

## LIGHTNING SAFETY GUIDELINES

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**Abstract - This paper introduces lightning to the layman, noting the right behaviour in front of thunderstorms as well as protective measures against lightning. It also contributes to the prevention of lightning injuries and damages. This report was prepared by the authors inside the AHG1 Group for IEC TC81 (Lightning Protection).**

### 1 - DANGER DUE TO LIGHTNING STRIKES

The goal of this document is to introduce lightning to the layman, noting the right behaviour in front of thunderstorms as well as protective measures against lightning. It contributes to the prevention of lightning injuries and damages.

Note, that so far there is no means to avoid lightning. Anyway, following some elementary rules, we can protect people, animals and objects against its deleterious effects.

#### 1.1. What are the damages?

Generally, the energy brought by lightning is relatively low, though the instantaneous electrical power is very high. Indeed, this energy acts on an element during less than some milliseconds (ms). High voltages can occur and currents as large as 200 kA can flow. Consequently, thin wires melt and objects are heated up so strongly that highly flammable substances get on fire or explode.

If the lightning current finds its way over damp walls, joists, roofs or trees, these can suddenly explode. Indeed, objects struck by lightning can explode or ignite.

Lightning currents can penetrate into buildings and structures, along telecommunication lines and power lines, destroying electrical and electronic equipments.

#### 1.2. What are the dangerous places for human beings?

The effects of lightning are numerous.

##### 1.2.1. Direct strikes

The **direct lightning strike** is the most dangerous. The lightning current flows through man and causes

unconsciousness, inner or outer burnings, apnoea, cardiac arrests or paralyses.

In open air, living beings are not only sensitive to *direct strikes* (more likely when they are standing up), but also to *side flashes*, *induced discharges*, *touch voltages*, and *step voltages*.

##### 1.2.2. Side flash

It is dangerous to stay under an isolated tree (or a wooden mast) because if the human body is at less than several meters from the trunk, it may experience a **side flash** at the head or shoulder level.

##### 1.2.3. Induced voltages

Generally, all non-protected structures have to be avoided. It is better not to use small isolated structures (i.e., huts and barns) as shelters from lightning, nor buildings with metallic roofs isolated from ground, for example, supported by non-conducting poles (*electric discharge induced* by capacitive coupling).

##### 1.2.4. Touch or contact voltages

It is advised to stay far from metallic structures, not only to avoid side flashes, but also to reduce the risk of electrification by touch voltages. Indeed, *electrification* by *touch voltages* (or *contact voltages*) occurs when people with feet in contact with the sufficiently conductive ground touch a conductive structure that may be at a different potential due to a lightning strike to that structure or its lightning protective system. Avoid touching metallic objects during thunderstorms.

##### 1.2.5. Step voltages

When lightning strikes the ground, the lightning current is spread out through the various layers of the soil. A high potential rise occurs at the point of strike. *Step voltage* can be experienced near this point, especially for quadrupeds that will be electrocuted because of a *potential gradient* applied between anterior legs and posterior legs. In the latter case, electric currents cross the body passing through the heart. Lots of lightning hazards to sheep and cattle have been reported.

When walking, people can experience an *electrification by step voltage*; this situation is more hazardous if the

ground resistivity is higher, the distance to the strike point is smaller and the distance between the two feet is larger.

## 2 – EFFECTS OF LIGHTNING STRIKES TO HUMAN BEINGS

### 2.1. What are the possible injuries?

When a human being is directly struck by lightning, the voltage climbs up to 300 kV (100 to 500 kV) from feet to head. The far largest portion of the lightning current does not flow through the body but on its surface. Due to this effect, many people have survived after a direct lightning strike.

Physiological effects range from being dazzled to almost instantaneous death (full cardiac arrest), through neurological troubles, visual loss or cataract, deafness or ruptured eardrum, paralysis, temporary fainting (sometimes with short respiratory arrest), short or long-duration comas...

The *body crossing* from feet (tree-like burns) to head (electrically, the human body behaves like a gel, with an internal resistance of about 300 ohms) leads to serious or even fatal injuries. Nevertheless, ionized skin and wet clothes represent a preferred path for the electrical discharge which licks the body under the clothes avoiding the whole lightning current crossing the body itself. Clothes blow up under the pressure wave generated violently. Even shoes can be blown at large distances. This thermal shock is so short that only superficial burns can occur, but metallic objects (i.e., necklaces) can reach high temperature (at least superficially) leading to deeper burns.

Generally burns are superficial (deeply cutaneous close to the incoming and outgoing points, linearly superficial corresponding to the quick bypassing electrical discharge, superficial but spread out by the electrical arc). Those occurring through hot metallic objects are more serious.

Lightning victims can also have erythemateous treelike discharges or Lichtenberg figures which are keraunographic fractally-shaped prints initiated by a leader circulating between clothes and skin. These pathognomonic figures, which testify for the current flow, do not become white on pressure and disappear after one or two days. The lightning current also burns hair.

A lightning strike can cause abrupt loss of consciousness and sometimes incontinence of urine and/or ejaculation of semen. Commonly, there is cessation of heart action and breathing so that the victim appears clinically dead. Injury to the cardiovascular system can lead to cardiorespiratory arrest (asystolic arrest) which requires urgent management. Other arrhythmias (tachycardia, bradycardia...) and ventricular premature contractions have been reported. Brain injury is often present as well (amnesia, papillary abnormalities, painful paresthesiae, aphasia, headaches...).

Some injuries only occur after some days or even some months: chronic pains, high blood pressure, memory failures and even personality changes.

**Burns** (flash burns, feathering, erythema, linear streaking, punctuate full-thickness skin loss, contact burn from metal)

**Heart** (cardiac arrest, ventricular fibrillation, heart damages, hypertension...)

**Brain** (central nervous system failures, brain damages, keraunoparalysis, unconsciousness, amnesia, personality changes...)

**Respiratory system** (respiratory arrest, bronchospasm, pulmonary oedema, apnoea...)

**Musculoskeleton system** (keraunoparalysis, contusions, lacerations, fractures of bones, chronic pains...)

**Eyes** (corneal flash burns, vitreous hemorrhage, retinal tear, macular puncture, retinal detachment...)

**Ears** (barotrauma, ruptured tympanic membrane, deafness, otorrhea, ataxia, nystagmus...)

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### Possible injuries due to lightning strikes

### 2.2. How can we help injured people?

Lightning injuries can generally be grouped into three classes of severity: mild, moderate and severe. The emergency treatment must be appropriate to the level of injury. Anyway, you need to immediately call a medical help and a rescue service. A first-aid can be life-saving.

The mildly injured patient is often just stunned by the lightning strike. They are usually awake though confused and amnesic for the event. Recovery can be gradual, but they may complain of paresthesia and muscular pain lasting for several months. First of all, assess the situation. Then provide supportive and physical care to the patient, urging him to be transported to the hospital for evaluation and treatment.

The moderately injured patient may be disoriented with keraunoparalysis of the extremities lasting for several hours. Hypotension, tympanic membrane injury, burns (first- and second- degree) are common. Though he is likely to survive, he may have permanent sequelae (sleep disorders, personality changes, difficulty with some mental functions...). The patient should be evaluated with an electrocardiogram. Moreover if the victim is unconscious, pulses should be sought centrally in the carotid or femoral area. If the victim does not breathe and does not have a pulse, cardiopulmonary resuscitation should be started immediately.

After calling emergency services, check the victim's breathing. If there is a cardiac electronic defibrillator available in the area, use it first. The victim lies on his back. Press the victim's forehead back with one hand, lift the jaw with two fingers of the second hand and check

airway. If the breathing has stopped or is not normal, start resuscitation. Press the victim breastbone with both hands (one over the other) with your arms stretched out, push 30 times in 20 seconds so that the breastbone is each time depressed 5 cm. Check airway again, press the victim's nostrils tight with two fingers, press your lips to his mouth and blow twice so that the breast rises. Repeat the cycle "30 pushes - 2 blows" until breathing is restored or other aid is available.

The severely injured victim often experience a cardiac arrest with either ventricular standstill or fibrillation. Cardiac resuscitation may be successful. Direct brain damage may occur; blunt trauma, skull fracture, intracranial injuries are common. Recovery is generally poor in this case, if a medical response team is not present early enough.

### **3. HOW TO BEHAVE FACING A THUNDERSTORM**

#### 3.1. How can we detect a lightning risk?

Weather forecasts mention the approach of thunderstorms in your region. Looking at Internet, you can even follow this approach in real-time in many regions during about two hours.

Lightning warning systems can also be used both for industrial sites and private activities. Network of detectors exist in some countries and provide, by Internet or by other means (fax, phone, mail ...), a warning on the occurrence of a lightning event. An industrial dangerous activity can be stopped, people can be transferred to safe shelters and exposed activity (for example, on roof or tanks) can be avoided. Local detectors also exist. Some sensors can be portable but are generally less reliable than others. Being light and quite inexpensive, they can be used as an ultimate barrier for people having open field activity. Fixed sensors are more bulky but also more reliable especially in their capability of giving an early warning. They can be used for industrial sites but are also efficient for golf courses and camping camps, for example. The warning time is generally less than 30 minutes, so a safe shelter on the site is strongly recommended .

You can evaluate the risk for your activity, by watching the approach of the thunderclouds (cumulonimbus) with the eventual far flashes and by listening to the thunder. The actual distance of a thunderstorm can be roughly estimated: the number of seconds between the flash and the thunder divided by 3 gives you the distance in kilometers. From 5 km, an outdoor sport event should be interrupted and you should avoid dangerous places, like isolated trees.

Half an hour after the last flash you see or the thunder you hear, you can assume that the lightning risk is over.

A correct behaviour considerably reduces the risk of being injured by lightning. Lightning is unpredictable, don't trust your good luck!

#### 3.2. Where do we find safe locations?

Inside buildings equipped with lightning protective systems (external and internal), there is no danger for human beings, animals and devices.

At home, without any lightning protective devices, it is advised to close doors and windows to repel air streams, to sit down around the family table far from any fireside or other chimney. Avoid open spaces such as balconies.

The preferred option consists of installing Surge Protective Devices (SPDs) in the incoming panelboard to protect the electrical devices, TV, antennas or telecommunication cables (even when these cables are underground!). When this is not provided you should unplug those devices.

Use mobile phones and cordless telephones. Don't call from a cord phone. Keep clear from electrical power lines, telecommunication lines, water or gas metallic pipes, as well as household electrical (i.e., extractor hoods, dishwashers, electric heaters). Don't take a shower or bath during a thunderstorm.

Remote lightning elements can also further cause overvoltages in buildings which are not equipped with professional protective systems.

You should stay in the middle of the room with closed feet and even in the squatting position inside barns, wood or stone huts without lightning protective systems. You also adopt the same rule in the middle of an open side as far away as possible from the walls in partly open shelters like bus shelters.

An SPD should be provided at the entry point of each power and telecommunication line.

#### 3.3. What to do outdoors?

If the probability of lightning strike is higher on tall objects like trees or masts, don't forget that it may strike anywhere.

Don't walk close to rivers and, more importantly, don't swim during a thunderstorm. Avoid horse riding, bicycle or motorcycle, convertible cars, routier tractors, harvesters (several farmers were struck by lightning).

In town, rush into a store or a public building where you are protected.

In the countryside, walk far from highest points, don't stay in a group, and move away from street lights, towers and metallic fences as well as isolated trees.

Isolated trees are particularly hazardous. A safety distance of 10 m should be kept from the trunk and from the tree branches.

The ideal position to be adopted in open air is surely not the standing one on the ground but the crouching down one, with the head as close as possible to ground and arms encircling legs. Human beings standing up with joined feet can be hit by a *direct strike*.

It is also dangerous to stay at the edge of a forest; in this case, it is better to stand inside the woods in the middle of the trees.

Keep away from fences and other metallic structures, ditches and other wet places, open fields, hilltops and shores. Don't hold long metallic or other conducting objects in your hands.

If you are absolutely obliged to travel under a thunderstorm, take short steps or run (in which case only one foot touches the ground) by avoiding to unfold any protruding metallic object (umbrellas...).

If no protected area is available, you should leave free areas like dykes or grazing land.

You should stay at least half a meter from walls, supports, metal fences, particularly from parts of the lightning protective system (derivations).

Join your feet to avoid a possible surface voltage gradient. If several persons stand together, these should not touch themselves but keep a distance of at least half a meter to each other.

Don't use bicycles, motorbikes, horse-riding, open vehicles and boats, sailing boats (unless properly protected against lightning), tents, open picnic pavilions, trams with open windows, umbrellas.

### 3.4. Hazardous situation in a car

A metallic car constitutes a good protection (Faraday cage) if windows are rolled up. As a good electrical conductor, a car keeps the passengers protected against lightning. Nevertheless it is advised to drive carefully (at a moderate speed) in a thunderstorm to avoid uncontrollable jumps issued from lightning terrors.

But vehicles with fiber-glass bodywork (e.g. mobile homes) as well as convertibles without roof metallic framework or roll bar offer a far lower protection.

Driving a car is nevertheless dangerous during a thunderstorm:

- the vehicle can be damaged through the tires due to the warmth brought by the derived current; tires have no protecting effect;
- don't touch metallic parts while sitting in the car;
- the electronics can be perturbed by the electromagnetic field accompanying the lightning current (check the functionality of the car electronics after a thunderstorm!);
- shrill flashes and simultaneous loud thunder may cause fatal driving errors and a heavy rain obstructs the view;
- traffic lights and signals may be out of proper work.

You should delay your journey for the duration of an intense thunderstorm.

Similarly, in a plane with metallic skin, there is nothing to be afraid of since pilots and passengers are protected

inside a Faraday cage. Scientists have proved that planes and rockets initiate lightning discharges from their extremities. Anyway, planes are subject to be snapped up by strong downward airstreams, particularly at the edges of cumulonimbus clouds, crashing to the ground. Pilots must avoid such dangerous air regions.

### 3.5. What to do in case of camping?

In a camping tent or trailer, be sure that a metallic conductor surrounding the whole volume to be protected is correctly earthed.

Caravans and mobile homes with an outer metallic skin offer the same safe protection as cars with metallic bodywork. However, persons inside vehicles with fiber-glass bodywork are endangered.

Recommendations:

- never put up tents, estate cars and caravans in prominent sites, on hilltops at the edge of the forest or under isolated trees;
- hold at least three meters from neighbouring tents and camping cars;
- don't install metallic wires between tents and camping cars;
- stay inside the tent in the crouching down position, keeping distance to the metallic tent poles ;
- unplug all lines by pulling the plugs out of the parking space;
- remove outdoor antennas;
- don't forget that metallic tent pegs, connected to the bodywork of mobile homes generally act as lightning conductors.

### 3.6. Thunderstorms in mountainous regions

In the mountains, lightning is extremely dangerous for hikers and mountaineers. Don't forget that the weather can change very quickly. Run away quickly from the top and stay far from walls, cracks, crevices, edges, protuberances and trees. Get rid of metallic objects. It is better to crouch down in order to decrease the body surface and to protect yourself against diverted currents.

Don't touch a rock face with hands or feet; a lightning current could flow through your body and throw you several meters away.

Stop climbing up the mountain when a thunderstorm is approaching and try to reach a safe mountain hut (with lightning protective system) or the accommodation exit in the valley before the outbreak of the thunderstorm.

If this is not possible, metal bivouac boxes offer a certain protection on fixed rope routes. You are also relatively safe in caves under ledges or at the lower parts of rock faces. There try to keep half a meter away from the wall.

Metallic ropes, wet climbing ropes, ladders and bars as well as damp rock faces should not be touched.

Thunderstorms can initiate rock fallings and dangerous avalanches.

### 3.7. What to do on the water?

Keep away from water sports : no swimming, no surfing, no canoeing, no yachting, unless boats are adequately protected by means of external metallic structures used as lightning rods and plunging into water with their bottom part (electrical connection to water).

When a thunderstorm approaches, leave the water as well as the shore zone and run to a protected area. In the water, the lightning current is spread over large surfaces: at 100 m from the strike point the current is still hazardous.

Caution should also be drawn while scuba-diving. Although the danger of a direct lightning strike is low underwater, some vaporizing of the water can be triggered by lightning, generating a shock-wave. Possible injuries reach from the ruptured eardrum to embolism and loss of consciousness. When leaving the water people are endangered.

Boat masts are attracting prominent points with respect to sea or lake level. During a thunderstorm, don't stay on the deck and stop fishing. Squat with closed legs as deeply as possible into the boat and avoid touching the rigging or other metallic parts.

### 3.8. What to do in case of open air festivals?

The same elementary rules apply to open air events as in the case of other outdoors activities..

In principle, spectators sitting or standing on open platforms are endangered; when a thunderstorm approaches, they should run to lightning protected areas. Platforms equipped with a lightning protective system or covered with a roof made of metal or reinforced concrete are regarded as protected areas.

No metallic parts, columns, walls, jamming fences, jostling bars should be touched. Keep away more than half a meter from all these.

You should narrowly join your feet to avoid a possible surface voltage gradient.

Before any event with many spectators attending, correct information on the forecasting should be brought.

### 3.9. What to do when playing outdoors sports?

Golf courses belong to particularly dangerous places during thunderstorms, due to the area profile and the presence of isolated trees or clusters of trees as well as the golf equipment. Relatively frequent injuries and deaths occur on golf courses by lightning strikes.

Lightning accidents also happen when football players are directly hit and seriously injured. Referees and coaches should therefore call the players out of the unprotected field and accompany them to safe accommodation places.

When a thunderstorm approaches, staying in the open air should be avoided and the game or training should be interrupted.

Buildings with lightning protective systems or closed vehicles offer the best protection.

If these are not available, the following areas should be considered as the second best possibility:

- buildings without lightning protection systems;
- large tents;
- short distance environment of buildings or metallic masts; a distance of at least 0.5 m, or better 3 m, is to be kept to walls and metallic parts;
- in order to reduce the surface voltage gradients, feet must be joined.

If no protected zone is available, e.g. a football field without masts nor shelters, players should crouch down, not touching the ground with hands to support themselves.

You should never consider trees as protected zones and you should avoid standing in groups; keeping a distance of at least 5 m from each other is highly recommended.

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