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Lightning Safety and Outdoor Stadiums

Event managers should consider the safety of spectators when lightning threatens a large outdoor gathering.

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15 November 2004

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1.) Introduction

The authors attended the University of Colorado's football game at Denver's Invesco Field on Saturday, 20 August 2003. For this highly contentious game between intra-state rivals Colorado State and the University of Colorado, Invesco Field provided a neutral site and the capacity to accommodate large crowds. The official stadium attendance for that night was 76, 219 people.

During the third quarter, lightning lit-up the southern sky as heavy rains blanketed the stadium. A public address announcement stated that the game was suspended due to lightning, and all players, coaches, and stadium personnel on the field immediately ran for cover. Remarkably, during this 30-45 minute delay, stadium management did not provide any instructions to spectators. Many crowded the exit ramps and concourses to escape the downpour while others remained in their seats during the storm. The game eventually resumed with no reported injuries to players or spectators resulting from the storm. Yet, the authors wondered why the event managers gave no warning and took no action to protect the 76,125 spectators from the dangers of lightning.

A review of lightning casualty cases identified a woman who was struck as an off-field spectator at a concert held in Washington D.C.'s Robert F. Kennedy stadium on 6 June 1998 (Milzman 1999). Stadium officials evacuated more than 50,000 spectators shortly after that strike. This event demonstrates the reality that lightning can strike and injure spectators in outdoor stadiums. Furthermore, experiences at Invesco Field and RFK stadium reveal a lack of consensus and expertise when dealing with lightning safety procedures for spectators en masse.

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Large outdoor stadiums face a significant and growing vulnerability to lightning due to increased size and frequency of events. This growth is not paralleled in the knowledge and management of spectator safety. To date, there have been few casualties in the United States from direct lightning strikes to a stadium or from the mass movement of spectators when lightning threatens. However, if no further action is taken, stadium managers are overlooking an opportunity to prevent a potential disaster as the probability of a tragic event continues to increase while the costs of intervention remain substantially low. This paper will use Collegiate Division-I football stadiums as a proxy for all large outdoor stadiums due to their large capacity, high attendance rates, and event frequency.

2.) Growing Vulnerability

Each year, attendance at Collegiate Division-I football games increases. The total attendance, including neutral site games and bowl games, increased from 29,258,933 in 2000 to 34,647,132 in 2003, ~18% growth in four years. This growth is perpetuated by the constant demand for seats and its positive return on investment for stadium expansions. Another reason for the growth in attendance at Division-I college football games is an increase in the frequency of events. Including neutral site and bowl games, there were 776 home games across the 117 teams in Division-I football in 2003, a significant increase from the 665 games in 2000. The 15% increase in games is due to more bowl games and the addition of 3 teams to D-I football since 2000 (NCAA 2004). Because Division-I football games generate large revenues, it is reasonable to assume that attendance will continue to increase.

In addition to event frequency, crowd density is an overwhelming factor in lighting safety policies. Division-I college football games have especially high attendance averages as a percent of capacity. Of the 117 teams representing Division-I football, 19 (16%) of them have reported 100% or higher attendance at home games through the 2003 season. In addition, 45 (38%) of schools averaged between 90-100% capacity (NCAA

2004). The frequency of NCAA Division-I football games is nothing near that of Major League Baseball (MLB) with 30 teams and 162 games each (approximately 2400 games per season). However, the crowd density at MLB games averages only 61% of capacity through the 2002/2003 season (Ballpark Digest 2003) whereas the majority of NCAA Division-I stadiums average 90-100% of capacity. If a stadium is relatively empty, it is easier for spectators to seek shelter. Additionally, there is a smaller chance of lightning hitting a fan in a less crowded stadium.

3.) Risks to Spectators

According to the International Association of Assembly Managers' (IAAM) Safety and Security Task Force, an 'emergency situation' is, "…any incident, situation, or occurrence that could affect the safety/security of occupants…of the facility." These incidents may include:

- Medical emergencies
- Fire/fire alarm
- Bomb threat/explosion
- Mechanical/structural failure
- Civil Disturbance
- Hazardous materials release
- Terrorism
- Building evacuation
- Natural disasters/severe weather

The development of emergency plans (e.g. fire safety) is required to meet legal statutes and recommended to meet the professional standards and expectations of providing a safe, non-threatening environment for the facility occupants (IAAM 2002). During an emergency situation, the responsibility of fan safety falls upon stadium management. Stadium managers are equipped with the resources to communicate and coordinate with local authorities to identify a possible emergency situation and to conduct a response. Emergency situations occur very infrequently but may develop quickly and with little warning.

In terms of lightning, spectators will still attend a football game with thunderstorms in the forecast. Most spectators assume (correctly) that the chance of lightning occurring over the stadium during game time is quite low. With this assumption, spectators enter the stadium and surrender any access to real-time warnings of thunderstorms (with the exception of the minority of spectators with wireless weather access via a cell phone/PDA). Therefore, it is the responsibility of stadium management to monitor any lightning activity.

Surprisingly, lightning as an emergency situation at outdoor stadiums does not receive a high level of attention, most likely due to the isolated nature of lightning incidents. Natural hazards such as tornadoes, hurricanes, and earthquakes receive mass media coverage while lighting is typically reported in the local media (Milzman 1999). Still, some broad lightning safety guidelines do exist for large stadiums.

The National Association of Athletic Trainers (NAAT) position statement on lightning safety during athletic and recreation events provides detailed guidelines to aid in developing a lightning safety policy for specific locations. Yet, the lightning safety guidelines provided by the NAAT are specific only when dealing with smaller-scale fields and facilities. When these guidelines address the issue of "extremely large athletic events," their guidelines are very general, advising an integrated approach with "weather forecasts, real-time thunderstorm data, a weather watcher, and the flash-to-bang count (discussed later) to aid in decision making" (Walsh 2000). Most literature mirrors these non-specific recommendations concerning lightning safety and large events and does not provide specific mitigation/crowd management suggestions. Large amounts of unconnected knowledge exist on lightning behavior and protection, safer locations for people, and crowd control. A synthesis of this information does not exist in any official form.

The National Oceanic and Atmospheric Administration (NOAA) makes a concerted effort in lightning safety education with its summer "Lightning Safety Awareness Week. Yet again, this program does not address issues relating to lightning safety for large crowds even though a promotional video about lightning safety airs in Washington D.C.'s RFK stadium (the same stadium where the woman was struck in 1998) at the beginning of summer soccer games.

The lack of specific policies addressing lightning safety at large stadiums may be due to inadequate assumptions of event managers. They may assume that they cannot protect their facility from lightning and that the evacuation of an entire facility is not a reasonable response to the threat. Converse to these assumptions, measures to protect a facility and its occupants are rather inexpensive compared with the cost of large construction projects, perhaps as low as tens of thousands of dollars for a large stadium (C. Andrews 2003, personal communication). Furthermore, without a well-planned lightning evacuation procedure, the uncontrolled movement/panic of a crowd attempting to seek shelter has the potential to harm many more people than the few that could experience a direct harm from a lightning strike.

Note: The authors stress that spectators face short-term weather risks beyond that of lighting and at other large gatherings not necessarily within stadiums. It is hoped that this paper's focus on developing a lighting safety policy for stadiums will lead to the development of other severe weather safety policies (e.g. for hail and tornadoes) for stadiums as well as for other outdoor venues.

4.) The Lightning Threat

Many of the largest collegiate football stadiums are located in lightning prone locations. Figure 1 shows the location of the 50 stadiums with the highest average attendance superimposed on a map of average annual lightning strikes computed during the five-year period 1996-2000. Each ranked stadium is described further in Table 1. The area of greatest lightning frequency is generally co-located with the largest collegiate stadiums across the central and southern sections of the United States. Although the statistical threat of a lightning strike within a stadium is very low, Figure 1 should at least serve as a qualitative warning to stadium managers. To be fair, the lightning density presented is for an entire year whereas the college football season lasts from August through early January. Even though much of the United States' lightning occurs during the non-football months of summer, powerful autumn storm systems frequent the eastern half of the country producing thunderstorms and lightning. Thus, the autumn lightning threat should not be pushed aside.

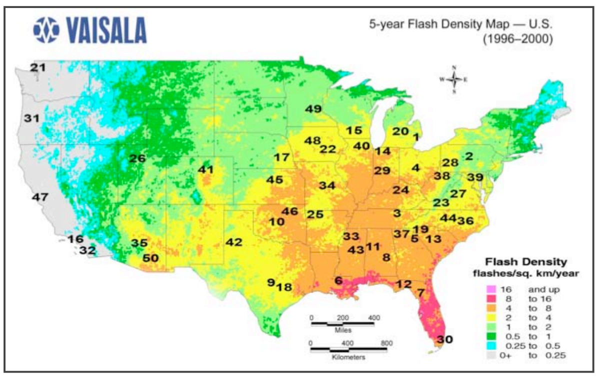

FIGURE 1: Average density of lightning strikes over five years. Strike density is measured in strikes per km^2 per year. Black numbers [1-50] denote the largest 50 NCAA Division-I football stadiums based on average per game attendance for the 2003 season. Table 1 provides more information on each school. (Base map courtesy of Vaisala 2003)

Lightning is the most dangerous weather hazard that people encounter each year (Holle and Lopez 1999). Agencies within NOAA issue watches, warnings, and other forecasts to protect against loss of life and property resulting from three of the top four killers in Figure 2 (floods, tornadoes, and hurricanes), however warnings and forecasts are not typically issued specifically for lightning. Since lightning strikes are so frequent and widespread, it is impossible to warn each person of every flash.

The severe weather watches and warnings issed by NOAA agencies do not provide stadium managers with the specificity necessary to address lightning. The Storm Prediction Center (SPC) may issue severe thunderstorm watches up to six hours prior to an expected event. A severe thunderstorm watch outlines an area where 3/4 inch or larger diameter hail and damaging thunderstorm winds are expected to occur (SPC 2003), yet lightning can occur in any thunderstorm including those that do not fall under 'severe' criteria. Watches typically cover about 25,000 square miles, or about half the size of Iowa.

Rank	*School*	*Avg. Attendance per game*
1	Michigan	110,918
2	Penn State	105,629
3	Tennessee	105,038
4	Ohio State	104,870
5	Georgia	92,058
6	LSU	90,974
7	Florida	90,177
8	Auburn	85,203
9	Texas	83,339
10	Oklahoma	83,202
11	Alabama	83,189
12	Florida State	83,149
13	South Carolina	80,844
14	Notre Dame	80,795
15	Wisconsin	78,486
16	Southern	77,804
17	Nebraska	77,754
18	Texas A&M	76,243
19	Clemson	75,286
20	Michigan State	72,830
21	Washington	71,906
22	Iowa	65,798
23	Virginia Tech	65,115
24	Kentucky	64,922
25	Arkansas	63,588
26	Brigham Young	61,501
27	Virginia	60,424
28	Pittsburgh	59,197
29	Purdue	58,597
30	Miami (Fla.)	58,135
31	Oregon	57,701
32	UCLA	56,636
33	Mississippi	56,509
34	Missouri	55,833
35	Arizona State	54,248
36	North Carolina	53,274
37	Georgia Tech	52,862
38	West Virginia	52,205
39	Maryland	51,236
40	Illinois	50,961
41	Colorado	50,423
42	Texas Tech	49,608
43	Mississippi	47,667
44	North Carolina	47,133
45	Kansas State	47,110
46	Oklahoma	44,872
47	Stanford	44870
48	Iowa State	44,822
49	Minnesota	44,148
50	Arizona	42,765

TABLE 1: The 50 largest NCAA Division-I football stadiums by average game attendance for the 2003 season.

Therefore watches provide notice that lightning may be observed in a general area, though they are not useful in short-term decision-making.

The next step in prediction is the severe thunderstorm warning issued by a local National Weather Service (NWS) forecast office. Warnings are issued on a county-by-county basis and typically precede a storm by 20-30 minutes (NWS 2003). While this lead-time may be adequate for individuals and small groups to prepare for the onset of severe weather, 20 minutes may not be enough time for tens of thousands of spectators to take action. Furthermore, it should be reiterated that any thunderstorm can produce dangerous lightning, not just severe storms. Consequently, it is wise for stadium managers to look beyond official NWS severe thunderstorm watches and warnings.

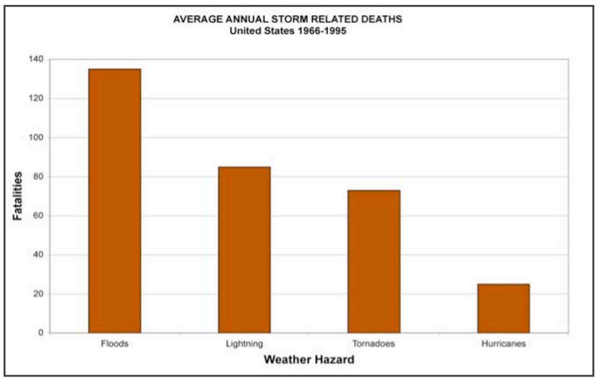

FIGURE 2: Average annual number of storm-related deaths in the U.S. from 1966-1995, derived from Storm Data (Holle 1999).

The North American Lightning Detection Network (NALDN) provides real-time lighting data with an estimated median accuracy of nearly 1/3 mile or 1650 feet (Idone et al. 1998a) and a flash detection efficiency of 80-90% (Idone et al. 1998b; Cummins et al. 1998). Numerous private weather companies have access to the NALDN and provide fee-for-forecast services including telephone, e-mail, and pager notification. With added prediction software, one company claims to be able to predict lighting up to 30 minutes before the threat arrives (Weatherdata 2002).

If venues do not have access to real-time lightning data, the 30-30 rule is suggested (Holle and Lopez 1999). The first 30 applies to counting the number of seconds between observing the lightning flash and hearing the thunder; if the time between the two is 30 seconds or less, lightning is likely within 6 miles (using 5 seconds = 1 mile) of the observed location and persons should take shelter immediately. The final 30 refers to waiting 30 minutes after observing the last flash before resuming the prior activity. No place is absolutely safe from the lightning threat, however the following guidelines provide measures to greatly mitigate the threat:

- Seek large enclosed structures
- Seek fully enclosed metal vehicles such as cars, buses, etc.
- Avoid being near high places and open areas
- Avoid using/touching any conductive surfaces, such as metal doors, windows, plumbing, or the use of a land-line telephone.

Because the exact timing and location of lightning cannot be anticipated reliably before the onset of an event, the responsibility for monitoring and taking action to reduce the threat must rest on the stadium management – not the spectators. Real-time lighting monitoring systems are widely available and there is general agreement concerning locations that substantially reduce the lighting threat. With this knowledge, stadium managers can take proactive steps to mitigate the risks posed by lightning rather than embrace the false assumption that no specific lightning policy can anticipate/control the threat.

5.) Recent Collegiate Stadium Lightning Incidents

The National Collegiate Athletic Association (NCAA) is a leader in addressing the threat of lightning (R. Holle 2003, personal communication). The NCAA's 2003 Sports Medicine Handbook highlights six steps to mitigate the lightning hazard. These steps include recommendations that school officials designate a chain of command for who monitors threatening weather and who makes the decision to remove a team or individuals from an athletics site or event. These steps also include the formulation of an emergency plan which contains instruction for both participants and spectators. Brian Bennett of the College of William and Mary, along with Ronald Holle and Raul Lopez (both formerly with the National Severe Storms Laboratory) were instrumental in developing the aforementioned lighting safety guidelines and applying them to high risk situations faced by outdoor collegiate athletics (NCAA 2003). However, by the global nature of these NCAA guidelines, decisions concerning exactly when to postpone the game as well any direction given to athletes and spectators is entirely at the discretion of individual stadiums. Stadium decisions, also known as home management strategies, vary significantly from stadium to stadium.

Five incidents involving lightning during Division-I football games are highlighted in Table 2. Each school's actions – from the method of detecting lightning in the area to any direction given to players and fans – are the sole decision of the school itself. However, NCAA guidelines recommend that all concerned parties should be in a safe location before lightning is observed within six miles of the location (NCAA 2003). Most of these schools did not initiate action until lightning was detected within six miles of the stadium. Following, spectators did not have enough

	VIRGINIA TECH	UNIV. of OKLAHOMA	UNIV. of SOUTH CAROLINA	UNIV. of FLORIDA	UNIV. of ALABAMA
Date of Incident	8/11/2000	9/14/2002	9/14/2002	9/14/2002	9/27/2003
Average per-game Attendance for Respective Season	52,339*	75,104	82,138	85,185	82,857
How Lightning was Detected	Visual	National Weather Service	Visual	Lightning Tracking Software (NALDN)	National Weather Service
Lead time/distance Between Lightning Detection and Affect on Stadium	<1 minute 0.6 miles	18 minutes 5 miles	12 minutes 5 miles	20 minutes 6 miles	10 minutes 6 miles
On-field Notification	**YES** Personnel Moved Off Field	**YES** Personnel Moved Off Field	**YES** Personnel Moved Off Field	**YES** Personnel Moved Off Field	**YES** Personnel Moved Off Field
Spectator Notification	**NO**	**YES** Controlled Evacuation	**YES** Voluntary Evacuation	**YES** Voluntary Evacuation	**YES** Voluntary Evacuation
Problems during Incident	Mass confusion, uncontrolled crowd movement (see description below)	Some Spectators Remained in Seats	Slow Evacuation	Some Spectators Remained in Seats	Uncontrolled crowd movement, Injuries During Evacuation
Lightning Policy changed since Incident?	**YES** (see description below)	**NO**	**NO**	**NO**	**NO**

TABLE 2: Summary of recent lightning incidents at NCAA Division-I football stadiums. (denotes actual attendance during the incident)*

time to seek appropriate shelter resulting in situations where all fans could not evacuate the open seating areas before lightning arrived. Also, note the contrast between player safety (all players removed from field) and spectator safety (not all spectators could move to safety due to crowd congestion at exits). Of these five incidents, the incident at Virginia Tech presents a worse case scenario and is explored in detail below.

Virginia-Tech, August 27th, 2000

Virginia Tech was scheduled to play a home game against Georgia Tech on Sunday, August 27th at 8:00pm. During the kick-off at 8:05 pm, a lightning bolt (Figure 3) struck the ground 6/10 of a mile away from the stadium and rain started to pour.

FIGURE 3: Looking west, north-west from Virginia Tech's Lane Stadium as lightning strikes at a distance of 0.6 miles (1km). The strike occurred at 8:05pm on 27 August 2000 – moments before the opening kickoff (Roanoke Times 2000).

Fans quickly reacted by moving out of the stands, crowding stadium tunnels, and braving the weather in the open. Carol Hart (2000), a Roanoke columnist, commented:

"What I saw disturbed me, the tunnels leading from the stands to the concourse were packed solid. Ushers, emergency, or security should have been clearing those people out. Some fans tried leaving the stadium, but could not get through the tunnels. They were forced to find protection in the open." Hart stated later: "What we did not see was a person of authority. There were no policemen, no ushers, no one with a bull-horn, radio, walkie-talkie, or mega-phone telling us what the situation was, no one directing us…Any official voice would have been a comfort on Sunday night."

The stadium management and game officials could not communicate to the crowds due to an inadequate loudspeaker system. It took one hour before the game was officially canceled, yet the inadequate loudspeaker system prevented a public announcement of the cancellation, leaving fans continuing to seek shelter

Earlier that day, the National Weather Service (NWS) issued a Sunday afternoon forecast for a twenty percent chance of showers, which was updated to a forty percent chance of showers at 6:30 pm. The clear skies during the late afternoon/early evening hours gave many a false sense of security. During a television network pre-game show, a commentator said that it was a great night for football. At 7:00 pm, the NWS issued another zone forecast which stated, "Scattered showers and thunderstorms will continue to form and build over the area through 830 PM. A storm containing heavy rain and lightning is expected to move across central Pulaski County [county north of Virginia Tech]… Elsewhere in the area…scattered storms are expected to form suddenly…producing heavy downpours in isolated locations. Outdoor interests should keep an eye to the sky for these fast forming storms."

FIGURE 4: Lightning strikes around Virginia Tech's Lane Stadium during a 10-minute period shortly after 8:00pm. While these 22 strikes hit within a few miles of the stadium, many spectators were left out in the open due to poor crowd management planning (Emlaw 2000).

Post analysis using the NALDN showed that 124 lightning strikes occurred within 5 miles of the stadium (Emlaw 2000). The majority of lightning strikes occurred 5 to 10 miles west of the stadium and up to 20 minutes prior to kickoff, yet stadium managers took no advanced action. At 8:00pm, a bolt struck the ground four miles away. At 8:05pm, the lightning bolt responsible for halting the game hit the ground towards the northwest side of the stadium (Figure 3). Beginning with the 8:05pm strike, twelve lightning strikes occurred within one mile of the center of the stadium in a ten-minute period (Figure 4). Additionally, four lightning strikes occurred 1/2 mile or less from the center of the stadium throughout the course of the evening.

The severe weather seemed to catch everyone by surprise. Prior to the start of the game, the crowd noise likely inhibited people from hearing thunder. Only those in the east stands would have been able to see the lightning as the storm approached (note in Figure 3, the press box faces away (east) from the oncoming storms, likely contributing to the lack of advanced visual warning by stadium authorities). Officials, security, and ushers were still tending to the incoming crowds when the first lightning bolt occurred. Essentially, there was no lead-time in the notification of decision makers.

During this event in 2000, Virginia Tech did not have a severe weather policy. Current Virginia Tech policy, modified after this event, informs fans of approaching lightning within twenty miles of the stadium. If approaching lightning creates a need, the stadium management requests a partial or full evacuation of the stadium facilitated by police officers with bullhorns. While this policy is a step in the right direction, a partial or full spectator evacuation may be counterproductive for the safety of spectators where many fans are left the open while moving to other buildings or vehicles.

6.) Current Collegiate Lightning Policies

Five other football stadiums, in addition to the previous five where high-profile incidents occurred, are presented in Table 3. These five stadiums were selected

	UNIV. of MICHIGAN	UNIV. of TENNESSEE	LOUISIANA STATE UNIV.	UNIV. of NEBRASKA	UNIV. of COLORADO
Average Attendance (2003)	110,918	105,038	90,974	77,754	50,423
Attendance Rank in NCAA (1=biggest)	1	3	6	17	41
Specific Lightning Policy which Actively Addresses Fan Safety?	NO	YES	NO	NO	NO
Details of Policy	Stadium may use general evacuation plan if necessary.	Athletic staff monitor weather with lightening software. When lightening strikes within 10 miles, officials stop game. Fans follow official evacuation directions by management and police. (see description below)	Athletic staff monitor weather with lightening software. When lightening strikes within **3** miles, officials stop game. Management makes announcement to fans about approaching weather; no direction given.	Management relies upon local 911 emergency center for notification of lightning. Management makes announcement to fans about approaching weather; no direction given.	Management relies upon local NWS to monitor severe weather. When lightning strikes within 6 miles, officials stop game. Management makes announcement to fans about approaching weather; no direction given.

TABLE 3: Summary of lightning safety policies at selected Universities. To qualify as an active lightning safety policy, plans must specific directions for spectators rather than a general evacuation order.

to represent several different football conferences within the NCAA and to distinguish the severe weather policy differences that exist between stadiums of varied location and size. The authors insist that this small sample of college football stadium policies cannot provide an accurate portrayal of lightning policies/procedures held by all stadiums in the NCAA. Yet, the collection of policies in Table 4 is helpful to define the scope of current lightning safety procedures at stadiums.

The University of Tennessee (UT) in Knoxville, a member of the NCAA's South Eastern Conference (SEC), created a lightning policy that actively addresses fan safety. UT developed this policy despite the fact that they have not experienced a lightning incident that caused a delay or the cancellation of a game. The policy addresses the initial detection of lightning and also crowd control during evacuation (Figure 5), making it unique from the NCAA and SEC general policies.

According to the SEC, they do not mention spectators in their lightning safety policy because spectators at a football game are there on a voluntary basis. When lightning threatens, the SEC wants to stop the game so that fans would not have any reason to remain in the stands. Once game officials remove the players from the field, the SEC assumes that spectators will follow suit. As a result, the responsibility to ensure fan safety falls upon the fans themselves and the local stadium management.

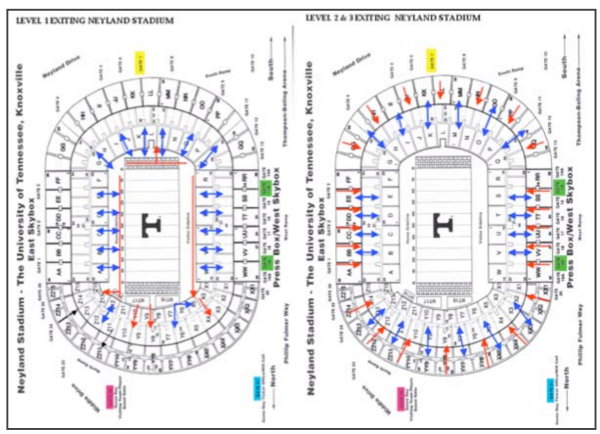

Figure 5: University of Tennessee's evacuation strategy employed when lightning is within 10 miles of the stadium. The arrows on the left map provide direction for spectators on the first level. The arrows on the right map provide direction for spectators on the second and third seating levels. Trained personnel direct evacuations, as fans are not expected to read and/or memorize these maps. (Courtesy of the University of Tennessee)

7.) Recommendations

Existing NCAA guidelines form a reasonable basis for individual stadiums to create their lighting safety policies. The two most important factors outlined in the NCAA guidelines are:

- "As a minimum, the National Severe Storms Laboratory staff strongly recommend that by the time the monitor obtains a flash-to-bang count of 30 seconds [lightning is six or less miles from the stadium] all individuals should have left the athletics site and reached a safe structure or location." According to Holle (2003), six miles is recommended because current lightning research shows that lightning can 'jump' six miles from strike to strike.

- An emergency action plan should include instructions for participants as well as spectators.

These general guidelines were enacted in 1997, yet Table 2 and Table 3 indicate that many stadiums' lightning safety policies used in 2002 and 2003 do not follow the NCAA recommendations. Currently, implementation of NCAA lightning safety guidelines is voluntary.

<u>Possible Solution #1</u>

The NCAA should mandate all schools to follow existing lightning safety guidelines. Schools must complete lightning protection plans for both players and spectators before lightning is within six miles.

Because players and spectators should be in a safe place by the time lightning is within six miles, stadiums must employ an appropriate plan to detect lightning at distances further than six miles. For larger stadiums, which require greater lead times to implement safety plans, in-house lightning detection computer software is useful. In-house software allows for real-time monitoring of lightning and puts stadium officials in charge of their own activities rather than relying on an outside source. Also, stadiums may hire private weather companies, who themselves have access to real-time lightning data, to alert them during any threatening situation.

While both the in-house and private company options require a few thousand-dollar investment per year, large stadiums/schools likely have the budget and large risk to rationalize the expenditure. Smaller stadiums/schools that are unwilling to use their money and/or personnel for lightning detection may choose to rely upon free services provided by local National Weather Service (NWS) offices. Local NWS offices may call stadium managers when lightning is within a certain distance, specified by the manager. While in-house lightning monitoring or hiring a private company is most effective in terms of timing, local NWS personnel are also a useful resource for stadiums unwilling to use their own resources for lightning detection. In either case, lightning warnings for stadium managers are only effective if they provide a the manager with a lead time which allows both players and spectators to seek shelter before lightning is within six miles.

Passive Evacuation

Many stadiums currently use voluntary evacuation strategies to protect fans from lightning. Public address announcements may suggest that fans exit the open seating area of stadiums and seek shelter. Other announcements allow fans to leave the stadium to seek shelter and allow them to return once the lightning threat has passed. This is by far the easiest spectator safety strategy since stadium managers leave decisions for appropriate action to the spectators themselves. While managers cannot force a spectator to make certain decisions, leaving tens of thousands of spectators to individually decide upon a course of action creates a dangerous crowd situation. Past events that employed a passive evacuation strategy resulted in borderline crowd panic situations and the blocking of exits so that some fans could not move into protected areas (Table 2).

Active Evacuation

Virginia Tech and the University of Tennessee's current lightning safety plans provide an active evacuation policy. Tabletop planning (i.e. no simulated drills/actual events have taken place) produced plans at each school that identified where to evacuate spectators based upon their location in the stadium. With prior knowledge of desired crowd movement patterns, on-site emergency personnel/ushers can direct spectators so that crowd control is not compromised. While this active evacuation strategy may be more effective than a passive strategy, large assumptions are made concerning the time necessary to evacuate the spectators and the space available for spectators to find safe shelter.

To fill this void, stadium managers should look to the study of crowd dynamics, which can provide reasonable assumptions of crowd egress time, load points where the crowd flow may encounter problems (e.g. a single escalator/turnstile), and how many people can fit in a specified area. For example, at approximately 3ft^2 per person, involuntary touching and brushing against others will occur which is a physical threshold that should be avoided (Fruin 1984). With this knowledge, stadium managers could easily calculate the available square footage of the stadium that would be considered a safe shelter from lightning. If this square footage cannot accommodate the anticipated number of people at a spacing of at least 3ft^2 per person, than alternative forms of protection (e.g. a shelter in a building other than the stadium or in-situ protection) should be made. Using computer modeling, crowd dynamics may also estimate the time necessary for an active evacuation, providing stadium managers with a basis to decide upon an optimal lead-time for notification.

Possible Solution #2

In-Situ protection can protect a facility and its occupants from lightning by retrofitting stadiums with lengths of wire and additional lightning rods.

When properly grounded, these small additions could protect an entire stadium from lightning with an average of 93% efficacy (C. Andrews, personal communication). Design features such as wires and lightning rods are often used to protect the stadium infrastructure by attracting a lightning strike and dissipating its electrical energy safely rather than through internal stadium wiring, plumbing, or other sensitive components. By extending these features to protect the entire stadium area, players and spectators could be considered safe from the lightning threat (Andrews 2003). In combination, existing structures, new lightning rods, and hanging wires provide near complete protection as seen in Figure 6. While in situ protection is relatively cheap (a one-time expense of tens of thousands of dollars), it requires that spectators remain seated, get wet from the rain, and remain calm in an open location during a potentially frightening (close lightning flashes and thunder) situation. If spectators do not remain seated, then crowd control problems will be an issue.

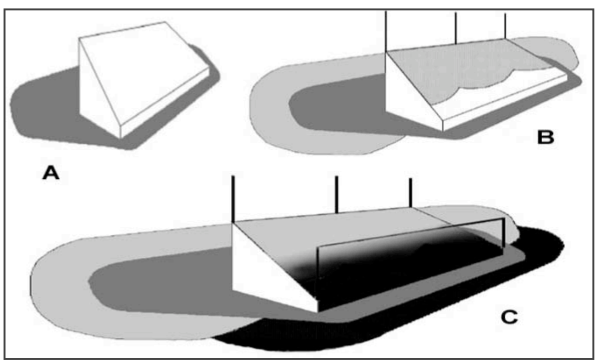

FIGURE 6: Various zones of protection from lightning. A) Zone of protection (dark grey) created by stand-alone seating. B) Augmented zone of protection (light grey) created by fitting the existing seating area with three lightning rods. C) Additional zone of protection (black) created by hanging a thin wire across the front of the seating area. (Andrews 2003)

8.) Conclusions

Stadium managers should either implement active evacuation measures incorporating the study of crowd dynamics or in-situ protection. Both options should safely protect spectators. An active evacuation strategy implicitly addresses the human desire to shield one's self from the uncomfortable weather of rain/lightning/thunder, and also makes a reasonable assumption that actual crowd behavior can be modeled and controlled with proper planning and execution. In-situ protection negates the need to model and manage crowd behavior, but also makes the assumption that spectators will remain in their seats when directed. Crowd dynamics could become an issue if spectators disobey these orders in favor of seeking a dry, sheltered area.

Active evacuation and in-situ protection both provide a reasonable response by stadium managers to the lightning threat. Addressing spectator safety risks posed by lightning should occur in order to maintain the professional safety standards of a large public facility. However, the increase in recent understanding and observation of lightning means that in the court of law, lightning is not always considered an act of god. It is generally accepted that a slight chance of a great harm (lightning) can be condemned as an unreasonable risk, especially where the burden of adequate precautions is relatively slight (Andrews 1992). Consequently, stadiums may face legal action if they do not implement a responsible approach to lighting safety and an occupant is harmed.

Lightning impacted the operation of large stadiums numerous times in the past and will continue to do so in the future. To ensure that all stadium occupants are safe from a potential lightning strike and uncontrolled crowd movements, stadium managers must implement a lightning safety policy using active evacuation methods or in-situ protection. It is impossible to advocate one of these alternatives due to the variety in stadium design, crowd behavior, etc. Therefore, the alternative selected should be based upon minimizing costs while maximizing protection to all spectators, players, and participants in the event.

Acknowledgements:
The authors thank Ronald Holle for his expertise and encouragement as well as Roger Pielke Jr. who provided constant guidance and editorial suggestion. This project was completed as part of a graduate policy class assignment in the Environmental Studies program, and the authors appreciate the constructive comments from all members of this policy class.

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