/7.9	45.8428	-87.0650
Aug 28, 2007	04:50:40 AM	-12.8	5.0/8.1	45.8368	-87.0199
Aug 28, 2007	04:46:45 AM	-15.8	5.0/8.1	45.8447	-87.0627
Aug 28, 2007	04:48:12 AM	-11.6	5.1/8.2	45.8406	-87.0272
Aug 28, 2007	04:45:27 AM	-10.3	5.3/8.5	45.8482	-87.0674
Aug 28, 2007	04:42:40 AM	-22.1	5.3/8.5	45.8461	-87.0915
Aug 28, 2007	05:07:06 AM	-18.9	5.3/8.6	45.6944	-87.0544
Aug 28, 2007	04:54:17 AM	-12.2	5.5/8.8	45.7975	-86.9580
Aug 28, 2007	04:57:17 AM	-9.7	5.5/8.8	45.7951	-86.9566
Aug 28, 2007	04:43:30 AM	-20.2	5.5/8.9	45.8514	-87.0571
Aug 28, 2007	04:55:23 AM	-23.4	5.5/9.0	45.8040	-86.9598
Aug 28, 2007	05:05:08 AM	-17.9	5.6/9.0	45.6917	-87.0817
Aug 28, 2007	04:47:49 AM	15.8	5.6/9.0	45.7656	-87.1812
Aug 28, 2007	05:07:06 AM	-7.7	5.6/9.1	45.6902	-87.0548
Aug 28, 2007	05:08:29 AM	-23.6	5.7/9.2	45.6910	-87.0362
Aug 28, 2007	04:53:12 AM	-17.4	5.8/9.4	45.8322	-86.9814
Aug 28, 2007	05:10:50 AM	-14.4	5.9/9.6	45.6915	-87.0206
Aug 28, 2007	04:42:02 AM	-9.0	6.9/11.1	45.8690	-87.0955
Aug 28, 2007	04:51:42 AM	-6.5	7.0/11.2	45.8424	-86.9625
Aug 28, 2007	04:59:56 AM	-12.0	7.1/11.4	45.8283	-86.9434
Aug 28, 2007	04:56:51 AM	-12.4	8.9/14.4	45.8094	-87.2435
Aug 28, 2007	04:39:00 AM	-12.5	9.1/14.6	45.9029	-87.0608
Aug 28, 2007	05:00:38 AM	-10.8	10.9/17.6	45.9032	-86.9392
Aug 28, 2007	04:44:37 AM	-14.5	16.7/26.9	46.0039	-86.9671

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APPENDIX 6.3

Matrix of Lightning Protection Defenses

MATRIX OF LIGHTNING PROTECTION DEFENSES

Apply these sub-systems as appropriate (YES or N/A) to specific facilities or structures.

	DIRECT STRIKE	INDIRECT STRIKE	EXTERIOR LOCATION	INTERIOR LOCATION	PEOPLE SAFETY	STRUCTURE SAFETY
AIR TERMINALS	YES	N/A	YES	N/A	N/A	YES
DOWN-CONDUCTORS	YES	N/A	YES	YES	N/A	YES
BONDING	YES	YES	YES	YES	YES	YES
GROUNDING	YES	YES	YES	YES	YES	YES
SHIELDING	YES	YES	YES	YES	YES	YES
SURGE PROTECTION	YES	YES	YES	YES	YES	YES
DETECTION	YES	YES	YES	YES	YES	YES
POLICIES & PROCEDURES	YES	YES	N/A	N/A	YES	YES

Per NLSI, 2007

APPENDIX 6.4

21^{st} Century Lightning Safety for Environments Containing Sensitive Electronics, Explosives and Volatile Substances

Presented To: Department of Energy Subcommittee on Consequence Assessment and Protective Actions (SCAPA) NV 2000; Lockheed Martin Aeronautic Co. Weekly Activity Report – F-16 Support and Services WUC-1100, 2000; Power Quality Assurance Magazine, 2001; US Army Explosives Safety Bulletin, Defense Ammunition Center, 2001; US Dept. Energy TA 16 Buildings Assessment, Los Alamos NL NM 2001; US Dep. Energy Explosives Safety Committee, 440.1 Lightning Code Review, NM 2001; Department of Defense Explosive Safety Board Bi-Annual Conference GA, 2002; International Lightning Detection Conference, AZ, 2002; DoD Joint Spectrum Center E3 Bulletin AZ 2003; DoD Annual Meeting, Electromagnetic/Environmental/Effects Program Review GA 2003; Russian-USA Lightning Workshop Picatinny Arsenal NJ 2003; US Navy SWFLANT Kings Bay GA 2003; HQ AFSC/SEW Kirtland AFB NM 2003; Tobyhanna Army Depot PA 2004; US Navy NSBNL New London CT, 2004; SLIDA Colombo Sri Lanka, 2004; DSTA Min. Defense Singapore, 2004; NASA Wallops Island VA, 2004; Russian-USA WSSX Meeting, Albuquerque NM, 2004; EEM Workshop Kuala Lumpur 2005; Barrick Pierina & Alto Chicama Peru 2005; USAF E3/HERO/CE3PO Review KAFB NM 2005; NASA Pad 39 Catenary Meeting KSC 2006; Newmont Mining MYSRL Peru 2006; CUC, Cayman Islands 2007; Barrick Gold, Papua New Guinea 2007; Credit-Suisse, New Jersey 2007; NASA Johnson Space Center Texas 2007; Arcelor Mittal, Mexico 2007.

21st CENTURY LIGHTNING SAFETY FOR ENVIRONMENTS CONTAINING SENSITIVE ELECTRONICS, EXPLOSIVES AND VOLATILE SUBSTANCES.

by Richard Kithil, Founder & CEO
National Lightning Safety Institute (NLSI)
www.lightningsafety.com

1. ABSTRACT.

In the USA civilian sector lightning causes $4-5 billion losses per year (NLSI, 1999). In the government sector, the military (DDESB - Department of Defense Explosive Safety Board) has reported 88 identifiable lightning induced munitions explosions with costs and deaths not calculated. DDESB was formed as a result of the July 1926 Picatinny Arsenal incident which killed 14 people and cost $70 million. The US Department of Energy (DOE) has reported 346 known lightning events to its facilities during the 1990-2000 period. Recent Russian lightning incidents to arsenals include: June 1998 near Losiniy (Yekaterinburg); and June 2001 near Nerchinsk (Siberia). In Beira Mozambique (October 2002) lightning exploded a military ammunition storage depot with considerable loss of lives and collateral damage. The most recent examples of lightning-caused munitions explosions are: 13 Feb 2005, Hezbollah's two-story ammunition storage complex near Majadel Lebanon; 12 Sept 05 police ammunition depot at Camp Bagong Diwa, Taguig Philippines; and 29 Nov 2005 the government arms depot near Walikale, Democratic Republic of Congo. According to SmallArmsSurvey.Org records, some 5% of ammunition explosions are lightning-initiated. With such facts it is difficult to support a position that catastrophic lightning incidents are rare. How to mitigate the lightning hazard at sensitive facilities? This paper suggests adoption of a homologuous lightning safety planning process which can be applied to most contemporary environments.

2. LIGHTNING BEHAVIOR & CHARACTERISTICS.

2.1. Physics of Lightning. Lightning's characteristics include current levels approaching 400 kA with the 50% average being about 25kA, temperatures to 15,000 C, and voltages in the hundreds of millions. There are some ten cloud-to-cloud lightnings for each cloud-to-ground lightning flash. Globally, some 2000 on-going thunderstorms generate about 50-100 lightning strikes to earth per second. Lightning is the agency which maintains the earth's electrical balance. The phenomenology of lightning flashes to earth, as presently understood, follows an approximate behavior: the downward Leader (gas plasma channel) from a thundercloud pulses toward earth. Ground-based air terminators such as fences, trees, blades of grass, corners of buildings, people, lightning rods, power poles etc., etc. emit varying degrees of induced electric activity. They may respond at breakdown voltage by forming upward Streamers. In this intensified local field some Leader(s) likely will connect with some Streamer(s). Then, the "switch" is closed and the current flows. Lightning flashes to ground are the result. A series of return strokes follow.

2.2 Lightning Effects . Thermal stress of materials around the attachment point is determined by: a) heat conduction from arc root; b) heat radiation from arc channel; and, c) Joule heating. The radial acoustic shock wave can cause mechanical damage. Magnetic pressures – up to 6000 atmospheres for a 200 kA flash - are proportional to the square of the current and inversely proportional to the square of the diameter of struck objects. Voltage sparking is a result of dielectric breakdown. Thermal sparking is caused is caused when melted materials are thrown out from hot spots. Exploding high current arcs, due to the rapid heating of air in enclosed spaces, have been observed to fracture massive objects (i.e. concrete and rocks). Voltage transfers from an intended lightning conductor into electrical circuits can occur due to capacitive coupling, inductive coupling, and/or resistance (i.e. insulation breakdown) coupling. Transfer impedance, due to loss of skin effect attenuation or shielding, can radiate interference and noise into power and signal lines. Transfer inductance (mutual coupling) can induce voltages into a loop which can cause current flows in other coupled circuits.

2.3 Behavior of Lightning. Absolute protection from lightning may exist in a thick-walled and fully enclosed Faraday Cage, however this is impractical in most cases. Lightning "prevention" exists only as a vendor-inspired marketing tool. Important new information about lightning may affect sensitive facilities. First, the average distance between successive cloud-to-ground flashes is greater than previously thought. The old recommended safe distance from the previous flash was 1-3 miles. New information suggests that a safe distance should be 6-8 miles (Lopez & Holle, National Severe Storm Center, 1998). Second, some 40% of cloud-to-ground lightnings are forked, with two or more attachment points to the earth. This means there is more lightning to earth than previously measured (Krider, Intl. Conf. Atmospheric Electricity,1998). Third, radial horizontal arcing in excess of 20 m from the base of the lightning flash extends the hazardous environment (Sandia Labs, 1997). Lightning is a capricious, random, stochastic and unpredictable event. At the macro-level, much about lightning is understood. At the micro-level, much has yet to be learned.

When lightning strikes an asset, facility or structure (AFS) return-stroke current will divide up among all parallel conductive paths between attachment point and earth. Division of current will be inversely proportional to the AFS path impedance, Z ($Z = R + XL$, resistance plus inductive reactance). The resistance term will be low assuming effectively bonded metallic conductors. The inductance, and related inductive reactance, presented to the total return stroke current will be determined by the combination of all the individual inductive paths in parallel. Essentially lightning is a current source. A given stroke will contain a given amount of charge (coulombs = amp/seconds) that must be neutralized during the discharge process. If the return stroke current is 50kA – that is the magnitude of the current that will flow, whether it flows through one ohm or 1000 ohms. Therefore, achieving the lowest possible impedance serves to minimize the transient voltage developed across the AFS path through which the current is flowing [$e(t) = I(t)R + L\, di/dt$].

3. LIGHTNING PROTECTION DESIGNS.

Mitigation of lightning consequences can be achieved by the use of a detailed systems approach, described below in general terms.

3.1 Air Terminals. Since Franklin's day lightning rods have been installed upon ordinary structures as sacrificial attachment points, intending to conduct direct flashes to earth. This *integral air terminal design* does not provide protection for electronics, explosives, or people inside modern structures. Inductive and capacitive coupling (transfer impedance) from lightning-energized conductors can result in significant voltages and currents on interior power, signal and other conductors. Overhead shield wires and mast systems located above or next to the structure are suggested alternatives in many circumstances. These are termed *indirect air terminal designs*. Such methods presume to collect lightning above or away from the sensitive structure, thus avoiding or reducing flashover attachment of unwanted currents and voltages to the facility and equipments. These designs have been in use by the electric power industry for over 100 years. Investigation into applicability of dielectric shielding may provide additional protection where upward leader suppression may influence breakdown voltages (Sandia Laboratories, 1997). Faraday-like interior shielding, either via rebar or inner-wall screening, is under investigation for critical applications (US Army Tacom-Ardec).

Unconventional air terminal designs which claim the elimination or redirecting of lightning (DAS/CTS - charge dissipators) or lightning preferential capture (early streamer emitters - ESE) deserve a very skeptical reception. Their uselessness has been well-described in publications such as: NASA/Navy Tall Tower Study; 1975, R.H. Golde "Lightning" 1977; FAA Airport Study 1989; T. Horvath "Computation of Lightning Protection" 1991; D. MacKerras et al, IEE Proc-Sci Meas. Technol, V. 144, No. 1 1997; National Lightning Safety Institute "Royal Thai Air Force Study" 1997; A. Mousa "IEEE Trans. Power Delivery, V. 13, No. 4 1998; International Conference on Lightning Protection - Technical Committee personal correspondence 2000; Uman & Rakov "Critical Review of Nonconventional Approaches to Lightning Protection", AMS Dec. 2002; etc. Merits of radioactive air terminals have been investigated and dismissed by reputable scientists (R.H. Golde op cit and C.B. Moore personal correspondence, 2000).

3.2 Downconductors. Downconductor pathways should be installed outside of the structure. Rigid strap is preferred to flexible cable due to inductance advantages. Conductors should not be painted, since this will increase impedance. Gradual bends always should be employed to avoid flashover problems. Building structural steel also may be used in place of downconductors where practical as a beneficial subsystem emulating the Faraday Cage concept.

3.3 Bonding assures that unrelated conductive objects are at the same electrical potential. Without proper bonding, lightning protection systems will not work. All metallic conductors entering structures (ex. AC power lines, gas and water pipes, data and signal lines, HVAC ducting, conduits and piping, railroad tracks, overhead bridge cranes, roll up doors, personnel metal door frames, hand railings, etc.) should be electrically referenced to the same ground potential. Connector bonding should be exothermal and not mechanical wherever possible, especially in below-grade locations. Mechanical bonds are subject to corrosion and physical damage. HVAC vents that penetrate one structure from another should not be ignored as they may become troublesome electrical pathways. Frequent inspection and resistance measuring (maximum 10 milliohms) of connectors to assure continuity is recommended.

3.4 Grounding. The grounding system must address low earth impedance as well as low resistance. A spectral study of lightning's typical impulse reveals both a high and a low frequency content. The grounding system appears to the lightning impulse as a transmission line where wave propagation theory applies. A considerable part of lightning's current responds horizontally when striking the ground: it is estimated that less than 15% of it penetrates the earth. As a result, low resistance values (25 ohms per NEC) are less important that volumetric efficiencies.

Equipotential grounding is achieved when all equipments within the structure(s) are referenced to a master bus bar which in turn is bonded to the external grounding system. Earth loops and consequential differential rise times must be avoided. The grounding system should be designed to reduce AC impedance and DC resistance. The use of buried linear or radial techniques can lower impedance as they allow lightning energy to diverge as each buried conductor shares voltage gradients. Ground rings connected around structures are useful. Proper use of concrete footing and foundations (Ufer grounds) increases volume. Where high resistance soils or poor moisture content or absence of salts or freezing temperatures are present, treatment of soils with carbon, Coke Breeze, concrete, natural salts or other low resistance additives may be useful. These should be deployed on a case-by-case basis where lowering grounding impedances are difficult an/or expensive by traditional means.

3.5 Corrosion and cathodic reactance issues should be considered during the site analysis phase. Where incompatible materials are joined, suitable bi-metallic connectors should be adopted. Joining of aluminum down conductors together with copper ground wires is a typical situation promising future troubles.

3.6 Transients and Surges. Electronic and electrical protection approaches are well-described in IEEE1100. Ordinary fuses and circuit breakers are not capable of dealing with lightning-induced transients. Surge protection devices (SPD aka transient limiters) may shunt current, block energy from traveling down the wire, filter certain frequencies, clamp voltage levels, or perform a combination of these tasks. Voltage clamping devices capable of handling extremely high amperages of the surge, as well as reducing the extremely fast rising edge (dv/dt and di/dt) of the transient are recommended.

Protecting the AC power main panel; protecting all relevant secondary distribution panels; and protecting all valuable plug-in devices such as process control instrumentation, computers, printers, fire alarms, data recording & SCADA equipment, etc. are suggested. Protecting incoming and outgoing data and signal lines (modem, LAN, etc.) is essential. All electrical devices which serve the primary asset such as well heads, remote security alarms, CCTV cameras, high mast lighting, etc. should be included.

Transient limiters should be installed with short lead lengths to their respective panels. Under fast rise time conditions, cable inductance becomes important and high transient voltages can be developed across long leads. SPDs with replacable internal modules are suggested.

In all instances the use high quality, high speed, self-diagnosing SPD components is suggested. Transient limiting devices may use spark gap, diverters, metal oxide varistors, gas tube arrestors, silicon avalanche diodes, or other technologies. Hybrid devices, using a combination of these techniques, are preferred. SPDs conforming to the European CE mark are tested to a 10 X 350 us waveform, while those tested to IEEE and UL standards only meet a 8 X 20 us waveform. It is suggested that user SPD requirements and specifications conform to the CE mark, as well as ISO 9000-9001 series quality control standards.

Uninterupted Power Supplies (UPSs) provide battery backup in cases of power quality anomalies…brownouts, capacitor bank switching, outages, lightning, etc. UPSs are employed as back-up or temporary power supplies. They should not be used in place of dedicated SPD devices. Correct Category A installation configuration is: AC wall outlet to SPD to UPS to equipment.

3.7 Detection. Lightning detectors, available at differing costs and technologies, are useful to provide early warning. Their sensors acquire lightning signals such as RF, EF, or light from Cloud-to-Cloud or Cloud-to-Ground or atmospheric gradients. Users should beware of over-confidence in detection equipment. It is not perfect and it does not always acquire all lightning all the tiem. Detectors cannot "predict" lightning. Detectors cannot help with "Bolt From The Blue" events. An interesting application is their use to disconnect from AC line power and to engage standby power before the arrival of lightning. A notification system of radios, sirens, loudspeakers or other communication means should be coupled with the detector. See the NLSI WWW site for a more detailed treatment of detectors.

3.8 Testing & Maintenance. Modern diagnostic testing is available to "verify" the performance of lightning conducting devices as well as to indicate the general route of lightning through structures. With such techniques, lightning pathways can be inferred reliably. Sensors which register lightning current attachments can be fastened to downconductors. Regular physical inspections and testing should be a part of an established preventive maintenance program. Failure to maintain any lightning protection system may render it ineffective.

4. PERSONNEL SAFETY ISSUES.

Lightning safety should be practiced by all people during thunderstorms. Measuring lightning's distance is useful. Using the "Flash/Bang" (F/B) technique, for every five seconds - from the time of seeing the lightning flash to hearing the associated thunder - lightning is one mile away. A F/B of 10 = 2 miles; a F/B of 20 = 4 miles, etc. The distance from Strike A to Strike B to Strike C can be as much as 5-8 miles. The National Lightning Safety Institute recommends the 30/30 Rule: suspend activities at a F/B of 30 (6 miles), or when first hearing thunder. Outdoor activities should not be resumed until 30 minutes has expired from the last observed thunder or lightning. This is a conservative approach: perhaps it is not practical in all circumstances.

If one is suddenly exposed to nearby lightning, adopting the so-called Lightning Safety Position (LSP) is suggested. LSP means staying away from other people, removing metal objects, crouching with feet together, head bowed, and placing hands on ears to reduce acoustic shock from nearby thunder. When lightning threatens, standard safety measures should include: avoid water and all metal objects; get off the higher elevations including rooftops; avoid solitary trees; stay off the telephone. A fully enclosed metal vehicle – van, car or truck – is a safe place because of the (partial) Faraday Cage effect. A large permanent building can be considered a safe place. In all situations, people should avoid becoming a part of the electrical circuit. [Benjamin

Franklin's advice was to lie in a silk hammock, supported by two wooden posts, located inside a house.]

Every organization should consider adopting and promulgating a Lightning Safety Plan specific to its operations. An all-encompassing General Rule should be: "If you can hear it (thunder), clear it (evacuate); if you can see it (lightning), flee it."

5. CODES AND STANDARDS.

In the USA there is no single lightning safety code or standard providing comprehensive assistance. US Government lightning protection documents should be consulted. The Federal Aviation Administration FAA-STD-019d is valuable. The IEEE 142 and IEEE 1100 are suggested. Other recommended federal codes include military documents MIL HDBK 419A, Army PAM 385-64, NAVSEA OP 5, AFI 32-1065, NASA STD E0012E, MIL STD 188-124B, MIL STD 1542B, MIL STD 5087B, and UFC 3-570-01. The DOE M440.1-1 and the British Code BS 6551 are helpful. The German lightning protection standard for nuclear power plants KTA 2206 places special emphasis on the coupling of overvoltages at instrument and control cables. The International Electrotechnical Commission IEC 62305 series for lightning protection is the single best reference document for the lightning protection engineer. Adopted by many countries, IEC 62305 is a science-based document applicable to many design situations. Too often ignored in most Codes is the very essential electromagnetic compatibility (EMC) subject, especially important for explosives safety and facilities containing electronics, VSDs, PLCs, and monitoring equipment.

6. CONCLUSION.

Lightning has its own agenda and may cause damage despite application of best efforts. Any comprehensive approach for protection should be site-specific to attain maximum efficiencies. In order to mitigate the hazard, systematic attention to details of grounding, bonding, shielding, air terminals, surge protection devices, detection & notification, personnel education, maintenance, and employment of risk management principles is recommended. Protection now or protection later? Lightning doesn't care.

7. REFERENCES.

7.1 International Conference on Lightning Protection (ICLP) Proceedings, Avignon (2004), Cracow (2002), Athens (2000), Birmingham (1998), Florence (1996).

7.2 IEEE STD 142-1991 Grounding of Industrial and Commercial Power Systems.

7.3 IEEE STD 1100-1999 Powering and Grounding Electronic Equipment

7.3 IEEE Transactions on Electromagnetic Compatibility, Nov. 1998

7.4 National Research Council, Transportation Research Board, NCHRP Report 317, June 1989

7.5 International Electrotechnical Commission (IEC), International Standard for Lightning Protection. See: http://www.iec.ch

7.6 Gardner RL, Lightning Electromagnetics, Hemisphere Publishing, NY NY 1991

7.7 EMC for Systems and Installations, T. Williams and K. Armstrong, Newnes, Oxford UK, 2000.

7.8 NATO STANAG 4236, Lightning Environmental Conditions, 1995.

APPENDIX 6.5

NLSI-Approved SPD Vendor Sources

NLSI-APPROVED SPD SOURCES

1. **Entry (Main) & Branch (Secondary) Panel (IEEE Cat. C & B Locations).**

   1.1 First Tier : *Dehn & Sons (www.dehn.de) ; Lightning Protection Corp. (www.lightningprotectioncor.com) ; MCG Electronics (www.mcgsurge.com) ; *MTL Instruments (www.mtlsurge.com) ; *OBO Bettermann (www.obo-bettermann.com) ; *Phoenix Contact (www.phoenixcontact.com) ; Polyphaser (www.polyphaser.com).

   1.2 Second Tier (from FAA Vendor List): Transtector; PowerLogics; Advanced Protection Technology (ATC); *Raychem Rayvoss; Leviton; Cutler Hammer; Northern Technologies.

2. **Plug-In (IEEE Cat. A Locations): APC; Panamax; Polyphaser. Other Vendors: select highest Joules (watt/seconds) rating with min. 3000J.**

3. **Data and Signal Line Locations.**

   3.1 *CITEL (www.citel.com) ; EDCO (www.edcosurge.com) ; *Huber-Suhner (www.hubersuhnerinc.com) ; Polyphaser (www.polyphaser.com); Telebyte (www.telebyteusa.com)

   3.2 Optical Isolators: B&B Electronics (www.bb-elec.com)

Note: *CE mark on product indicates compliance to international testing standard 10X350 us.

APPENDIX 6.6

NLSI DVD Lightning Safety 101

APPENDIX 6.7

NLSI DVD Case Study in Lightning Hazard Mitigation

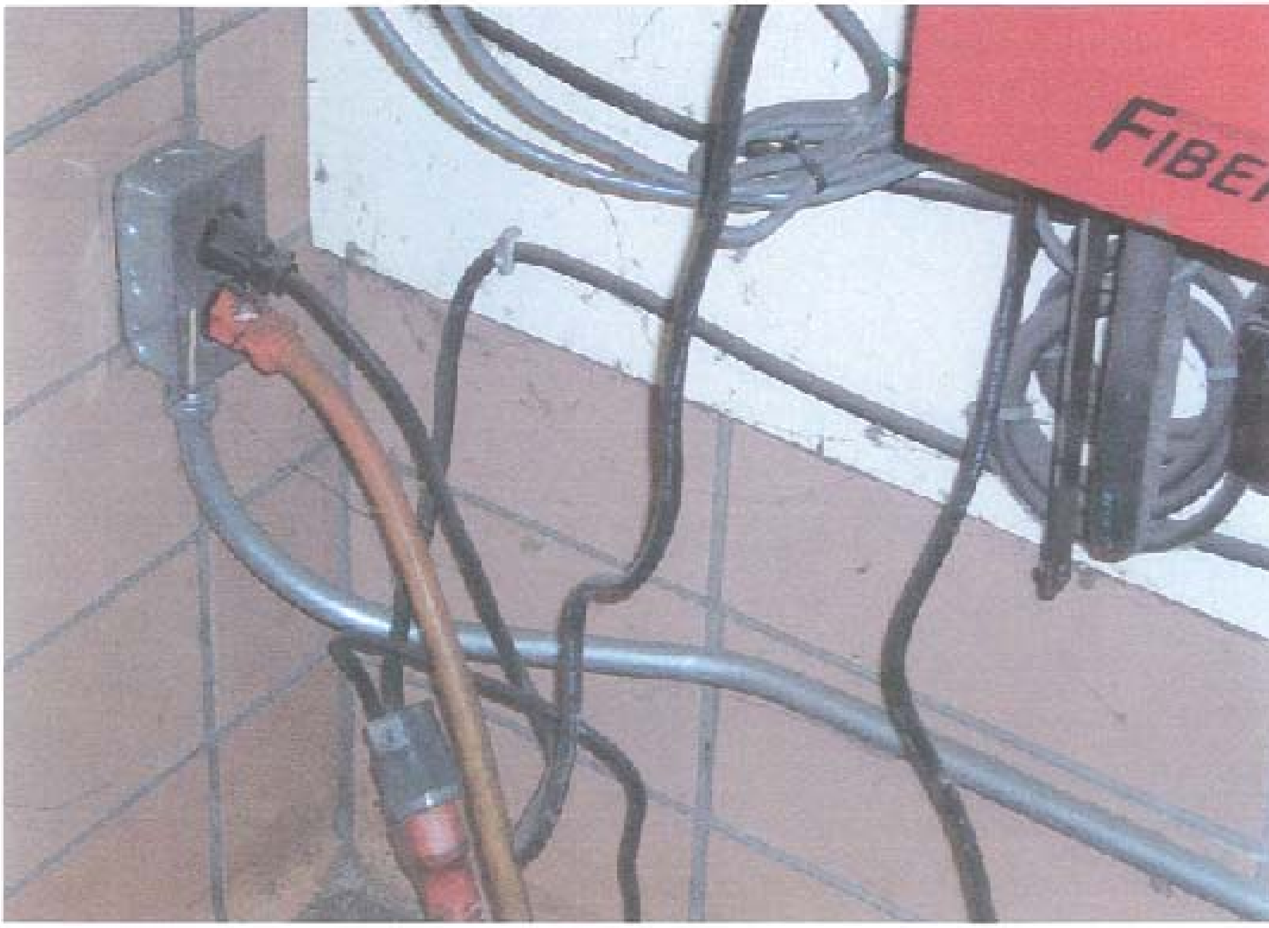
APPENDIX 6.8

NLSI book *Lightning Protection for Engineers*

APPENDIX 6.9

Representative Photographs

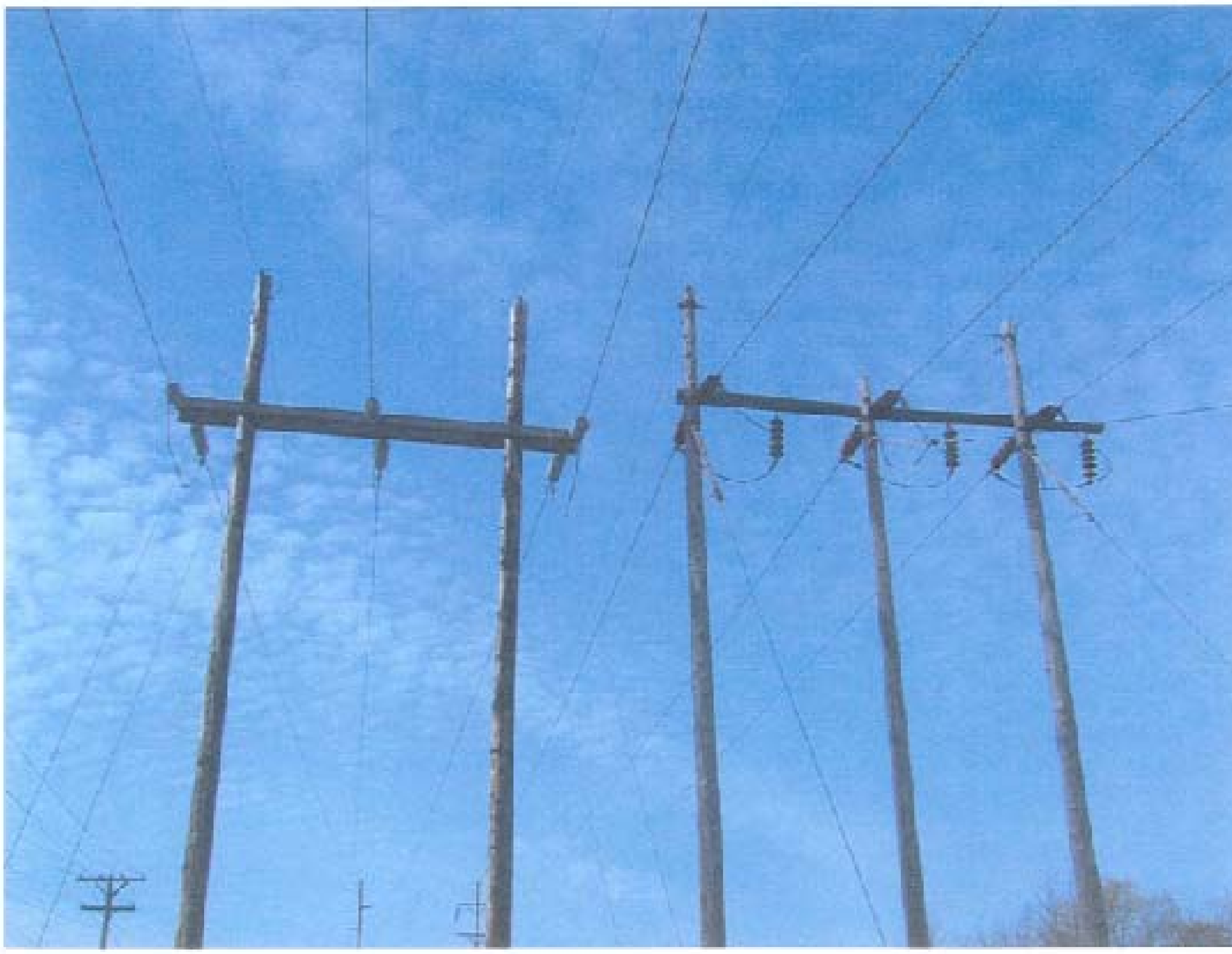
MCC next to Steel Beam, North Side Interior of Generator Plant. Lightning after striking the upper roof above this area created parallel paths in building steel. Induced voltages created havoc in the MCC and in downstream electrical circuits.



Surge Protection at Critical 120V Outlets. (Example shown at telephone switch at building west entry.) Install min. 3000 Joules plug-in type SPDs at all critical 120V outlets.

Protection of T&D Yard by OSW.

Four existing OSWs from poles do not describe a 30 degree protective angle to all the equipment in the T&D Yard. Add OSWs to two southern most poles so as to provide coverage to southern part of T&D Yard.



Five Tall Wooden Poles West of T&D Yard.

1. Two southern most pole downconductors should be attached to OSWs at pole tops.
2. Grounding wires of four existing downconductors should be connected together at ground level and should be buried min. 18 inches below grade. Use compression connectors.

OSWs supported by Existing Steel Columns at East Side of T&D Yard. OSWs are not sufficiently tall to describe thirty degrees shielding angle. Install two inch dia. X 10 ft. tall steel poles to existing twelve I-beams so as to obtain required coverage.

T&D Yard. Melted switches were caused when three lightning events attacked within one second of time.

New West Yard. Overhead shield wires (OSW) do not "shadow" the transformer, leaving it vulnerable to lightning strikes. Install OSWs so as to describe a 30 degree zone of protection.

New West Yard. Steel antenna support pole must be grounded. Use bare No. 6 attached to opposite side of wooden pole from coaxial cable. Run bare ground wire to common earth reference.