Lightning
Elements of industrial accidentology

France, 1967 - 2007

In Greek and Roman mythology, "*lightning"* is depicted as a fiery and zigzag bolt. It is the weapon and attribute that Zeus (Jupiter) used to fight enemies and establish his supremacy over the gods. Lightning was reputed to comprise three thunderbolts: the first to warn, the second to punish and the third to destroy the world marking the end of time.

Lightning is still feared in current times, more so as a physical phenomena resulting in substantial damage or victims than a divine manifestation. In industrial facilities, it results in equipment damage including failure and may jeopardise the safety of equipment, people and environment.

The accidentology analysis presented in the following pages describes the impact of lightning on industrial facilities in **France**. The analysis is based on events recorded in the ARIA database (Analysis, Research and Information on Accidents) managed by the Risk Prevention Department of the French Ministry of Ecology, Energy, Sustainable Development and Town Planning.[1]

The ARIA database records 101 lightning accidents that took place between October 1967 and July 2007 that impacted or were likely to impact classified installations. Due to lack of information, the accident sample in all likelihood is not fully representative of the accidents occurred. Moreover, keeping in mind the available data, this work can only be considered as a statistical survey.

The list of illustrative French accidents is included in appendix 1. Fifty lightning accidents that occurred outside France are also recorded in the ARIA database in appendix 2.

The summaries are characterised by the 4 indices referring to the 18 parameters of the scale made official by the Committee of Competent Authorities of the Member States which oversees the application of the 'SEVESO' directive. These indices correspond to:


Dangerous materials released


Human and social consequences


Environmental consequences


Economic consequences

Each index is rated on a scale of 6 according to the European rating rules that can be consulted on the website **www.aria.developpement-durable.gouv.fr**.

[1] The ARIA database is essentially a record of the accidental incidents which have or could have been hazards to human health or public safety, agriculture, nature or the environment. For the most part, these incidents result from the activities of factories, workshops, warehouses, work sites, breeding operations, etc. which are classified under the legislation relating to Classified Facilities, as well as from the transport of hazardous materials. The recording and analysis of these accidents and incidents, in France and abroad, have been organised since 1992.

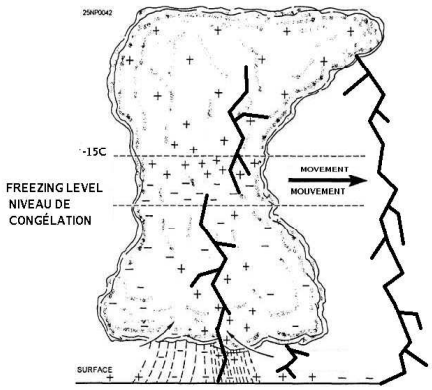
A – Lightning and its effects

Meteorological phenomena

Thunder clouds (cumulo-nimbus) create weather conditions that favour the accumulation of electrical charge and consequently the creation of a giant condenser.

- a significant temperature difference between the top and bottom of the cloud results in violent air movements;
- the presence of various particles such as ice and dust that facilitate the removal or addition of electrons according to the charge by triboelectric effect (exchange of electrons between 2 different materials)
- since air (and its constituents) is electrically charged, zones with different electric potentials are created in the clouds: negative at the bottom and positive at the top. This results in a strong electric field.

When this electrostatic field exceeds the dielectric limits of the air (variable depending on humidity and pressure conditions) a lightning discharge aimed at re-establishing the electrostatic balance is observed.



D.R.

Distribution of electric charge in a cloud

In the analysed accidents, the lightning impact mainly results in:

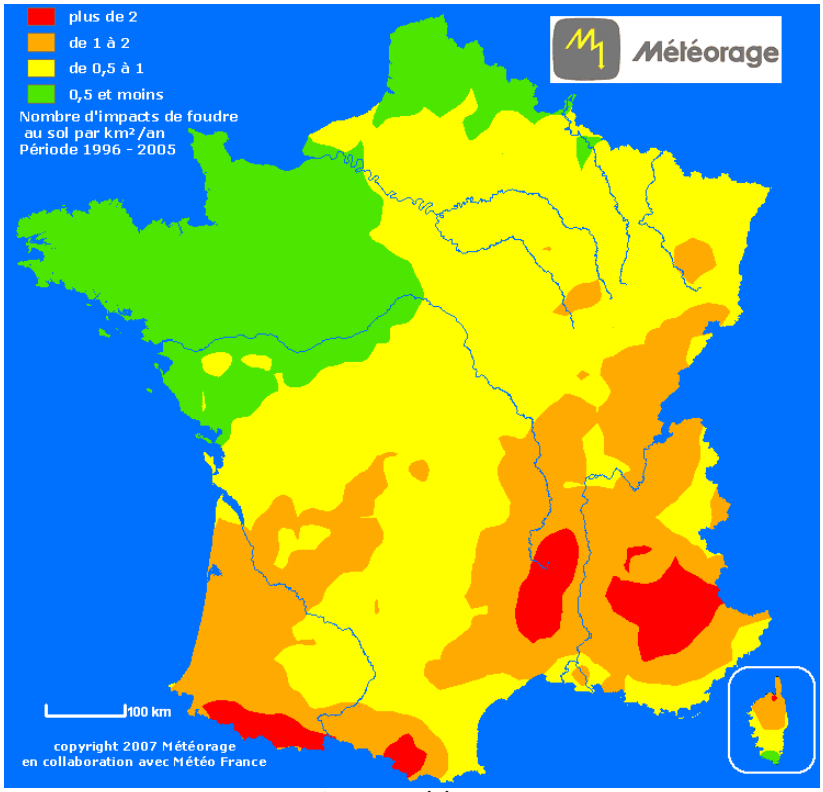
- thermoelectric **effects**: a very strong flow of electric current heats materials and often causes significant even spectacular material damage.

- electromagnetic **effects**: lightning current creates an exceptionally intense electromagnetic field and voltage. This results in very powerful parasite electrical pulses that are responsible for damage in a majority of cases according to statistics. These electrical pulses are enough to damage sensitive electronic material even if lightning strikes far away.

- conduction (pace voltage): when lightning strikes the earth, the electrical charges dissipate in the soil and create a strong electric voltage. Depending on the nature of the soil (its resistivity) and impact distance, the current can pass through the lower limbs of human being.

Information on the possible effects of lightning on structures and utilities is available in the French standards documents (CEI and NF EN 62305-1 §5). The standard does not deal with some underground pipes and power or transmission lines.

As shown in the lightning map created by the company Météorage covering the period 1996 – 2005, all regions in France are prone to thunderstorms and are likely to be impacted by lightning.



Source : Météorage

B - Types of activities concerned

All industrial and agricultural sectors are potentially exposed to the risks of lightning:

- chemical industry *(ARIA 1884, 2715, 3707, 5874, 8885, 9996, 10074, 11262, 11562, 15749, 15833, 18563, 25147, 27506, 30199, 30325, 30894, 31773, 33604)*
- agricultural activities and animal husbandry *(ARIA 5870, 5871, 7168, 7663, 7664, 12937, 15849, 15934, 16412, 20662, 21493, 22776, 25463, 33277)*
- refinery *(ARIA 6277, 15215, 26503, 26535, 26577, 26579, 30892)*
- food industry *(ARIA 8909, 16283, 18325, 20844, 25617, 33120)*
- nuclear production and transformation sites *(ARIA 343, 4507, 19716)*
- pipeline transport *(ARIA 5678, 7508, 7545, 23626, 30130)*
- …

The distribution of accidents in the national territory mainly depends on the density of implantation of facilities, their vulnerability, as well as the intensity and frequency of thunderstorms. Some regions show a greater number of recorded events (Rhône Alpes, Provence Alpes Côte d'Azur, Midi Pyrénées, Aquitaine). This observation is consistent with the lightning map• published by Météorage.

• The number of lightning impacts on ground per km² per year is different from the keraunic level defined by the average number of days per year when thunder can be heard.

C – Typology of accidents

Table 1 presents the main typologies of the accidents included in the sample:

*Typology**	*No. of cases*
Fire	70
Emission of dangerous substances or pollutants	30
Fall / projection of equipment	3
Explosion	10

***Lightning may sometimes generate several typologies (e.g. explosion with projection of equipment followed by fire – ARIA 8885).*

Table 1

Fire is the most commonly observed typology (70% cases) and concerns both industrial units as well as farm and livestock buildings (*ARIA 3707, 6277, 7168, 7664, 8885, 9996, 10074, 11262, 11562, 12937, 15215, 15849, etc.)*. Fire-fighting operations often last long *(ARIA 4801, 7664, 12948, 18325, 25440, 33120)*. Rescue services are likely to face problems due to tough climate conditions as well *(heavy rains preventing the fire smoke from rising, violent winds helping fire to spread ARIA 9996, 12948)*.

In over 10% cases, fires *(ARIA 4801, 12948, 15689, 23626, 24526, 27885, 29439, 30894, 33120)* spread to electrical equipment *(ARIA 4801),* gas pipes *(ARIA 23626),* flammable product storage sites *(ARIA 24526),* buildings *(ARIA 27885),* etc.

To prevent or curtail the spread of fire, the electrical fire protection equipment (sprinkler network pump, etc.) must be protected from the effects of lightning *(ARIA 33544)* and from frequent power cuts during thunderstorms.

Foreign accidents

ARIA 8183 – 24/10/95 – INDONESIA – CILACAP

Lightning struck the automatic gauging device of a 38,800 m³ fixed-roof tank being filled with kerosene. The poor equipotentiality of the device resulted in sparks that triggered a fire. The gaseous cloud over the tank exploded destroying the roof. The burning liquid spread the fire to six other tanks in the dike. The residents and staff members were evacuated. No victims were reported. Nearly 600 homes were damaged and some hundred water bodies were polluted. The fire was extinguished after three days. The damages are assessed at 560 MF**.**

The emission of dangerous substances or pollutants is often the result of direct or indirect effects of lightning:

- spillage or leakage following impacts on equipment or pipes (*pipes: ARIA 5675, 5678, 7508, 7545 - destruction of transformers: ARIA 7348, 8909, 12150, 33092 – damage to video surveillance equipment ARIA 2715*) ;
- polluting or toxic emissions subsequent to power cuts or electrical disturbances *(ARIA 1884, 5874, 15749, 18563, 30199, 30894).*

Moreover, several cases of explosion accompany accidental spillage *(ARIA 6139, 7348, 11239, 12150, 12220).*

D - Causes

Even though lightning is the external factor triggering accidents in an industrial site, lack of protection or management of electrical networks and equipment, electrical problems, faults in designing, poor site operation and managing are often the root causes of incidents or accidents.

Several accidents result from electrical malfunctions *(ARIA 2715, 5874, 15749, 15934, 19539, 20844, 30199, 30892, etc.)* subsequent to the impact of lightning:

- rupture of a 225 kV electric cable *(ARIA 19539) ;*
- formation of an electric arc with ignition of propane *(ARIA 5675)* ;
- electric overvoltage *(ARIA 20844) ;*
- power supply failure *(ARIA 1884, 5874) ;*
- inadequate protection of electrical devices or circuits *(ARIA 1200, 2715, 26577, 32016, etc.)*.

Momentary or total loss of power supply is likely to impact all electrical devices and equipment supplied leading to alarm, sensor (*ARIA 26577)*, and equipment *(ARIA 4507)* failure and more often failure of the control system lure that results in accidental emissions or spills.

Faults in design, operation and management involve:

- insufficient analysis of lightning risks *(ARIA 3707, 27506, 33544) ;*
- poor management of sudden stop *(ARIA 15749)* or start-up phases of units *(ARIA 26503, 26579)* during thunderstorms without an adapted inspection of potentially impacted devices and equipment;
- non-functional data communication systems.

E - Consequences

The distribution of consequences is indicated in table 2:

*Consequences**	*No. of cases*
Deaths	2
Injury	10
Internal equipment damage	87
Internal operation loss	39
Technical unemployment	6
Deprivation of use - electricity	3
Deprivation of use - gas	3
Atmospheric pollution	13
Soil contamination	6
Impact on farm animals	4

Tableau 2-

**A single accident may have several types of consequences*

Human casualty was reported in two accidents:

- 4 people died and 25 sustained injury in an explosion in an aluminium foundry *(ARIA 6139)* ;
- 3 sailors, 2 operators and a truck driver were killed in an explosion of an oil tanker anchored to the port in a terminal struck by lightning *(ARIA 12220)*.

Foreign accidents

ARIA 1001– 12/08/1989 – CHINA – QINGDAO
A tanker in an oil depot was struck by lightning and resulted in a fire that consumed over 40,000 tonnes of crude oil. A significant amount of resources were used to stop the fire including 100 fire engines and several helicopters. 19 people died and 74 (mostly fire-fighters) people were reported to have sustained injuries.

Incidents of farm animal mortality have also been reported subsequent to the impact of lightning on facilities *(ARIA 7663, 25463, 15934, 22776)*.

Several cases of malfunctioning of wastewater treatment plants struck by lighting have lead to water pollution *(ARIA 1200, 2715, 23150)* sometimes resulting in the death of aquatic fauna *(ARIA 1200, 32016, etc.).*

Incidents of air pollution *(ARIA 343, 1884, 5060, 5874, 12948, 18563, 20354, etc)* mainly include:

- emission of gas or particles *(ARIA 1884, 5874, 18563, etc.)* further to electrical disturbances impacting their treatment;
- fire smoke *(ARIA 12948, 25440, etc.)*

Lightning can also result in significant equipment damage in the site *(ARIA 3707, 4801, 4900, 6109, 6277, 7663, 8885, 12948, 18325, 19539, 25440, 30199, etc.)* worth millions of euros.

Lastly, demarcating a danger area during an accident can also entail serious economic and social consequences (evacuation of homes, interruption of road and rail traffic: *ARIA 14352, 23626, 27506*).

Foreign accidents

ARIA 13942– 14/08/1998 – UNITED STATES – PERRY
In a natural gas compression facility, lightning possibly triggered a fire that resulted in several explosions. A fireball over 1000 m high was formed. Five people including several firemen sustained injuries and about half a dozen houses were damaged. Residents within a radius of 3.5 km were evacuated. The three gas lines supplying the entire Florida had to be cut, causing activities of several companies to plummet.

F – Lessons learnt

The analysis of these events underlines the need to take the direct and indirect effects of lightning into account in lightning prevention and protection studies. The foreseeable direct and indirect effects need to be clearly identified on vulnerable facilities (capacities, units, piping, etc.) including electrical equipment on the one hand and a concrete risk prevention strategy protecting equipment, environment and people must be put in place on the other hand.

This strategy depends on implementing surveillance and prevention measures consistent with the possible impacts and the identified weaknesses. Managers must be made aware of these risks and the staff properly trained to handle any emergency.

Technical study and analysis of risks related to lightning

The effects of lightning are taken into account by implementing safety devices and preventive measures drafted after the completion of the technical study based on the risk analysis.

The lack of conducting new lightning studies and updating existing ones along with insufficient analysis of lightning related risks clearly appear to be one of the causes behind the accident in several cases:

- a fire broke out in a sawdust silo and destroyed the building. There was no lightning protection *(ARIA 15689)*
- a fire also started in a paint and varnish factory. Lightning studies were not carried out *(ARIA 27506)*
- a fire resulting from lightning broke out in the transformer room of a felt production plant for cars: lightning studies were not updated and the recommendations were not followed *(ARIA 33544).*

Lightning strikes on facilities and electrical problem clearly need to be the focus of studies.

Impact of lightning on facilities and their operation

Several summaries have reported on incidents involving lightning strikes on storage capacities, pipes and transformers *(ARIA 5678, 15215, etc.).*

Lightning can result in **equipment damage** such as perforation of metal covering and cause **flammable** or explosive atmosphere to **ignite**. Accidentology shows the damage done to piping and tanks *(ARIA 5678, 7545, etc.),* fires in the roof joint zone of floating roof tanks where flammable fumes appear *(ARIA 12229, 12231, 20819)*, the shell/roof equipotential bonding may not be strong enough to ensure smooth and uninterrupted flow of current.

Lightning can also lead to the **destruction of electric and electronic equipment** or **disturb overall functioning** due to variations in the electric potential of the ground subsequent to impacts *(ARIA 2715).*

The main preventive and protective measures include:

- channel the flow of electricity to a low-risk area
- ensure adequate electric conduction to earth to avoid overheating or damage to equipment (equipotentiality, appropriate metallic sag sections, adequate earthing, etc.)
- avoid leakage of flammable material or fuels as well as creation of flammable atmosphere by ensuring that the equipment is leakproof
- protect electric and electronic equipment that especially designed for safety purposes
- have fire-fighting measures ready in place

Several accidents recorded in the ARIA *(1884, 5874, 11562, etc.)* database are subsequent to **partial or total failure of power supply** following lightning impacts. Furthermore, it is essential to draw up an exhaustive list of consequences of such failures on the various safety functions as well as on equipment processing waste released into the water or air to clearly identify dangerous events.

This analysis must result in an action plan that aims at prioritising the distribution of residual power or power derived from internal backup sources to equipment and units having high priority in terms of safety.

Besides following weather alerts, several measures can be implemented to safeguard against power supply failure or disturbances related to lightning:

- switching on of the generator *(ARIA 30199) ;*
- switching supply onto a protected line (second power supply line when the company has several supply lines, inverter, generator, etc.)
- putting operating units in stop or safety mode
- stopping operations involving any particular risk
- protecting sensitive equipment at risk in the event of lightning impact *(ARIA 6277).*

Accident prevention also depends on a good organisation and redundancy of electrical systems and circuits vital to the safety of the site.

Alerting rescue service requires functional telecommunication devices. The lessons learnt from accident analysis includes having telephone lines away from power supply lines such that both lines are not destroyed in the event of a lightning strike *(ARIA 23150*), and having a direct telephone connection with the rescue centres *(ARIA 23150, 25147).*

Lastly, **restarting the site after thunderstorms** must be carefully monitored to detect any possible malfunctioning induced (electric and electronic equipment) mainly by the effects of lightning *(ARIA n°26503).*

The safety of a facility during thunderstorms depends on the risk **awareness** levels of the staff and sub-contractors and their appropriate **organisation**.

Right individual behaviour in the event of a thunderstorm

- keep calm
- do not be a target for lightning
- do not be in positions that may lead to a potential difference between the two parts of the body
- seek a low-roof shelter in a place where the roof is earthed or seek a metallic shelter (e.g. car, etc.)
- keep away from high places
- avoid contact and keep away from metal structures and the electric line connecting the lightning conductor to the ground
- do not carry or wear metal objects. Remove any such objects in the event of a thunderstorm
- avoid or keep the use of telephone to a strict minimum (standard landline).

Identifying needs, defining and dispensing an appropriate training programme to the staff are the essential elements of the lightning risk prevention and protection plan

Regular testing of the warning systems and preventive measures, as well as the emergency intervention measures during drills helps anticipate, at least to a certain extent, possible organisational problems and improve corresponding solutions.

Moreover, it is advisable to involve all concerned players in the preventive approach that must not be limited to technical solutions and drafting guidelines. The prevention of lightning-related accidents calls for, like for other accident causes, an optimal management of technical and organisational resources.