

Lightning Risk at Outdoor Concerts and Events

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Background

On 27th June 2009, a lightning strike at an outdoor re-enactment of Roman history in Germany left 13 injured.

On 25th July 2009, the first day of the Virgin Festival at Deer Lake Park in Canada was cut short due to lightning. According to reports, the organisers felt that the risks involved in a large crowd standing out in the open during a thunderstorm were too great.

During June 2009, thunderstorms raged around the Glastonbury site, but the festival continued. The same storms passed close to a Madness concert at Gatcombe where CA was responsible for site safety. A call to the stage supplier revealed that they had no documented risk assessment, policy or guidance relating to safety on stage or around their structures during a lightning strike.

A search through available publications shows there is very little if any guidance or standards applicable to outdoor events. We have collected together here any relevant published information we were able to find.

The key questions are whether a mass public outdoor gathering can be considered safe when thunderstorms are nearby, and whether employers are putting workers (outdoors, on stages, at FOH positions etc) at unacceptable risk.

Basic Physics of Lightning

What is Lightning

During Thunderstorms clouds build up an electrical charge. During a lightning strike electrical current flows between differently charged areas. Strikes are classified as follows:

Cloud to Ground

Known as 'Fork Lightning' – the charge can flow in either direction, from ground to cloud (more common negative strike) or cloud to ground (less common positive stroke). From a terrestrial perspective (rather than an airborne one), these are the strikes that are hazardous.

When the buildup of charge in the cloud reaches a sufficient level, a stepped leader (an ionised channel) proceeds

downwards. The field draws charge up from the ground, and charged streamers start rising up from high conductive points. Lightning occurs when a streamer reaches the leader from the cloud completing a path for current to flow. A huge current flows from the ground up to the cloud (or for a positive strike the other way), creating the flash, the bang and the hazard. The exact location where the strike hits the ground is unpredictable.

Negative Lightning involves currents of about 30 kA. The less common Positive CG strikes involve currents of about ten times this.

Intra / Inter Cloud

Usually seen as sheet lightning, a discharge between two clouds, or within one storm cloud tends to light up the whole cloud and therefore sky. These strikes only present an immediate risk to aircraft. IC strikes are frequently a precursor to CG strikes. So an approaching storm that reveals itself in distant sheet lightning cannot be ignored. CG strikes may well follow.

Flash and Bang

A lightning flash is always accompanied by the sound of thunder, but if the flash is sufficiently distant the thunder may be inaudible. Whilst the flash can be seen over many miles, the thunder is usually only audible within about 12 miles.

The light from the flash travels almost instantaneously, whilst sound travels at approximately 330ms^{-1} . The time between flash and bang therefore tells us how distant the strike was – with roughly 3 seconds representing one kilometer (or roughly 5 seconds for a mile).

Within a storm cell, the lightning strikes can reach over quite some horizontal distance, and frequently stretch out towards the leading edge of the storm. The generally accepted 'safe' distance seems to be about 6-8 miles. Lightning any closer than this means the next strike could hit your location. That means anything less than a 30 second gap means there is a risk of an immediate local strike.

This gives rise to the '30/30' rule – when outdoors you should seek safety when the lightning/thunder gap is less than 30 seconds. And you should stay there until 30 minutes after the last audible or visible strike to be sure lightning activity has passed.

This rule has been generally superseded by 'when thunder roars, go indoors'. The speed with which a storm cell could be moving means that by the time you've counted to 30, the storm could be overhead! So a better rule may be to seek shelter as soon as thunder is audible, which means the strike is likely to be no more than 12 miles away.

Hazards and Effects

Direct Injury to people

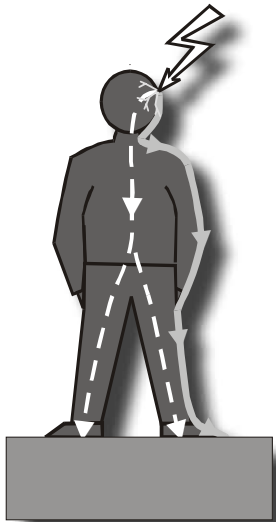
Lightning can cause injury or death in a number of ways:

Direct strike

A person standing in the open can suffer a direct lightning strike.

Contact Voltage

A person inside or outside a structure that is struck by lightning who is in contact with a conductor (either part of a lightning protection system, or that is inadvertently conducting the lightning strike) may (depending on their contact with earth) suffer a contact voltage.

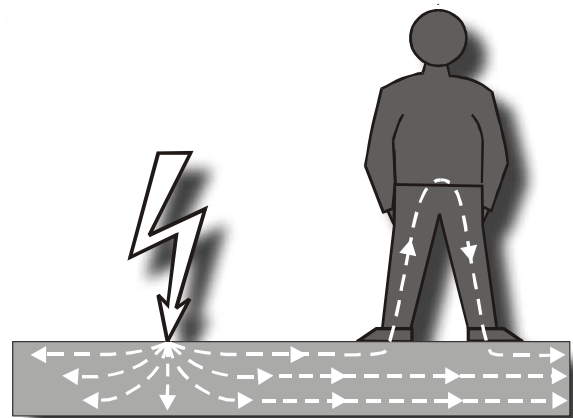
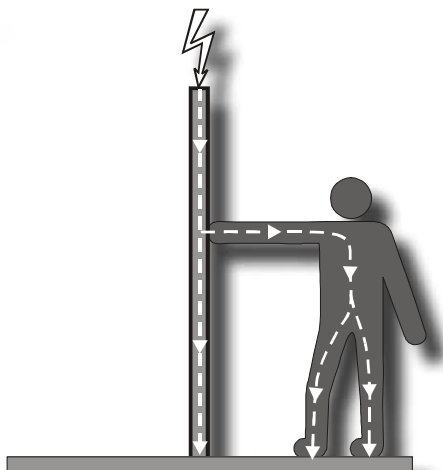
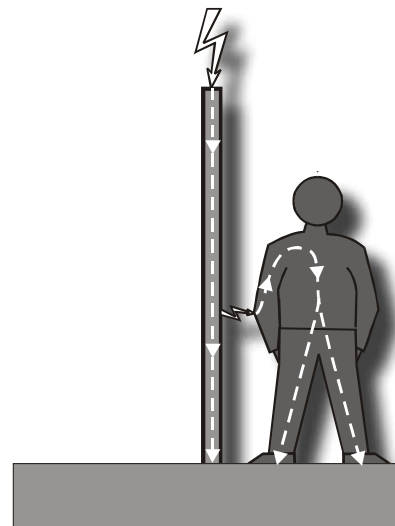


Side Flash

Lightning involves high voltages that can arc or flash across large air gaps. A person near a conductor carrying a lightning strike either inside or outside a structure may suffer a side flash.

Step Voltage

Lightning can cause extreme potential differences within the ground – a person standing on the ground within about 3m of a lightning strike can have such a large voltage across their two feet that a potentially fatal current can flow.



Indirect Injury to People

Fire/Explosion

Equipment connected to electrical systems that are struck by lightning could ignite or explode. Additionally the voltages involved are great enough to cause explosion when passing through materials with a high water content, eg concrete or earth.

Damage to Property

As well as the risk of injury or death, lightning can of course cause considerable damage to property. In the context of events there is also the potential of economic loss (maybe due to cancellation of an event) and reputational loss.

Societal Risks

Lightning has the potential to cause mass casualties and deaths, along with widespread damage to property and crowd panic. The Societal risk of a major disaster therefore needs to be considered over and above the consideration of individual risk.

Current Guidance

There is little available guidance that specifically applies to UK outdoor events.

Most guidance and advice seems to relate to sporting events, and ROSPA's 5 recommendations are taken from a 2002 report *Makdissis, M. and P. Brukner, Recommendations for lightning protection in sport, Medical Journal of Australia, Volume 177, 1 July 2002.*

The guidance is pretty clear that outdoor leisure activities should cease during local thunderstorms. However the requirement for spectators to move to a safe structure / location may be impossible for a large scale concert / festival on a greenfield site.

BS 62305

The IEC has recently published an updated standard for lightning protection to buildings and structures. This standard is in the process of being accepted as a British Standard, which will replace the current lightning protection standards.

Although the standard applies essentially to buildings and lightning conductors, it contains a methodology for assessing lightning risk that is applicable to any scenario.

ROSPA

Rospa published guidance called 'Lightning at Leisure' in 2007. The specific guidance aimed at events is as follows:

Workplaces have a duty to ensure the health, safety and welfare of their staff under the Health and Safety at Work Act 1974 Section 2(1). If staff are working outdoors in exposed areas, this must be reflected in the risk assessment.

Events must be thoroughly risk assessed, and if there is a risk of being struck by lightning this must be looked at and control measures put in place with a lightning safety plan.

Think about the following recommendations :

In case of an event, monitor the local weather from the day before activity to the end of play and the dispersal of crowds.

Have an efficient method of warning people at risk, and evacuation if necessary.

Define and list safe structures and locations. Safe structures can include a large/substantial building with plumbing and wiring that will conduct lightning to the ground such as a clubhouse, or fully enclosed metal vehicles including buses.

Determine criteria for suspension and resumption of activity – for example, use the 30/30 rule.

Ensure the dissemination of information – participants, officials, spectators, and staff must be aware of potential dangers and how to minimise the risk of injury.



NLSI

In the US, the National Lightning Safety Institute publishes guidance. Their recommendations for outdoor workers are as follows:

1. Lightning safety awareness is a priority at all outdoor activities. No place outdoors is 100% safe from lightning. The important thing to remember is to “Anticipate a high-risk situation and move to a low-risk location.” A comprehensive lightning safety program consists of the following details:
2. Detection. Lightning conditions are to be monitored continuously. In most cases, a combination of a lightning network subscription service, a professional-grade lightning warning system, and a high-quality hand-held detector is suggested. However, if thunder is heard, the danger is close enough to suspend operations and to seek refuge.
3. Notification. Suspension and resumption of work activities are planned in advance:
 - Yellow condition: 20-40 miles (30-60 km). Threat may exist.
 - Amber condition: 10-20 miles (16-30 km). Threat is nearby
 - Red alert: 0-10 miles (0-16 km). No one is permitted outdoors.
4. Safe shelter. Safe evacuation sites include:
 - Fully enclosed all-metal vehicles
 - Permanent, substantial buildings
 - Designated metal shelters especially designed
 - Other locations as identified by ES&H personnel
5. Unsafe areas during thunderstorms include proximity to all metal objects, such as power poles, fences and gates, light poles, metal machinery, electrical equipment, hauling machinery, and radio equipment. Avoid rooftops. Avoid water. Avoid all open areas.
6. Re-assess the threat. Wait until thunder is no longer heard before resuming activities. Be extra cautious during this storm phase, as the lightning danger still may be a significant hazard.
7. Resume normal outdoor activities.
8. Policies & procedures. Education & training.

Estimating Risk

On the one hand, the probability of being struck by lightning is put at a vanishingly small annual 1 in 18 million. This is even less likely than a set of six particular numbers winning the lottery at about 1 in 14 million. So lightning risks seem too small to worry about. On the other hand guidance from ROSPA and NLSI is for all outdoor work and leisure activities to cease when lightning is nearby, with both workers and public seeking shelter. A numerical assessment of the risks involved is needed together with some benchmarks on what risk levels are considered tolerable.

We need to focus on two different groups of people – the public (who arguably make their own decision to be in an open field during a storm – and the hazard is an act of god not a result of their chosen leisure activity) and workers (who will be treated differently both under UK law, and also from a moral perspective).

We also need to look at the risk from simply being outdoors during a thunderstorm, and the risks associated with temporary structures (eg stages, PA masts).

If the risk of being outdoors is unacceptable, the only risk reduction measure would probably be to cancel the event – providing an indoors refuge for tens of thousands of people is impracticable. This is what happened at the Virgin Festival in Canada.

Should the risks associated with temporary structures be unacceptable, several routes to reducing the risk are possible. Temporary evacuation of the structure to a safe place might be possible. Or physical protection measures might sufficiently lower the risk to the occupants of the structure.



Risk calculated according to BS 62305:2

The standard defines methods to calculate the following risks:

- R_1 risk of loss of human life
- R_2 risk of loss of service to the public
- R_3 risk of loss of cultural heritage
- R_4 risk of loss of economic value

We're only going to concern ourselves with R_1 here. $R_{2,3}$ are more applicable to buildings, say stately homes (cultural heritage) or power plants (loss of service). And R_4 relates to ensuing economic loss, which is of interest but less significant for our purposes than direct loss of life.

R_1 is made up from two components – R_A (lightning flash to the structure) and R_U (lightning flash to an incoming service). Although R_U might be applicable and could be significant, we'll confine ourselves for current purposes to R_A . The basic equation for calculating R_A is:

$$R_A = N_D \times P_A \times L_A$$

N_D is the average annual number of dangerous events due to flashes to the structure.

P_A is the probability that a flash to the structure will cause injury to living beings

L_A is the consequent loss

Consequent loss is calculated by determining the proportion of people present in a structure that are at risk, and the proportion of time that the structure is occupied. As we're talking about small structures, and we're looking at a single day rather than annual risk, we'll take L_A to be one.

Assessment of the annual number of dangerous events (N_D)

The generally accepted procedure is to multiply the lightning ground flash density (N_g) by the collection area of the object A_d . N_g is the number of lightning flashes per km² per year.

A very useful approximate method is given in the standard:

$$N_g = 0.1T_d$$

Where T_d is the number of 'thunderstorm days' for the location. In other words for an area of one square kilometer, typically a thundery day will result in 0.1 lightning strikes in that area.

That's useful because it allows us to extrapolate from annual risks (which the whole of the standard is based on) to the risks involved in one particular thundery day (much more

useful when discussing one off events rather than permanent structures).

Data and maps giving T_d are available for different locations, but an average we'll use for the UK is 7. We can therefore say that the number of lightning flashes per km² on a thundery day is 0.1, whereas the annual N_g is 0.7.

The collection area will vary depending on the particular event we're looking at. Typically it is defined as the intersection between the ground surface and a straight line with 1/3 slope which passes from the upper parts of the structure (touching it there) and rotating around it. In effect the collection area reaches out from the perimeter of the roofline three times the height of the structure.

For a person out in the open the collection area will be close to a circle with radius three times their height – so let's say approximately 100 m².

In a crowd a strike to a nearby person within about 3m could result in serious flash or step voltages. So it's useful to consider a collection area for a person and their neighbours within 3m. This is approximately 250 m².

For an isolated rectangular structure with length L , width W and height H on flat ground, collection area is given by:

$$A_d = L \times W + 6 \times H \times (L+W) + 9 \times \pi \times H^2$$

So for a stage (approximated to a rectangular structure) with width 20m, depth 20m and height 15m, A_d will be approximately 10,000 m².

We can now work out a few example likelihoods:

The likelihood that an isolated person stood outdoors during a local thunderstorm will suffer a strike. This is approximately $0.1 \times 100/1,000,000 = 1 \times 10^{-5}$

The likelihood that a person stood outdoors in a crowd during a local thunderstorm will suffer a strike near enough to be serious. This is approximately 2.5×10^{-5}

The likelihood that an isolated stage structure will suffer a strike during a local thunderstorm. This is approximately $0.1 \times 10,000/1,000,000 = 1 \times 10^{-3}$

Estimating P_A the probability that a flash will cause injury

For a person outside this is taken to be one – a flash is certain to cause injury.

For a stage, this is unclear. If a stage roof structure is directly earthed with a conductor of sufficient size to qualify as lightning protection, we can probably assume the stage is like a building with lightning protection. However on a stage there is lots of metal roof structure (effectively part

of the lightning protection system) that's within reach, and consequently a far greater risk of touch voltages than in a conventional building. Without sufficient earthing (which is highly likely to be the case in our experience), we can probably take the stage to be a building with no lightning protection.

We'll make an assumption that without proper earthing, P_A is 1, and with proper earthing P_A is 10^{-2} . This seems in line with the figures given by the standard for the probability of a strike causing injury to someone outside the structure who may be in reach of the down conductor parts of a lightning protection system. This assumption is not sufficiently justified, and more research is needed to determine exactly what the risks are of being on or near a stage structure during a lightning strike. We'd also need to take into account step voltages, and therefore look at the resistivity of the stage decking system etc.

So for the moment we have an estimation of these likelihoods:

Injury to an isolated person stood outdoors during a thunderstorm 1×10^{-5}

Injury to a person in a crowd outdoors during a thunderstorm 2.5×10^{-5}

Injury to a person on an isolated stage (properly earthed) during a thunderstorm 1×10^{-5}

Injury to a person on an isolated stage (no protection) during a thunderstorm 1×10^{-3}

As we're taking L_A to be one, these likelihoods are also the risk values R_A for each case.

Tolerability Of Risk

So what do these risks mean and are they to be considered tolerable? To give us some comparison, here are some annual risks of fatality for different activities:

5 hours of solo rock climbing every weekend
 1×10^{-2} (or 1 in 100)

Work in high risk groups within risky industries (eg mining)
 1×10^{-3} (or 1 in 1000)

General risk of death in a traffic accident
 1×10^{-4} (or 1 in 10,000)

Accident at work in the very safest industries
 1×10^{-5} (or 1 in 100,000)

In terms of BS62305, the maximum tolerable value of the risk of loss of human life or permanent injury is 10^{-5} . So the estimates we've calculated are at best borderline, and at worst a hundred times greater than the tolerable risk.

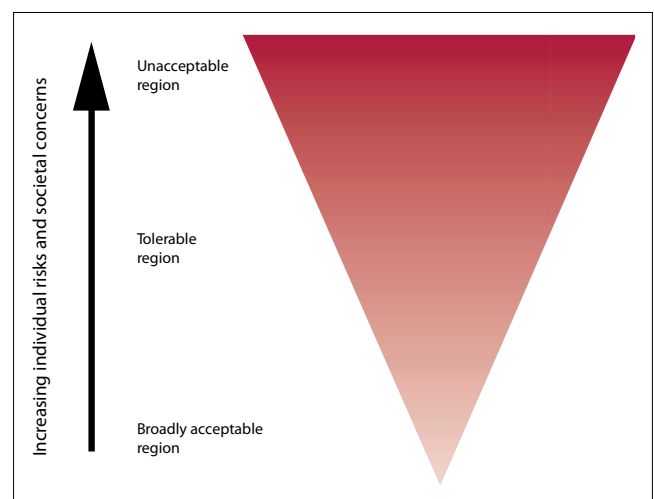
In terms of the HSE's view on tolerability of risk, we have to look at publications relating (by and large) to safety in the nuclear industry, for which much numerical calculation of risks is undertaken.

The broad view seems to be that for workers an absolute maximum annual risk of death is 1×10^{-3} . For the public (eg close to a nuclear plant) an absolute maximum annual risk of death is either 1×10^{-5} or 1×10^{-4} .

Specifically three regions are defined – Broadly acceptable (risks so low that the general public will accept the risks and no controls are necessary) is taken to be risks of about 1×10^{-6} or one in a million. The rationale is that these risks are about 100 times less likely than say the annual risk of death from a traffic accident, that the public accept willingly in every day life. The unacceptable region is risks so great that they are not tolerable under any circumstances. This is taken to be 1×10^{-3} or 1 in 1,000 for workers, and 1×10^{-4} or on in 10,000 for the public affected by work activities. Within the tolerable region in between risks must be reduced as low as is reasonably practicable.

As we're talking about the risk relating to one individual event, we can assume that risks should be lower than the annual figures to be considered tolerable.

That means that in all the cases of the public outside during a thunderstorm, workers outside in a thunderstorm, and workers on a stage during a thunderstorm, the risks that we've estimated are considered not tolerable. They will definitely be greater than the broadly acceptable limit, and therefore need to be reduced as low as is reasonably practicable. And in some cases may be borderline in terms of the absolute acceptability limit.



Suitable Control Measures for the Public

For the public, the risks from lightning obviously do not arise from a work activity. Lightning is an act of God, and it might be reasonable for an event organiser to ignore these risks to the public – lightning is completely beyond their control, and an audience make their own decision to be outdoors during lightning or not.

However it would appear the Virgin Festival in Canada canceled the first day for just these reasons, which indicates a contrary view. And all the advice for the public undertaking leisure activities such as golf or fishing is for them to seek refuge and not be outdoors during a thunderstorm, which again would suggest the risk is not acceptable.

We also need to remember that we've only looked at the risk of strikes to a person in the open. Despite all advice being to the contrary, the public will often seek shelter during a storm under trees, and many of them maybe located dangerously close to FOH towers or PA masts, that places them at greater risk. Under an isolated 25m high tree, your risk of a lightning strike increases from 10^{-5} to about 2×10^{-3} , which is well into the completely intolerable risk level.

Unlike many sporting events, it would not be possible to move the audience for an outdoor concert to safety within the site (which requires being inside a 'proper' building or a vehicle). The only option would be to evacuate the site and for the attendees to return home as happened in Canada.

As another option, the audience could be informed of the hazards, and in particular briefed not to stand under or near high structures. This would at least mean risks are probably tolerable if not broadly acceptable.

There appears to be no simple rule or consensus as to how to treat the audience at an outdoor event if a thunderstorm is approaching.

Suitable Control Measures for Workers

Further work is needed to more accurately estimate the risks of being on a stage during a thunderstorm. It may or may not be more dangerous than being out in the open.

For workers in the open the numerical risks are within the tolerable region, which means measures must be in place to reduce the risk as low as is reasonably practicable. Certainly all guidance (both US and UK) is that workers must not be outdoors during thunderstorms, and must seek safety in a refuge.

These risks should be identified and controlled in the risk assessments for any outdoor event.

We would suggest that during build periods for any outdoor event site, some kind of monitoring is essential. Before lightning is within strike range (ie thunder is audible), procedures should be in place to stop outdoor work, evacuate hazardous locations (eg working at height, PA masts, and maybe stages), and move all employees to an identified safe place. Monitoring would need to continue to determine when it is safe to return to work.

The same should apply at all times which would include during shows, which could include show stop procedures being initiated. Although at this point the public are on site, and so public safety will have to be considered too rather than considering employers in isolation.

Lightning Detection

Critical to controlling the risks associated with lightning is the detection of nearby lightning so that appropriate action can be taken. Three methods are recommended by the NLSI – online services, Static detectors, and handheld detectors.

Static Sensors

Most static sensors measure the RF signal given off by lightning strikes. Using two antenna they can be made directional. They have no way of detecting directly the distance of the strike, so rely on an assumption that weaker signals originate from further away. They can therefore confuse weak nearby strikes with stronger more distant ones. Software is usually able to differentiate between IC and CG strikes. See Boltek for some of the most common detectors, and software from Astrogenic. The Strikestar network use Boltek detectors and Astrogenic software.

Another type of sensor – the Electric Field Mill – doesn't detect lightning strikes, but the build of local electric field. It is therefore the only type of detector that can warn of strikes before they happen. Boltek also make field mills.

Online Services

Online services use either individual directional RF detectors, or more usual a network of detectors to triangulate the location of lightning strikes.

Blitzortung.org allows users to enter an exact location and see the number of strikes within a preset radius, even setting alarms. In use we've found its display to mirror accurately whether there is 'lots of lightning' or 'no lightning' around. But it's certainly not accurate enough to correctly detect the majority of individual strikes. There are no sensors in the UK in the network, which leads us to be dubious about the accuracy.

Strikestar UK doesn't seem to be very accurate at all. Sensors are based in the UK but the small number is probably not sufficient.

Strikestar EU seems generally to be accurate. Sensors are based all over UK and the EU. However there is no function to set a specific location of interest.

Some individual detectors make their data available online – for instance Newport weather.

Handheld Sensors

Several manufacturers make relatively cheap handheld detectors. These are not directional, but can give warnings of the distance of approaching storms, and in some cases an ETA. See Strikealert and Skyscan.

Advanced models such as the Thunderbolt storm tracker use on board software to predict whether a storm will hit or skirt round your location, when it will arrive, and when it will have passed. We have no information as to the accuracy of this product.

Summary

There is little clear consensus either on the risks to the public and the necessary control measures, or what lightning protection is necessary for outdoor structures.

We would welcome information from anyone with knowledge and experience in this field, and will produce updated versions of this white paper. Please contact the author James Cobb by email james@caevent.co.uk

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- HSE: Reducing risks, protecting people