

Protection against lightning

Early streamer emission lightning protection systems

F : Protection contre la foudre - Systèmes de protection contre la foudre à dispositif d'amorçage

D : Blitzschutz – Blitzableitersysteme mit Startvorrichtung

Officially approved French standard

On the decision of the Managing Director of AFNOR le 17th August 2011, with effect from 17th September 2011.

Intended to replace officially approved standard NF C 17-102 of july 1995 which remains in effect until September 2012.

Correspondence There is no equivalent IEC or CENELEC document.

Analysis This document describes the main dispositions in order to insure the protection of structures, buildings and open areas against direct lightning impact by early streamer emission protection system. Many tests on ESE are detailed and specific installation rules are introduced to ensure protection efficiency.

Descriptors Structures, building, open areas, lightning protection, protection device, air terminal, installation, design, down conductor, earthing, equipotential bonding, verification, periodic inspection, maintenance.

Modifications Previous edition of the standard has been upgraded to introduce more tests and also include new requirements both for product selection and installation rules.

Corrections



UTE has taken all reasonable measures to ensure the accuracy of this translation but regrets that no responsibility can be accepted for any error, omission or inaccuracy.
In cases of doubt or dispute, the original language text only is valid.

FOREWORD

There is no international standard or specific European standard about early streamer emission lightning protection systems

This document is intended to replace the 1995 edition of the NF C 17-102, with its second printing in 2009.

This document specifies requirements for design, in the present state of knowledge and technology, protection against lightning of structures (buildings, fixtures, etc.) and open areas (storage areas, rest areas or sports, etc.) by early streamer emission lightning protection systems and provides guidance on how to achieve this protection.

Installations for protection against lightning designed and made according to this document, may not, like everything about the natural elements, ensure the absolute protection of structures, people or objects; however, the application of this document must reduce significantly the risk of damage due to lightning on protected structures.

The provisions stated in this document are minimum requirements to ensure statistically an effective protection.

This new edition is a complete revision of the standard following the publication of the European standard series EN 62305 and more particularly to the EN 62305-3 giving the requirements for protection of structures against lightning

However, the EN 62305 series is not dealing with early streamer emission technology, the revision of the NF C 17-102 appeared essential to provide the design requirements of an early streamer emission air terminal and those for implementing the ESE lightning protection system.

In order to have no conflict with the European standard series, this document makes no reference to it, but repeats the necessary arrangements for the design and creation of the lightning protection system.

The UTE has established the following dates:

- Date on which the previous national standard will be canceled: September 2012;*
- Date of cessation of presumption of conformity of products manufactured under the superseded standard: September 2012.*

This document was approved June 28, 2011 by the Commission UF81, Protection against lightning.

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Early streamer emission Lightning protection systems

1 Scope

This standard is applicable to early streamer emission lightning protection systems provided to protect facilities and open areas against direct lightning impact. This ESESystem shall be tested, selected and installed according to the present standard.

2 Normative and regulation references

The following standards include provisions which, through reference in this text, are necessary to implement this standard. For dated references, only the adverted version is applicable. For non-dated references, the last edition of the reference is applicable (comprising possible amendments).

CLC/TS 61643-12	Low-voltage surge protective devices -- Part 12: Surge protective devices connected to low-voltage power distribution systems - Selection and application principles
EN 50164 (Series)	Lightning protection system components -
EN 50164-2 (C 17-151-2)	Lightning protection system components - Requirements for conductors and earth electrodes
EN 50164-3 (C 17-151-3)	Lightning protection system components - Requirements for isolating spark gaps
EN 50164-5 (C 17-151-5)	Lightning protection system components -
EN 50164-6 (C 17-151-6)	Lightning protection system components - Requirements for lightning strike counters (LSC)
EN 50164-7 (C 17-151-7)	Lightning protection system components - Requirements for earthing enhancing compounds
IEC 60060-1 (C 41-100-1)	High-voltage test techniques -- Part 1: General definitions and test requirements
EN 60068-2-52 (C 20-752)	Environmental testing -- Part 2: Tests - Test Kb: Salt mist, cyclic (sodium chloride solution
EN 60079-10 (C 23-579-10) (Série)	Electrical apparatus for explosive gas atmospheres
EN 61000-6-2 (C 91-006-2)	Electromagnetic compatibility (EMC) -- Part 6-2: Generic standards - Immunity for industrial environments
EN 61000-6-3 (C 91-006-3)	Electromagnetic compatibility (EMC) -- Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments
EN 61180-1 (C 41-106)	High-voltage test techniques for low-voltage equipment -- Part 1: Definitions, test and procedure requirements
EN 61241-10 (C 23-241-10)	Electrical apparatus for use in the presence of combustible dust -- Part 10: Classification of areas where combustible dust are or may be present

EN 61643 (Series)	Low-voltage surge protective devices -
EN 61643-11 (C 61-740)	Low-voltage surge protective devices -- Part 11: Surge protective devices connected to low-voltage power systems - Requirements and tests
NF EN ISO 6988 (A 05-106)	Metallic and other non organic coatings -- Sulfur dioxide test with general condensation of (A 05-106) moisture
UTE C 15-443	Guide pratique – Protection des installations électriques basse tension contre les surtensions d'origine atmosphérique ou dues à des manœuvres. Choix et installation des parafoudres
UTE C 15-712-1	Guide Pratique – Installations photovoltaïques raccordées au réseau public de distribution – Installation électrique à basse tension

3 Definitions

3.1

coordinated SPD protection

set of SPDs properly selected, coordinated and correctly installed to reduce failures of electrical and electronic systems

3.2

current impulse (I_{imp})

peak value (I_{peak}) defined by charge Q and specific energy W/R

3.3

dangerous event

lightning flash to the object to be protected or near the object to be protected

3.4

dangerous sparking

electrical discharge due to lightning which causes physical damage inside the structure to be protected

3.5

down-conductor

part of the Lightning Protection System intended to conduct the lightning current from ESEAT to the earth termination system

3.6

early streamer emission air terminal (ESEAT)

air terminal generating a streamer earlier than a simple rod air terminal when compared in the same conditions

NOTE – An early streamer emission air terminal is made up of a striking point, an emission device, a fixing element and a connection to the down conductors.

3.7

early streamer emission lightning protection system (ESESystem)

complete system based on one or more ESEAT and all elements to safely conduct lightning to earth in order to protect a structure, facility or open area against direct lightning impact.

NOTE – It comprises both internal and external lightning protection system.

3.8

earth termination system

part of an external ESESystem which is intended to conduct and disperse lightning current into the earth.

3.9

electrical system

system incorporating low voltage power supply components and ducts

3.10

electronic system

system incorporating sensitive electronic components such as communication equipment, computers, control and instrumentation systems, radio systems, power electronic installations

3.11

equipotential bonding

bonding to the ESESystem of separated conductive parts (see 5.5) of an installation, by direct connections or via surge protective devices, to reduce potential differences caused by lightning current.

3.12**equipotential bonding main bar**

a bar used to connect the natural components, ground conductors, earth conductors, screens, shields and conductors protecting telecommunication cables or other ones, to the lightning protection system.

3.13**equivalent collection area of a structure (A_d)**

a flat ground surface subjected to the same number of lightning strikes as the structure under consideration.

3.14**ESEAT efficiency (ΔT)**

difference expressed in micro-seconds between the emission time of an ESEAT and an SRAT measured in a laboratory under the conditions defined in this standard.

3.15**external ESESystem isolated from the structure to be protected**

LPS with an air-termination system and down-conductor system positioned in such a way that the path of the lightning current has no contact with the structure to be protected

NOTE: In an isolated LPS, dangerous sparks between the LPS and the structure are avoided.

3.16**external ESESystem not isolated from the structure to be protected**

LPS with an air-termination system and down-conductor system positioned in such a way that the path of the lightning current can be in contact with the structure to be protected

3.17**failure of electrical and electronic systems**

permanent damage of electrical and electronic systems due to LEMP

3.18**failure current (I_a)**

minimum peak value of lightning current that will cause damages

3.19**injuries to living beings**

injuries, including loss of life, to people or to animals due to touch and step voltages caused by lightning

3.20**interconnected reinforcing steel**

Steelwork within a concrete structure which is considered to provide an electrically continuity.

3.21**internal systems**

electrical and electronic systems within a structure

3.22**isolating Spark Gap (ISG)**

component with discharge distance for isolating electrically conductive installation parts.

NOTE In the event of a lightning strike, the installation parts are temporary connected conductively as the result of response of the discharge.

3.23**lightning electromagnetic impulse (LEMP)**

electromagnetic effects of lightning current

NOTE It includes conducted surges as well as radiated impulse electromagnetic field effects.

3.24**LEMP protection measures system (LPMS)**

complete system of protection measures for internal systems against LEMP

3.25**lightning ground flash density (N_g)**

is the number of lightning flashes per km^2 per year. This value is available from ground flash location networks

3.26**lightning flash near an object**

lightning flash striking close enough to an object to be protected that it may cause dangerous overvoltages

3.27**lightning flash to an object**

lightning flash striking an object to be protected

3.28**lightning flash to earth**

atmospheric originated electrical discharge between cloud and earth consisting of one or more arcs

3.29**lightning protection level (LPL)**

number related to a set of lightning current parameter values relevant to the probability that the associated maximum and minimum design values will not be exceeded in naturally occurring lightning

NOTE Lightning protection level is used to design protection measures according to the relevant appropriate set of lightning current parameters.

3.30**lightning protection zone (LPZ)**

zone where the lightning electromagnetic environment is defined

NOTE The zone boundaries of an LPZ are not necessarily physical ones (e.g. walls, floor and ceiling).

3.31**loss (L_x)**

mean amount of loss (humans and goods) consequent to a specified type of damage due to a dangerous event, relative to the value (humans and goods) of the object to be protected

3.32**natural component**

conductive element located outside the structure, sunk in the walls or located inside a structure and which may be used to supplement the ESESystem down conductors.

NOTE – For the protection with ESEATs, natural components may complement but never be the only down conductor except in the case of complete metallic structures.

3.33**node**

point on a service line at a which surge propagation can be assumed to be neglected

NOTE Examples of nodes are a connection of a HV/LV transformer, a multiplexer on a telecommunication line or SPD installed along a line.

3.34**Frequency of dangerous events due to flashes to a structure (N_D)**

expected average annual number of dangerous events due to lightning flashes to a structure

3.35**Frequency of dangerous events due to flashes to a service (N_L)**

expected average annual number of dangerous events due to lightning flashes to a service

3.36**Frequency of dangerous events due to flashes near a structure (N_M)**

expected average annual number of dangerous events due to lightning flashes near a structure

3.37**Frequency of dangerous events due to flashes near a service (N_I)**

expected average annual number of dangerous events due to lightning flashes near a service

3.38**object to be protected**

structure or service to be protected against the effects of lightning

NOTE A structure to be protected may be a part of a larger structure

3.39**physical damage**

damage to a structure (or to its content) or to a service due to mechanical, thermal, chemical or explosive effects of lightning.

3.40**pipes**

piping intended to convey a fluid into or out of a structure, such as gas pipe, water pipe, oil pipe

3.41**probability of damage (P_x)**

probability that a dangerous event will cause damage to or in an object to be protected

3.42**protected area**

zone protected by an early streamer emission lightning protection system.

3.43**protection measures**

measures to be adopted to the object to be protected, in order to reduce the risk

3.44**reference simple rod air terminal (SRAT)**

geometrical shape metal rod defined in this standard to be used as a reference.

3.45**rated impulse withstand voltage level (U_W)**

impulse withstand voltage assigned by the manufacturer to the equipment or to a part of it, characterizing the specified withstand capability of its insulation against overvoltages

NOTE For the purposes of this standard, only withstand voltage between live conductors and earth is considered.

3.46**risk (R)**

value of probable average annual loss (humans and goods) due to lightning, relative to the total value (humans and goods) of the object to be protected

3.47**risk component (R_x)**

partial risk depending on the source and the type of damage

3.48**rural environment**

area showing a low density of buildings.

NOTE 'Countryside' is an example of a rural environment.

3.49**separation distance**

distance between two conductive parts at which no dangerous sparking can occur.

3.50**specific downconductor**

downconductor complying with NF EN 50164-2 but being not a natural component of the structure

3.51**striking point**

point where a lightning stroke contacts the earth, a structure or a lightning protection system.

3.52**structures with risk of explosion**

structures containing solid explosive materials or hazardous zones as defined in accordance with IEC 60079-10 and IEC 61241-10

NOTE For the purposes of the risk assessment of this standard, only structures with hazardous zones type 0 or containing solid explosive materials are considered.

3.53**structures dangerous for the environment**

structures which may cause biological, chemical and radioactive emission as a consequence of lightning (such as chemical, petrochemical, nuclear plants, etc).

3.54**suburban environment**

area showing a medium density of buildings

NOTE 'Town outskirts' is an example of a suburban environment.

3.55**surge**

transient wave appearing as overvoltage and/or overcurrents caused by LEMP

NOTE Surges caused by LEMP can arise from (partial) lightning currents, from induction effects into installation loops and as remaining threats downstream from SPD.

3.56**surge protective device (SPD)**

device intended to limit transient overvoltages and drain away surge currents. It contains at least one non-linear component

3.57**telecommunication lines**

transmission medium intended for communication between equipment that may be located in separate structures, such as phone line and data line

3.58**test joint**

joint designed and placed to facilitate electrical testing and measurement of ESESystem components.

3.59**tolerable risk (R_T)**

maximum value of the risk which can be tolerated for the object to be protected

3.60**atmospheric originated transient surge voltage**

short-time overvoltage – not longer than few milliseconds - oscillatory or not, usually strongly damped.

3.61**urban environment**

area showing a high density of populated buildings and tall buildings

NOTE 'Town centre' is an example of an urban environment.

3.62**zone of a structure (Z_s)**

part of a structure showing homogeneous characteristics where only one set of parameters is involved in evaluating one risk component

4 Lightning protection system with Early Streamer Emission Air Terminal

4.1 Need of protection

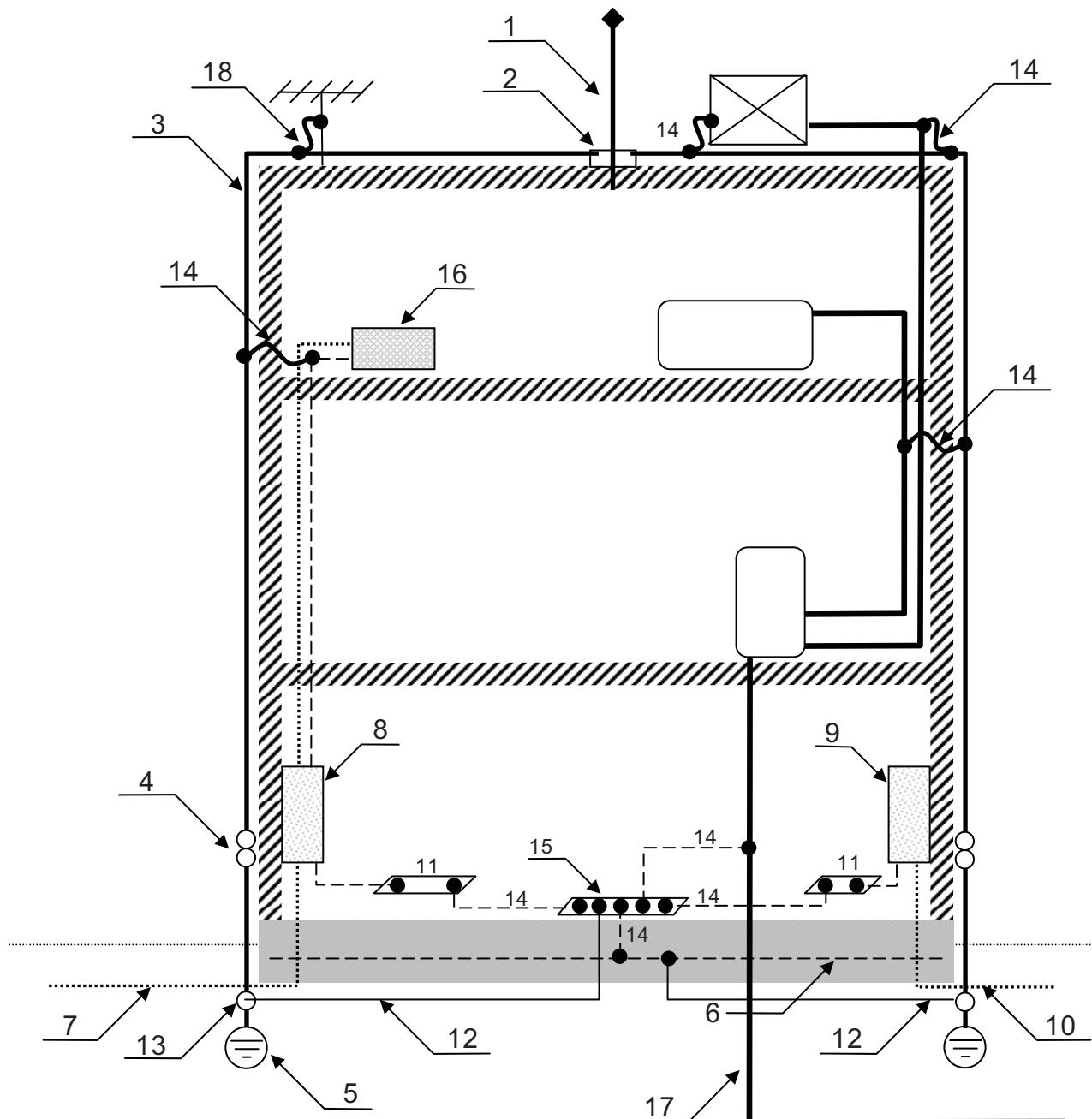
The need for protection is determined according to many parameters including the lightning flash density of the considered area. A risk analysis method is proposed in Annex A. The lightning flash density is given in annex B or by local data including for example detection network, maps and statistics.

NOTE 1: Other considerations may lead to take the decision to adopt protection measures for reasons other than statistical ones. For example, compulsory regulations or personal considerations since some factors cannot be estimated: the wish to avoid risk to life or to provide safety to the occupants of a building may require the use of protection, even though the calculated risk is under the tolerable level.

NOTE 2 Different normative documents give some risk analysis methods that can be used.

4.2 Components of the lightning protection system

The installation may be composed of the following elements:



Key :

- 1- One or more ESEAT
- 2- Connection component
- 3- One or more specific down-conductors
- 4- A test joint for each down-conductor
- 5- One earth termination for each specific down-conductor
- 6- Foundation earth electrode (earthing of the structure)
- 7- Electric power cable
- 8- Main electric power distribution box with SPD
- 9- Main telecom distribution box with SPD
- 10- Telecom cable with SPD
- 11- One or more equipotential bonding bars
- 12- One or more equipotential bondings between earth terminations
- 13- Disconnectable bonding device
- 14- One or more equipotential bondings (direct or via an Isolating SparkGap).
- 15- Main earthing bar
- 16- Electric equipment
- 17- Metallic pipe
- 18- One or more equipotential bondings through a spark gap for aerial mast

Figure 1 – Components of the lightning protection system

5 Early streamer emission lightning protection system

5.1 Design

Based on the necessary lightning protection level, a design should be made to determine the air terminal placement, the down-conductors paths and the location and type of the earth termination system.

This design should be based on available data and including:

- shape and slope of the roofs;
- material of the roof, walls and internal structure;
- metallic parts of the roof and important external metallic elements such as gas ducts, air-conditioning equipment, ladders, aerials, water tanks,...
- gutters and rainwater pipes;
- prominent parts of the structure and the material they are made (conductive or not);
- most vulnerable parts of the structure : the structural points considered as vulnerable are the prominent parts, particularly towers, weathervanes, sharp objects, chimneys, gutters, edges and ridges, metallic objects (air extractors, wall cleaning systems, rails, photovoltaic cells (UTE C 15-712-1), balustrades, ...), staircases, equipment rooms on flat roofs, etc.;
- positioning of the metallic ducts (water, power, gas...) of the structure;
- nearby obstacles that may influence the trajectory of the lightning discharge, such as overhead power lines, metallic fences, trees, etc.;
- the characteristics of the environment, that may be particularly corrosive (salty environment, petrochemical or cement factory, etc.);
- presence of flammable material or sensitive equipment such as computers or electronic equipment, high value or irreplaceable goods, etc..

5.2 Early Streamer Emission Terminal

5.2.1 General principles

An Early Streamer Emission Air Terminal (ESEAT) is composed of one striking point, emission device and a fixing element and a connection to the down-conductors.

The area protected by an ESEAT is determined according to its efficiency as defined in Clause 5.2.2.

The ESEAT should preferably be installed on the highest part of the structure. It shall be the highest point within the area to be protected.

5.2.2 ESEAT efficiency

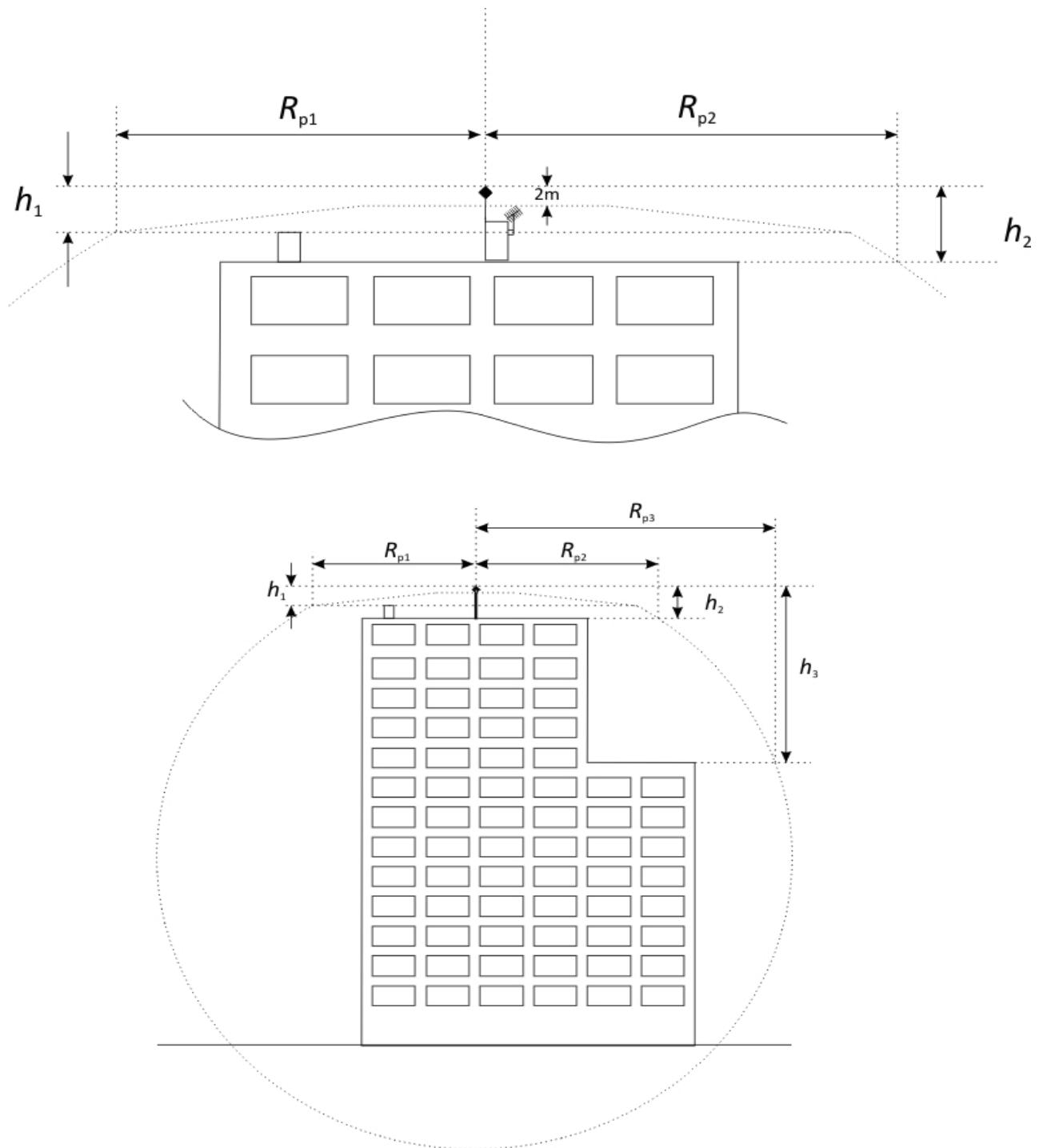
An ESEAT is characterized by its efficiency ΔT which is proved in the evaluation test (see Annexe C).

The maximum value for ΔT , whatever are the test results, is 60 μ s.

5.2.3 Positioning of the ESEAT

5.2.3.1 Protected area.

The protected area is delineated by a surface of revolution defined by the protection radii corresponding to the different considered heights h and which axis is the same as the one of the air terminal (see figure 2).



where:

h_n is the height of the ESEAT tip over the horizontal plane through the furthest point of the object to be protected

R_{pn} is the ESEAT protection radius to the considered height h_n .

Figure 2 – Protection Radii (with hypothesis $h_1 = 5$ m)

5.2.3.2 Protection radius.

The protection radius of an ESEAT is related to its height (h) relative to the surface to be protected, to its efficiency and to the selected protection level (see Annex A).

$$R_p(h) = \sqrt{2rh - h^2 + \Delta(2r + \Delta)} \quad \text{for } h \geq 5 \text{ m} \quad (1)$$

and

$$R_p = h \times R_p(5) / 5 \quad \text{for } 2 \text{ m} \leq h \leq 5 \text{ m} \quad (2)$$

where

$R_p(h)$ (m) is the protection radius at a given height h

h (m) is the height of the ESEAT tip over the horizontal plane through the furthest point of the object to be protected

r (m) 20 m for protection level I
30m for protection level II
45m for protection level III
60m for protection level IV

Δ (m) $\Delta = \Delta T \times 10^6$
Field experience has proved that Δ is equal to the efficiency obtained during the ESEAT evaluation tests

For buildings higher than 60m, the requirements in 5.2.3.4 should be applied.

5.2.3.3 Selection and positioning of the ESEAT

For the installation of each lightning protection system, a risk analysis must be made in order to determine the minimum required lightning protection level.

The positioning of the ESEAT is chosen according to 5.2.1 and 5.2.5.

The required protection radii to protect the structure are determined according to the features of the building.

Both height of the ESEAT and its efficiency are determined using the points and formulas cited above based on the selected ESEAT.

5.2.3.4 Protection of high rise buildings (height greater than 60 m)

Additional protection against direct lightning strike for the highest 20% of the structure height for buildings greater than 60 m or any point above 120 m, using ESEAT or any other means must be implemented at each façade wall according to a valid standard. Furthermore a minimum of 4 downconductors, interconnected by a ring conductor when applicable, shall be used, distributed along the perimeter and if possible at each angle of the building.

NOTE : in general the risk due to the lateral flashes is low because only a few percent of all flashes to tall structures will be to the side and moreover their parameters are a lot lower than those of flashes to the top of structures.

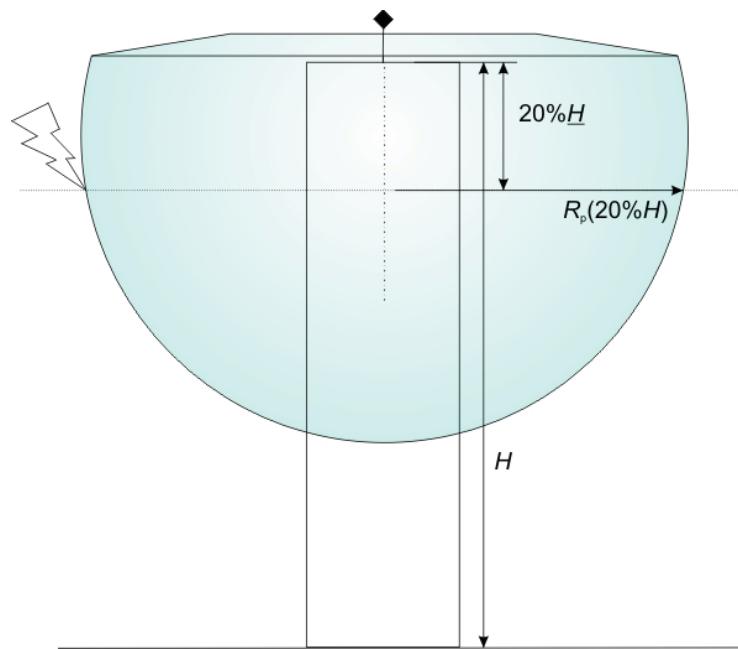


Figure 3 - Additional protection against direct lightning strike for the highest 20% of the structure height for buildings taller than 60 m

5.2.3.5 Protection of buildings for levels of protection I⁺ and I⁺⁺

Level of protection I⁺ : the ESESystem at level of protection 1 is additionnaly connected to the metal structure or reinforced bars of the buildings used as natural downconductors in addition to the dedicated downconductors included in the ESESystem according to 5.3. Connection to the natural downconductors shall be made at roof level and ground level. When the dowconductors are not interconnected at roof level, a ring conductor located above the roof can be used to achieve these requirements. The downconductors shall be interconnected at ground level either by the earthing loop or by a dedicated conductor.

If there is no natural downconductors or if one of the above requirements cannot be fulfilled, level I⁺ cannot be achieved.

Level of protection I⁺⁺ : the roof is protected at level I⁺ with an ESEAT having a radius of protection reduced by 40% compared to values given in 5.2.3.2 to achieve a complete protection of equipments on the roof against direct lightning strikes.

5.2.4 Materials and dimensions.

All materials should comply with EN 50164-2

5.2.5 Installation

The top of the ESEAT shall be installed at least 2 m over the area that it protects, including aerials, refrigerating towers, roofs, tanks, etc.

When designing the ESESystem, it is recommended to take into account the architectural spots that are adequate to place an ESEAT. These locations are high structural points like:

- rooms on the terraces;
- ridge;
- masonry or metallic chimneys.

Those ESEAT protecting open areas (sport fields, golf, swimming pools, campsites, etc.) will be installed over specific supports such as lighting masts, poles or any other nearby structure that allows the ESEAT to cover the whole area to be protected.

ESEAT can occasionally be placed over free-standing masts. In case of using conductive guy wires, they will be bonded, at the anchoring point on the ground, to the down-conductors using conductors according to EN 50164-2.

5.3 Down-conductors

5.3.1 General principles.

The function of the down-conductors is to conduct lightning current from the air terminal to the earth termination system. They will be placed preferably at the external part of the structure.

Each of the down-conductors will be fixed to the ESEAT by means of a connection system placed at the mast. The latter will comprise a mechanical adaptation element that will assure a permanent electrical contact.

When the down-conductor is placed on a wall made of combustible material, and not being a copper one, then at least one of the following conditions should be satisfied in order to avoid any dangerous temperature rise:

- + the separation is at least 0,10 m;
- + the conductor section is at least 100mm².

To be considered as 2 independent downconductors, they should not run in parallel (parallel means that there is a distance along a straight line higher than 2 m between downconductors). To take care of any practical problem that may be encountered, a tolerance of 5% of the total length of the shorter downconductor can run along the same path.

5.3.2 Number of down-conductors.

For non-isolated ESESystème, each ESEAT shall be connected to at least two downconductors. For a better current distribution, the two paths to ground should, be situated on two different facades unless in case of force majeure.

At least one of them must be a specific downconductor complying with EN 50164-2 since natural components may be modified or removed without taking into account the fact that they belong to a lightning protection system. When many ESEAT are located on the same building, the downconductors may be mutualized possible if the calculated separation distance for the whole system is allowing that number. Therefore, if there are n ESEAT on the roof, it is not systematically necessary to have $2n$ downconductors installed but a minimum of n specific downconductors is mandatory.

The number of specific downconductor according to EN 50164-2 should be at least equal to the number of ESEAT on the building. The distance of separation allows to determine the number of needed downconductors as well as possibility to mutualize the downconductors. Increasing the number of specific downconductors enables the decrease of the separation distance.

See Annex E for some examples of calculation of separation distance depending on the number of down conductors.

In case of an isolated ESESystème, at least one down-conductor is needed for each ESEAT.

In case of pylones, mast, chimneys and other metallic structures:

- If the metallic structure fulfill the requirements for natural components, it may be used as a first downconductor;
- If the structure is isolated, the structure may be used as the single needed downconductor. No other specific downconductor is then needed additionnaly;
- If the structure is non isolated, the structure may be considered as the two needed downconductors if its section area is greater or equal to 100 mm^2 . If the section area is between 50 mm^2 and 100 mm^2 , a second specific downconductor according to EN 50164-2 is necessary. A structure that do not fulfill the requirement of natural components, cannot be used as a downconductor so one or two specific downconductor are needed.

NOTE : the natural components shall have a low and permanent impedance value. It may be necessary to add a specific downconductor according to EN 50164-2 to obtain such low impedance.

5.3.3 Routing

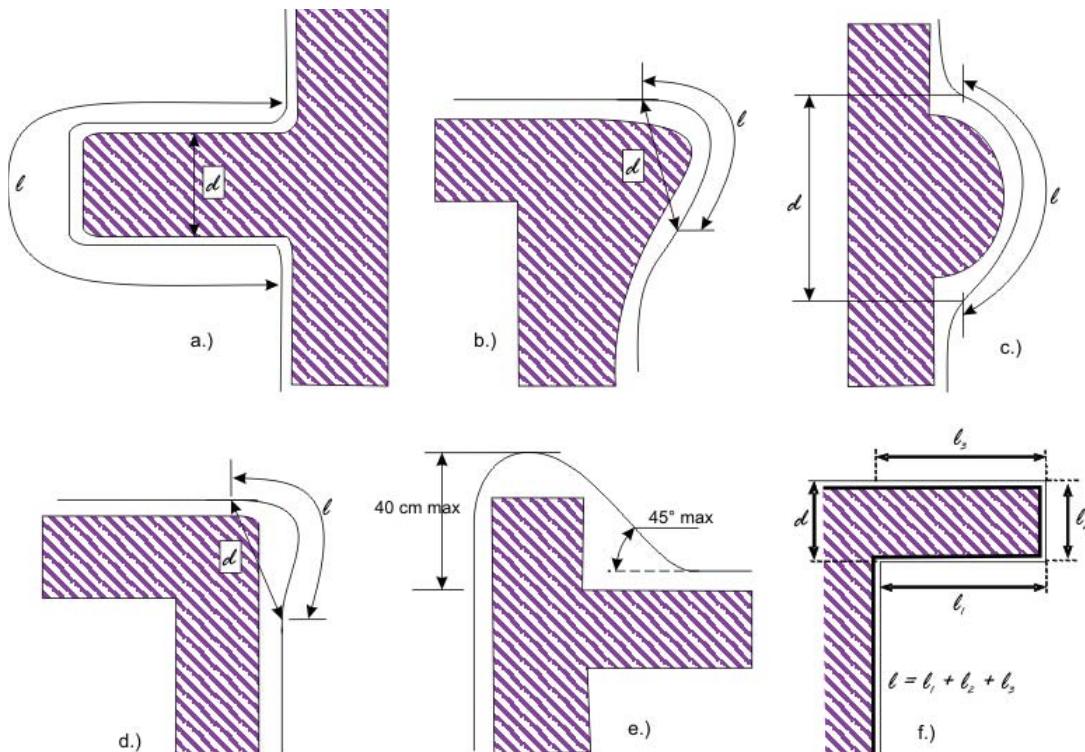
The downconductor should be installed in such a way that its path is as direct as possible. The routing of the down-conductor should be as straight as possible, following the shortest path, avoiding sharp bends or upward sections. The bend radii should not be less than 20 cm (see figure 4). For down-conductors, bends formed edgewise should preferably be used.

The down-conductors should not be routed along or across electrical conduits.

Routing round parapet walls or cornices or more generally obstacles should be avoided. Provisions should be made to ensure that down-conductor paths are as direct as possible. However, maximum height of 40cm is permissible for passing over an obstacle with a slope of 45° or less (see figure 4 case e).

Alternatively, the calculation of the separation distance, according to 5.6 with $l = l_1 + l_2 + l_3$ depending on case f below-cited, allows to determine the minimal bend radius.

In figure 4, case d, the condition $d > l/20$ is always fulfilled since $d = l/\sqrt{2}$ for any length l .



l : length of the loop, in meters

d : width of the loop, in meters

The risk of any dielectric breakdown is avoided if the condition $d > l/20$ is fulfilled.

Figure 4 – Down-conductor bend shapes

The distance between downconductors and possible interconnecting ring conductors are correlated with the separation distance.

The fixings of the down-conductors should be attached on the basis of three fixings per meter (every 33 cm). These fixings should be suitable for the supports and their installation should not alter the roof water-tightness. The fixings should allow for possible thermal expansion of the conductors. Systematic drilling through the downconductor in order to attach it to the support is forbidden.

All the conductors should be connected together with clamps of the same nature, using rivets, soldering or brazing.

Down-conductors should be protected against the risk of mechanical impact with guard tubes up to a height of at least 2m above the ground level.

NOTE: To avoid touch voltage, see Annex D.

5.3.4 Indoor routing

When a down conductor cannot be installed outside the structure, it can be fitted inside on a part or on the full height of the structure. In this case, the downconductor must be placed inside a dedicated non-flammable and insulating duct.

The separation distance shall be calculated also for indoor downconductors in order to be able to determine the necessary insulation level of the dedicated duct.

The building operator has to be aware of the resulting difficulties to check and maintain the down conductors, and of the resulting risks of over voltages inside the building.

Access of people to the specific cable channel should be avoided in stormy periods or measures of protection as per outdoor downconductors should be fulfilled (see Annex D) including equipotential bondings of floors with the downconductor.

5.3.5 Outside cladding

When a building is fitted with a metallic external cladding or stone facing or in glass, or in the case of a fixed covering part of the facade, the down conductor can be installed on the concrete façade or on the main structure, under the cladding.

In this case, the conductive parts of the cladding must be connected to the down conductor at the top and at the bottom.

The downconductor, if not a copper one, shall be located at more than 10 cm behind inflammable material of the outside cladding if its cross section area is lower than 100 mm². For cross section area of 100 mm² or greater, there is no need to keep a distance between the downconductor and the insulating material.

NOTE 1: a specific calculation of the temperature increase may be performed to validate a different rule.

NOTE 2: the same requirements apply also to all inflammable material even on the roof (e.g. thatched roof)

5.3.6 Materials and dimensions.

See EN 50164-2.

5.3.7 Test joint.

Each down-conductor should be provided with a test joint in order to disconnect the earth termination system for enabling measurements.

Test joints are usually installed at the bottom of the down-conductors. When downconductors are installed on metal walls or when ESESystems are not provided with specific downconductors, test joints will be inserted between each earthing system and the metallic item to which the earth termination system is connected. The test joints are then installed inside inspection pits (complying with EN-50164-5) showing the earth termination symbol.

5.3.8 Lightning event counter.

When the installation is provided with a lightning event counter, it should be placed at the most direct down-conductor above. It shall comply with EN 50164-6.

5.3.9 Natural components.

Some of the conductive structural components may replace all or part of a down-conductor or be a supplement for it.

5.3.9.1 Natural components which may replace the entire down-conductor or part of it.

Generally, external interconnected steel frames (metal structures) may be used as down-conductors if they are conductive and their resistance is 0.1Ω or lower.

In such case, the upper end of the ESEAT is connected directly to the metal frame whose lower end is to be connected to the earth termination system.

The use of a natural down-conductor should meet the equipotential bonding requirements in chapter 3.

5.3.9.2 Natural components that may be used to supplement down-conductor(s).

The following items may be used to supplement the lightning protection and bonded to it:

(a)interconnected steel frames providing electrical continuity:

- internal metallic structures, concrete reinforcements and metal structures inside the walls, provided that specific connection terminals exist for this purpose at the upper and lower part;
- External metallic structures which do not run over the entire structure height.

NOTE 1: when pre-stressed concrete is used, special attention should be paid to the risk of mechanical effects due to the lightning current flowing through the lightning protection system.

(b)metal sheets covering the area to be protected, provided that: :

- the electrical continuity among the different parts is made durable
- they are not coated with insulating material.

NOTE 2: a thin protective paint coat, 1mm concrete or 0,5mm PVC are not considered as an insulation.

(c)Metallic pipes if their thickness is at least 2mm

5.4 Equipotential bonding of metal parts

5.4.1 General

The internal ESESystem shall prevent the occurrence of dangerous sparking within the structure to be protected due to lightning current flowing in the external ESESystem or in other conductive parts of the structure.

Dangerous sparking may occur between the external ESESystem and the following components:

- the metal installations;
- the internal systems;
- the external conductive parts and lines connected to the structure.

Dangerous sparking between different parts can be avoided by means of

- equipotential bonding in accordance with 5.5, or
- electrical insulation between the parts in accordance with 5.6.

5.5 Lightning equipotential bonding

5.5.1 General

Equipotentialization is achieved by interconnecting the ESESystem with

- structural metal parts;
- metal installations;
- internal systems;
- external conductive parts and lines connected to the structure.

When lightning equipotential bonding is established to internal systems, part of the lightning current may flow into such systems and this effect shall be taken into account.

Interconnecting means can be:

- bonding conductors, where the electrical continuity is not provided by natural bonding;
- surge protective devices (SPDs), where direct connections with bonding conductors is not feasible.

The manner in which lightning equipotential bonding is achieved is important and shall be discussed with the operator of the telecommunication network, the electric power operator, and other operators or authorities concerned, as there may be conflicting requirements.

SPDs shall be installed in such a way that they can be inspected.

NOTE When an ESESystem is installed, metalwork external to the structure to be protected may be affected. This should be considered when designing such systems. Lightning equipotential bonding for external metalwork may also be necessary.

5.5.2 Lightning equipotential bonding for metal installations

In the case of an isolated external ESESystem, lightning equipotential bonding shall be established at ground level only.

For an external ESESystem which is not isolated, lightning equipotential bonding shall be installed at the following locations:

- a) in the basement or approximately at ground level. Bonding conductors shall be connected to a bonding bar constructed and installed in such a way that it allows easy access for inspection. The bonding bar shall be connected to the earth-termination system. For large structures (typically more than 20 m in length), more than one bonding bar can be installed, provided that they are interconnected;

b) where insulation requirements are not fulfilled (see 5.6).
 Lightning equipotential bonding connections shall be made as direct and straight as possible.

NOTE When lightning equipotential bonding is established to conducting parts of the structure, part of the lightning current may flow into the structure and this effect should be taken into account.

The minimum values of the cross-section of the bonding conductors connecting different bonding bars and of the conductors connecting the bars to the earth-termination system are listed in Table 1.

The minimum values of the cross-section of the bonding conductors connecting internal metal installations to the bonding bars are listed in Table 2.

Table 1 – Minimum dimensions of conductors connecting different bonding bars or connecting bonding bars to the earth-termination system

Protection Level	Material	Cross-section mm ²
I to IV	Copper	16
	Aluminum	22
	Steel	50

Table 2 – Minimum dimensions of conductors connecting internal metal installations to the bonding bar

Protection Level	Material	Cross-section mm ²
I to IV	Copper	6
	Aluminum	8
	Steel	16

Bonding may be achieved by a ISGs according to NF EN50164-3.

5.5.3 Lightning equipotential bonding for external conductive parts

For external conductive parts, lightning equipotential bonding shall be established as near as possible to the point of entry into the structure to be protected.

Bonding conductors shall be capable of withstanding part of the lightning current flowing through them.

Bonding may be achieved by a ISGs according to NF EN50164-3.

5.5.4 Lightning equipotential bonding for internal systems

It is imperative that lightning equipotential bonding is installed in accordance with 5.5.2 a) and 5.5.2 b).

If the internal systems conductors are screened or located in metal conduits, it may be sufficient to bond only these screens and conduits.

If conductors of internal systems are neither screened nor located in metal conduits, they shall be bonded via SPDs. In TN systems, PE and PEN conductors shall be bonded to the ESESystem directly or with a SPD.

Bonding conductors and SPDs shall have the same characteristics as indicated in 5.5.2.

If protection of internal systems against surges is required, a “coordinated SPD system” conforming to the requirements of NF EN 61643-11, CLC/TS 61643-12 shall be used.

5.5.5 Lightning equipotential bonding for lines connected to the structure to be protected

Lightning equipotential bonding for electrical and telecommunication lines shall be installed in accordance with 5.5.3.

All the conductors of each line should be bonded directly or with an SPD. Live conductors shall only be bonded to the bonding bar via an SPD. In TN systems, PE or PEN conductors shall be bonded directly or via SPD to the bonding bar.

If lines are screened or routed into metal conduits, these screens and conduits shall be bonded;

Lightning equipotential bonding of the cable screens or of the conduits shall be performed near the point where they enter the structure.

Bonding conductors and SPDs shall have the same characteristics as indicated in 5.5.3.

If protection against surges of internal systems connected to lines entering the structure is required, a “coordinated SPD system” conforming to the requirements of NF EN 61643-11 and CLC/TS 61643-12 and UTE C 15-443 shall be used.

5.6 Electrical insulation of the external ESESystem

The electrical insulation between the air termination or the down-conductor and the structural metal parts, the metal installations and the internal systems can be achieved by providing a separation distance “s” between the parts. The general equation for the calculation of “s” is given by:

$$s = k_i \frac{k_c}{k_m} I \text{ (m)} \quad (3)$$

where:

k_i depends on the selected Protection Level (see Table 3);

k_m depends on the electrical insulation material (see Table 4);

k_c depends on the lightning current flowing on the air termination and the down-conductor;

I is the length, in metres, along the air termination and the down-conductor from the point, where the separation distance is to be considered, to the nearest equipotential bonding point.

NOTE The length I along the air-termination can be disregarded in structures with continuous metal roof acting as natural air-termination system.

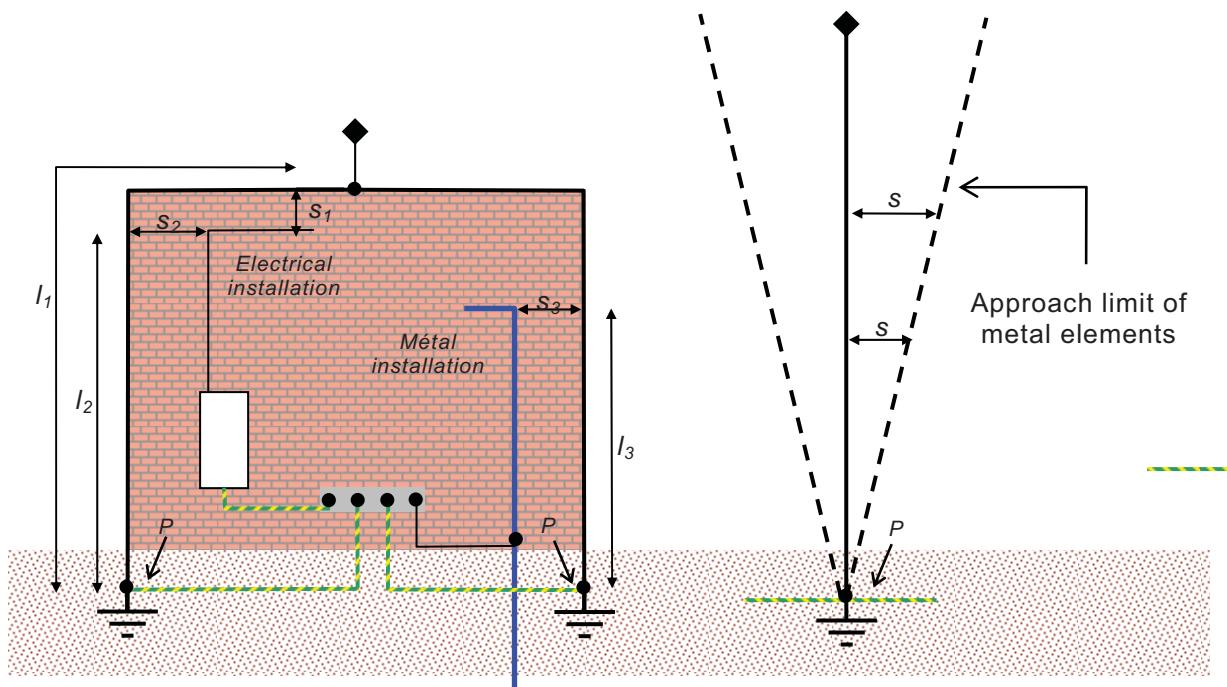


Figure 5 – Illustrations of the separation distance according to the length in question and the increase in potential difference as a function of the distance at the nearest equipotential point (P)

Table 3 – Isolation of external ESESystem – Values of coefficient k_i

Protection Level	k_i
I	0,08
II	0,06
III and IV	0,04

Table 4 – Isolation of External ESESystem – Values of coefficient k_m

Material	k_m
Air	1
Concrete, bricks	0,5

NOTE 1 When there are several insulating materials in series, it is a good practice to use the lower value for k_m .

NOTE 2 In using other insulating materials construction guidance and the value of k_m should be provided by the manufacturer.

In structures with metallic or electrically continuous connected reinforced concrete framework of the structures a separation distance is not required.

Table 5 – Isolation of external ESESystem – Values of coefficient k_c

Number of down-conductors <i>n</i>	k_c	
	Earthing arrangement type A1 or A2	Earthing arrangement type B
1	1	1
2	0,75 ^{c)}	1 ... 0,5 a)
3	0,60 ^{b,c)}	1 ... 1/n (see Figure E.1 and E.2) ^{a,b)}
4 and more	0,41 ^{b,c)}	1 ... 1/n (see Figure E.1 and E.2) ^{a,b)}

a) See Annex E
 b) If the down-conductors are connected horizontally by ring conductors, the current distribution is more homogeneous in the lower parts of the down-conductor system and k_c is further reduced. This is especially valid for tall structures.
 c) These values are valid for single earthing electrodes with comparable earthing resistances. If earthing resistances of single earthing electrodes are clearly different, $k_c = 1$ is to be assumed

NOTE Other values of k_c may be used if detailed calculations are performed.

6 Earth termination systems

6.1 General

All earthing system for a same structure should be interconnected

One earth termination will be provided for each downcuductor based on at least on two electrodes per earth termination.

Due to the impulsionnal nature of lightning current and in order to enhance the current draining to earth thus minimizing the risk of dangerous surges inside the protected volume, it is important to consider the shape and dimensions of the earth termination system as well as the value of its resistance.

A certain contact surface with the soil shall be assured in order to facilitate the lightning current dispersion in a short time.

Earth termination systems should meet the following requirements:

- the resistance value measured using a conventional equipment should be the lowest possible (less than 10Ω). This resistance should be measured on the earthing termination insulated from any other conductive component.
- earth termination systems having a single excessively long horizontal or vertical component ($> 20 \text{ m}$) should be avoided in order to minimise the inductive voltage drop.

The use of a single vertical termination system deeply buried to reach a humid layer of soil is thus not advantageous unless the surface resistivity is particularly high and there a high conductivity layer far below.

However it should be noted that such drilled earth termination systems have a high wave impedance when the depth exceeds 20 m. Then a greater number of horizontal conductors or vertical rods should be used, always perfectly electrically interconnected.

Earth termination systems should be made and laid out as stated above.

Unless there is a real impossibility, earth termination systems should always be directed outward from the buildings

NOTE : To avoid step voltages see Annex D.

6.2 Earth termination system types

The earth termination dimensions depend on the soil resistivity in which the earth termination systems are installed. The resistivity may vary, to a considerable extent depending on the soil material (clay, sand, rock...)

The resistivity can be assessed from the table 6 or measured using a suitable method with an earth meter.

For each down-conductor, the earth termination systems may consist of:

Type A: divided in:

- A1. conductors of the same nature and cross-sectional area as the down-conductors, except for aluminium, arranged in the shape of goose-foot of large dimensions and buried at a minimum depth of 50 cm.

Example: three 7-8 meter long conductors, buried horizontally at a minimum depth of 50 cm.

and:

- + A2. set of several vertical rods with a minimum length of 6 metres at a minimum depth of 50 cm.
 - arranged linearly or as a triangle and separated from each other by a distance equal to at least the buried length;
 - interconnected by a buried conductor which is identical to or has compatible characteristics compatible with the down-conductor.

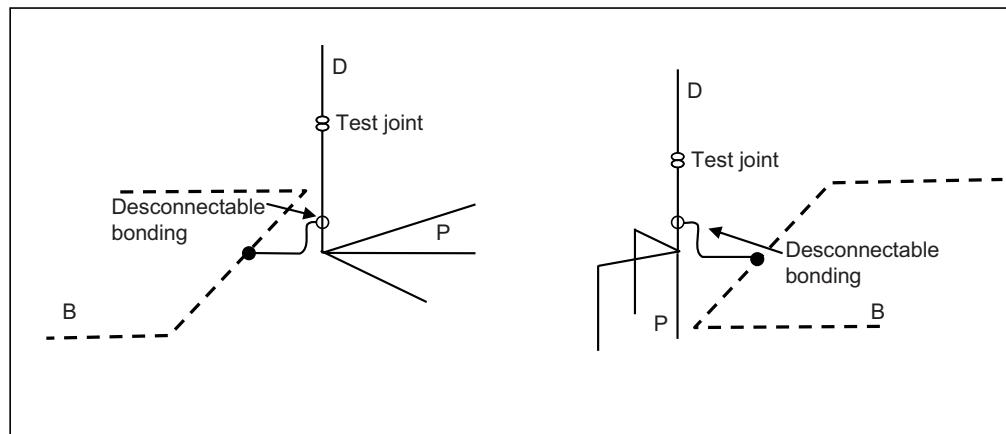
NOTE : the recommended arrangement is the triangle

Type B: Ring earth electrode

This type of arrangement comprises either a ring conductor external to the structure, in contact with the soil for at least 80% of its total length or a foundation earth electrode provided it is based on a 50 mm² conductor. The bottom of each downconductor should at least additionally be connected to either a 4 m minimum radial or a 2 m minimum rod.

Table 6 – Typical resistivity soil

Type of soil	Resistivity ($\Omega \cdot \text{m}$)
Swampy terrain	a few units up to 30
Silt	20-100
Humus	10-150
Wet peat	5-100
Soft clay	50
Marl and compact clay	100-200
Jurassic marl	30-40
Clayey sand	50-500
Siliceous sand	200-3000
Bare stony soil	1500-3000
Stony soil covered with grass	300-500
Soft limestone	100-300
Compact limestone	1000-5000
Fissured limestone	500-1000
Schist	50-300
Mica Schist	800
Weathered granite and sandstone	1500-10000
Highly weathered granite and sandstone	100-600



D: down-conductors

B: ring at the foundations of the building

P: ESESystem earthing

Figure 6 – Scheme of earthing types A1 and A2

6.3 Additional measures

When the high soil resistivity makes it impossible to achieve an earth termination system resistance lower than 10Ω using the above standard protective measures, then the following additional measures may be used:

- adding a non-corrosive soil-conductivity improver with a lower resistivity around the earth conductors;
- add earth rods to the goose-foot arrangement or connect them to the already existing rods;
- apply a ground improvement in accordance with NF EN 50164-7.

When all the above measures are adopted and a resistance value of less than 10 ohms cannot be obtained, it can be considered that the earth termination system Type A provides acceptable lightning current draining when it consists of a buried termination system at least:

- 160m long in case of Protection Level I;
- 100m long in case of Protection Level II, III, IV.

In any case, each vertical or horizontal element should not be longer than 20 m.

The need length may be a mix of radial (cumulated length L_1) and rods (cumulated length L_2) with the following requirement :

$$160 \text{ m (respectively 100 m)} \leq L_1 + 2 \times L_2$$

For Type B earthing system, when value of 10 ohms cannot be achieved, the cumulated length of the additional electrodes should be:

- 160 m for level of protection I (respectively 100 m for other levels of protection) for radial electrode;
- 80 m for level of protection I (respectively 50 m for other levels of protection) for rods;
- or a combination as explained above for Type A earthing system.

6.4 Earthing equipotentiality

When the building or the protected volume has a foundation earth termination system for the electrical system, the ESESystem earth termination systems should be connected to it with a standardised conductor (see NF EN 50164-2).

For new installations, this measure should be taken into account since the initial design stage, and the interconnection to the foundation earth circuit should be made right in front of each down-conductor by a device which can be disconnected and located in front of an inspection pit with the symbol .

For existing buildings and installations, the connections should be preferably made to the buried parts and it should be possible to disconnect them for inspection purposes. In case of interconnections inside a building, the routing of the bonding cable should avoid inductions on cables and objects in the surroundings.

When several separate structures are included in the protected volume, the earth termination system of the ESEAT should be bonded to the buried equipotential earth network that interconnects all the structures.

6.5 Proximity requirements

The ESESystem earth termination components should be at least 2 m distant from any buried metal pipe or electrical conduit, in case these conduits are not electrical connected to the main equipotential bonding of the structure.

For soils which resistivity is over $500 \Omega \cdot m$, the minimum distance should be 5 m.

6.6 Materials and dimensions

See NF EN 50164-2.

7 Special measures

7.1 Aerials

An aerial on the roof of a building increases the lightning stroke probability and is the first vulnerable element likely to receive the lightning discharge.

The aerial support mast should be connected directly or through an SPD or an isolated spark gap to the lightning protection system with a suitable conductor, unless the antenna is outside the protected area or on another roof. The coaxial cable should be protected with a surge protective device.

A common support mast may be used under the following conditions:

- the ESEAT is fixed to the tip of the mast;
- the ESEAT tip is at least 2 m above the nearest aerial;
- the down-conductor is fixed directly onto the air terminal with a clamp;
- the aerial coaxial cable is routed inside the antenna mast.

In case of a trestle tower, it is preferable to route the coaxial cable inside a metal tube.

7.2 Inflammable and explosive material storage areas

Tanks containing flammable fluids should be earthed. But such an earth connection does not provide adequate protection against atmospheric discharges. A thorough additional survey is therefore necessary.

ESEATs should be placed outside the safety area, higher than the installations to be protected. When it is possible down-conductors layout should be outside the safety area. When it is not feasible, special care shall be considered to avoid electrical arc.

Earth termination systems should be oriented opposite to the storage areas.

NOTE The installation of a lightning event counter is recommended.

7.3 Religious buildings

Steeples, towers, minarets and belfries are prone to being struck by lightning because of their prominence.

The main prominence(s) should be protected with ESEATs connected to the ground by a direct down-conductor routed along the main tower.

When the main prominence (s) is higher than 40 m, it is recommended that the second specific down-conductor should follow the nave ridge.

In case the end of the nave is fitted with a non-metallic cross or statue then such objects will be provided with an air terminal.

Both ESESystem earth termination systems and the electric earthing should be interconnected by an earth conductor.

Some religious buildings have electric bells. The electrical power supply must be protected against overvoltages using surge protective devices according to NF EN 61643-11 and CLC/TS 61643-12.

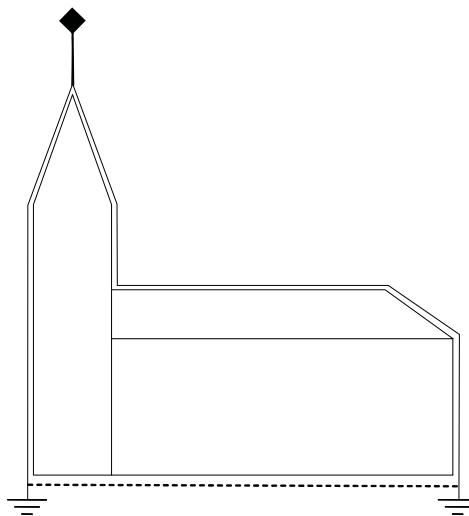


Figure 7 - Religious buildings

8 Execution file, vérification and maintenance

ESESystem layout and lightning protection components installed shall be verified in relation to the present document and the execution file. The good condition of ESESystem should be maintained throughout the ESESystem life.

8.1 Execution File

An execution file shall be established by the contractor once the ESESystem installation is completed and shall include at least the following:

- Required protection Level;
- Justification of the protection;
- Type and characteristics of ESEAT;
- ESEAT Test procedure;
- Number and localization of down-conductors;
- Existence and localization of lightning event counter;
- Justification of electrical insulation;
- Justification of lightning equipotential bonding including SPDs;
- Type and value of earth terminaisons systems;
- Justification of earth terminaisons systems dimensions if the value is higher than 10 Ω .

8.2 Orders of Verifications

Lightning protection systems should be subjected to verification:

- Initially once the ESESystem installation is completed;
- Periodically in accordance with following table 7;
- Whenever the protected structure is modified, repaired or when the structure has been struck by lightning.

NOTE 1: for levels of protection 1 and 2, a complete inspection is carried out when the structure has been struck by lightning.

Table 7 – Periodicity of inspection regarding the protection level

Protection level	Visual inspection (year)	Complete inspection (year)	Critical systems complete inspection (year)
I and II	1	2	1
III and IV	2	4	1

NOTE Lightning protection systems utilized in applications involving structures with a risk of explosion should be visually inspected every 6 months. Electrical testing of the installation should be performed once a year.

An acceptable exception to the yearly test schedule would be perform the tests on a 14 to 15 month cycle where it is considered beneficial to conduct earth resistance testing over different times of the year to get an indication of seasonal variations.

NOTE 2 Lightning flashes can be recorded by a lightning flash counter installed at one of the down-conductors.

NOTE 3 If national authorities or institutions require regular tests of the electrical system of a structure, it is recommended to test the lightning protection system with regard to the functioning of the Internal lightning protection measures including the lightning protection equipotential bonding with electric systems at the same time.

NOTE 4 Older installations should be related to a lightning protection level or the verifications intervals should be taken from the local or any other test specifications such as construction guide lines, technical regulations, instructions, industrial safety and protection of labour laws.

NOTE 5 Critical systems shall be defined by laws or final users.

8.3 Verification report

Each periodic inspection should be registered with a detailed report containing all the findings of the inspection and the corrective measures to be taken.

8.4 Initial verification

Initial verification should be performed once the ESESystem installation is completed in order to make sure that it complies with the provisions of this standard and the execution file.

This verification is based at least on the following points:

- ESEAT is 2 meters or more above any object in the protected area;
- ESEAT characteristics are conform to execution file;
- number of down-conductors;
- Compliance of ESESystem elements to this standard and to NF EN 50164 and NF EN 61643 series by marking, by statement or by documentation;
- routing, location and electrical continuity of the down-conductors;
- fixing of the different components;

- separation distances and/or equipotential bondings;
- earth termination system;
- interconnection of the ESESystem earth termination systems to the main equipotential bonding of the structure.

Anyway if a conductor is entirely or totally hidden, its electrical continuity should be checked

8.5 Visual verification

A visual inspection should be performed to make sure that:

- no damage related to lightning has been noted;
- Integrity of ESESystem has not been modified;
- no extension or modification of the protected structure needs the installation of additional lightning protection measures;
- the electrical continuity of visible conductors is correct;
- all component fasteners and mechanical protectors are in good condition;
- no parts have been weakened by corrosion;
- the separation distance is respected and there are enough equipotential bondings and their condition is correct;
- end of life indicator is correct;
- maintenance operations results are checked and recorded (see article 8.7).

8.6 Complete verification

Complete verification includes visual verification and the following measurements to check:

- the electrical continuity of hidden conductors;
- the earth termination system resistance values (any variation with regards to initial values > 50 % should be analysed);
- Properly working of ESEAT according to manufacturer procedure.

NOTE High frequency earth system measurement is feasible during installation or in maintenance operation in order to check the coherence between the needs and the installed earth system.

8.7 Maintenance

Any faults found in the ESESystem during an inspection should be corrected as soon as possible in order to maintain its optimal effectiveness.

Maintenance of components and protections system has to be conducted according to manufacturer documentations.

ANNEXE A (normative) RISK ANALYSIS

A.1 Explanation of terms

A.1.1 Damage and loss

A.1.1.1 Source of damage

The lightning current is the primary source of damage. The following sources are distinguished by the strike attachment point (see Table A.1):

- + S1: flashes to a structure;
- + S2: flashes near a structure;
- + S3: flashes to a service;
- + S4: flashes near a service.

A.1.1.2 Types of damage

A lightning flash may cause damage depending on the characteristics of the object to be protected. Some of the most important characteristics are: type of construction, contents and application, type of service and protection measures provided.

For practical applications of this risk assessment, it is useful to distinguish between three basic types of damage which can appear as the consequence of lightning flashes. They are as follows (see Table A.1):

- + D1: injury to living beings;
- D2: physical damage;
- + D3: failure of electrical and electronic systems.

The damage to a structure due to lightning may be limited to a part of the structure or may extend to the entire structure. It may also involve surrounding structures or the environment (e.g. chemical or radioactive emissions).

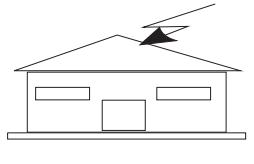
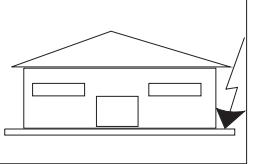
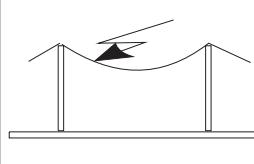
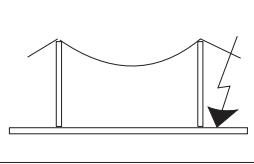
Lightning affecting a service can cause damage to the physical means itself – line or pipe – used to provide the service, as well as to related electrical and electronic systems. The damage may also extend to internal systems connected to the service.

A.1.1.3 Types of loss

Each type of damage, alone or in combination with others, may produce a different consequential loss in the object to be protected. The type of loss that may appear depends on the characteristics of the object itself and its content. The following types of loss shall be taken into account (see Table A.1):

- + L1: loss of human life;
- + L2: loss of service to the public;
- + L3: loss of cultural heritage;
- + L4: loss of economic value (structure and its content).

Table A.1 – Sources of damage, types of damage and types of loss according to the point of strike

		Structure		
Point of strike	Source of damage	Type of damage	Type of loss	
	S1	D1 D2 D3	L1, L42) L1, L2, L3, L4 L11), L2, L4	
	S2	D3	L11), L2, L4	
	S3	D1 D2 D3	L1, L42) L1, L2, L3, L4 L11), L2, L4	
	S4	D3	L11), L2, L4	
1) Only for structures with risk of explosion, and for hospitals or other structures where failures of internal systems immediately endangers human life. 2) Only for properties where animals may be lost.				

A.1.2 Risk and risk components

A.1.2.1 Risk

The risk R is the value of a probable average annual loss. For each type of loss which may appear in a structure or in a service, the relevant risk shall be evaluated.

The risks to be evaluated in a structure may be as follows:

- + 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.

To evaluate risks, R , the relevant risk components (partial risks depending on the source and type of damage) shall be defined and calculated.

Each risk, R , is the sum of its risk components. When calculating a risk, the risk components may be grouped according to the source of damage and the type of damage.

A.1.2.2 Risk components for a structure due to flashes to the structure

- R_A : Component related to injury to living beings caused by touch and step voltages in the zones up to 3 m outside the structure. Loss of type L1 and, in the case of structures holding livestock.

NOTE 1 The risk component caused by touch and step voltages inside the structure due to flashes to the structure is not considered in this standard.

NOTE 2 In special structures, people may be endangered by direct strikes (e.g. top level of garage parking or stadiums). These cases may also be considered using the principles of this standard.

- R_B : Component related to physical damage caused by dangerous sparking inside the structure triggering fire or explosion, which may also endanger the environment. All types of loss (L1, L2, L3) may arise.
- R_C : Component related to failure of internal systems caused by LEMP. Loss of type L2 could occur in all cases along with type L1 in the case of structures with risk of explosion and hospitals or other structures where failure of internal systems immediately endangers human life.

A.1.2.3 Risk component for a structure due to flashes near the structure

- R_M : Component related to failure of internal systems caused by LEMP. Loss of type L2 could occur in all cases, along with type L1 in the case of structures with risk of explosion and hospitals or other structures where failure of internal systems immediately endangers human life.

A.1.2.4 Risk components for a structure due to flashes to a service connected to the structure

- R_U : Component related to injury to living beings caused by touch voltage inside the structure, due to lightning current injected in a line entering the structure. Loss of type L1 and, in the case of agricultural properties.
- R_V : Component related to physical damage (fire or explosion triggered by dangerous sparking between external installation and metallic parts generally at the entrance point of the line into the structure) due to lightning current transmitted through or along incoming services. All types of loss (L1, L2, L3) may occur.
- R_W : Component related to failure of internal systems caused by overvoltages induced on incoming lines and transmitted to the structure. Loss of type L2 could occur in all cases; along with type L1 in the case of structures with risk of explosion and hospitals or other structures where failure of internal systems immediately endangers human life.

NOTE The services taken into account in this assessment are only the lines entering the structure. Lightning flashes to or near pipes are not considered as a source of damage based on the bonding of pipes to an equipotential bonding bar. If an equipotential bonding bar is not provided, such a threat must also be considered.

A.1.2.5 Risk component for a structure due to flashes near a service connected to the structure

- R_Z : Component related to failure of internal systems caused by overvoltages induced on incoming lines and transmitted to the structure. Loss of type L2 could occur in all cases; along with type L1 in the case of structures with risk of explosion and hospitals or other structures where failure of internal systems immediately endanger human life.

NOTE The services taken into account in this assessment are only the lines entering the structure. Lightning flashes to or near pipes are not considered as a source of damage based on the bonding of pipes to an equipotential bonding bar. If an equipotential bonding bar is not provided, such a threat must also be considered.

A.1.3 Composition of risk components related to a structure

Risk components to be considered for each type of loss in a structure are listed below:

- + R_1 : Risk of loss of human life:

$$R_1 = R_A + R_B + R_C^{1)} + R_M^{1)} + R_U + R_V + R_W^{1)} + R_Z^{1)} \quad (\text{A.1})$$

¹⁾ Only for structures with risk of explosion and for hospitals with life-saving electrical equipment or other structures where failure of internal systems immediately endangers human life.

- + R_2 : Risk of loss of service to the public:

$$R_2 = R_B + R_C + R_M + R_V + R_W + R_Z \quad (\text{A.2})$$

- + R_3 : Risk of loss of cultural heritage:

$$R_3 = R_B + R_V \quad (\text{A.3})$$

- + R_4 : Risk of loss of economic value:

$$R_4 = R_A^{2)} + R_B + R_C + R_M + R_U^{2)} + R_V + R_W + R_Z \quad (\text{A.4})$$

²⁾ Only for properties where animals may be lost.

The risk components corresponding to each type of loss are also combined in Table A.2.

Table A.2 – Risk components to be considered for each type of loss in a structure

Source of damage	Flash to a structure S1			Flash near a structure S2	Flash to a line connected to the structure S3			Flash near a line connected to the structure S4
Risk component	R_A	R_B	R_C	R_M	R_U	R_V	R_W	R_Z
Risk for each type of loss								
R_1	*	*	* ¹⁾	* ¹⁾	*	*	* ¹⁾	* ¹⁾
R_2		*	*	*		*	*	*
R_3		*	*	*		*	*	*
R_4	* ²⁾	*	*	*	* ²⁾	*	*	*

¹⁾ Only for structures with risk of explosion, and for hospitals or other structures where failure of internal systems immediately endangers human life.

²⁾ Only for properties where animals may be lost.

A.2 Risk management

A.2.1 Basic procedure

The following procedure shall be applied:

- identification of the object to be protected and its characteristics;
- identification of all the types of loss in the object and the relevant corresponding risk R (R_1 to R_4);
- evaluation of risk R for each type of loss (R_1 to R_4);
- evaluation of need of protection, by comparison of risk R_1 , R_2 and R_3 for a structure with the tolerable risk R_T ;
- evaluation of cost effectiveness of protection by comparison of the costs of total loss with and without protection measures. In this case, the assessment of components of risk R_4 for a structure shall be performed in order to evaluate such costs.

A.2.2 Structure to be considered for risk assessment

Structure to be considered includes:

- the structure itself ;
- installations in the structure ;
- contents of the structure ;
- persons in the structure or standing in the zones up to 3 m from the outside of the structure ;
- environment affected by a damage to the structure.

Protection does not include connected services outside of the structure.

NOTE The structure to be considered may be subdivided into several zones (see A.3.7).

A.2.3 Tolerable risk R_T

It is the responsibility of the authority having jurisdiction to identify the value of tolerable risk.

Representative values of tolerable risk R_T , where lightning flashes involve loss of human life or loss of social or cultural values, are given in Table A.3.

Table A.3 – Typical values of tolerable risk R_T

Types of loss	R_T (y^{-1})
Loss of human life or permanent injuries	10^{-5}
Loss of service to the public	10^{-3}
Loss of cultural heritage	10^{-3}

A.2.4 Specific procedure to evaluate the need of protection

The following risks shall be considered in the evaluation of the need of protection against lightning for an object:

- risks R_1 , R_2 and R_3 for a structure.

For each risk to be considered the following steps shall be taken:

- identification of the components R_X which make up the risk;
- calculation of the identified risk components R_X ;
- calculation of the total risk R (see A.1.2);
- identification of the tolerable risk R_T ;
- comparison of the risk R with the tolerable value R_T .

If $R \leq R_T$, lightning protection is not necessary.

If $R > R_T$ protection measures shall be adopted in order to reduce $R \leq R_T$ for all risks to which the object is subjected.

A.2.5 Procedure to evaluate the cost effectiveness of protection

Besides the need of lightning protection for a structure or for a service, it may be useful to ascertain the economic benefits of installing protection measures in order to reduce the economic loss L4.

The assessment of components of risk R_4 for a structure allows the user to evaluate the cost of the economic loss with and without the adopted protection measures.

The procedure to ascertain the cost effectiveness of protection requires:

- identification of the components R_X which make up the risk R_4 for a structure ;
- calculation of the identified risk components R_X in absence of new/additional protection measures ;
- calculation of the annual cost of loss due to each risk component R_X ;
- calculation of the annual cost C_L of total loss in the absence of protection measures ;
- adoption of selected protection measures ;
- calculation of risk components R_X with selected protection measures present ;
- calculation of the annual cost of residual loss due to each risk component R_X in the protected structure, or service;
- calculation of the total annual cost C_{RL} of residual loss with selected protection measures present;
- calculation of the annual cost C_{PM} of selected protection measures;
- comparison of costs.

If $C_L < C_{RL} + C_{PM}$, lightning protection may not be deemed to be cost effective.

If $C_L \geq C_{RL} + C_{PM}$, protection measures may prove to save money over the life of the structure or the service.

A.2.6 Selection of protection measures

The selection of the most suitable protection measures shall be made by the designer according to the share of each risk component in the total risk R and according to the technical and economic aspects of the different protection measures.

Critical parameters shall be identified to determine the more efficient measure to reduce the risk R .

For each type of loss, there is a number of protection measures which, individually or in combination, make the condition $R \leq R_T$. The solution to be adopted shall be selected with allowance for technical and economic aspects. A simplified procedure for selection of protective measures is given in the flow diagrams of Figure A.1 for structures. In any case the installer or planner should identify the most critical risk components and reduce them, also taking into account economic aspects.

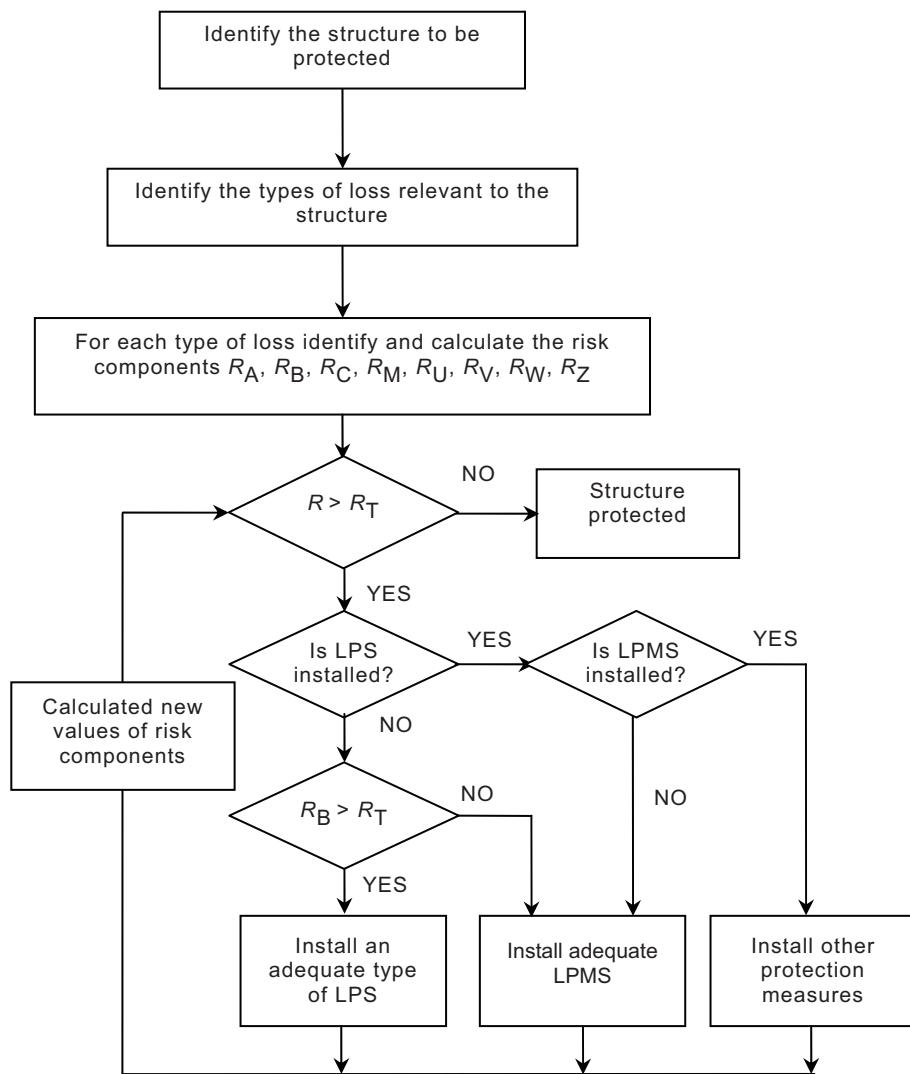


Figure A.1 – Procedure for selecting protection measures in structures

A.3 Assessment of risk components for a structure

A.3.1 Basic equation

Each risk component R_A , R_B , R_C , R_M , R_U , R_V , R_W and R_Z , as described in A.1, may be expressed by the following general equation

$$R_X = N_X \times P_X \times L_X \quad (\text{A.5})$$

Where

- + N_X is the number of dangerous events per annum (see also A.4);
- + P_X is the probability of damage to a structure (see also A.5);
- + L_X is the consequent loss (see also A.6).

NOTE 1 The number N_X of dangerous events is affected by lightning ground flash density (N_g) and by the physical characteristics of the object to be protected, its surroundings and the soil.

NOTE 2 The probability of damage P_X is affected by characteristics of the object to be protected and the protection measures provided.

NOTE 3 The consequent loss L_X is affected by the use to which the object is assigned, the attendance of persons, the type of service provided to public, the value of goods affected by the damage and the measures provided to limit the amount of loss.

A.3.2 Assessment of risk components due to flashes to the structure (S1)

For evaluation of risk components related to lightning flashes to the structure, the following relationship apply:

- component related to injury to living beings (D1)

$$R_A = N_D \times P_A \times L_A \quad (\text{A.6})$$

- component related to physical damage (D2)

$$R_B = N_D \times P_B \times L_B \quad (\text{A.7})$$

- component related to failure of internal systems (D3)

$$R_C = N_D \times P_C \times L_C \quad (\text{A.8})$$

A.3.3 Assessment of the risk component due to flashes near the structure (S2)

For evaluation of the risk component related to lightning flashes near the structure, the following relationship applies:

- component related to failure of internal systems (D3)

$$R_M = N_M \times P_M \times L_M \quad (\text{A.9})$$

A.3.4 Assessment of risk components due to flashes to a line connected to the structure (S3)

For evaluation of the risk components related to lightning flashes to an incoming line, the following relationships apply:

- component related to injury to living beings (D1)

$$R_U = (N_L - N_{Da}) \times P_U \times L_U \quad (A.10)$$

- component related to physical damage (D2)

$$R_V = (N_L - N_{Da}) \times P_V \times L_V \quad (A.11)$$

- component related to failure of internal systems (D3)

$$R_W = (N_L - N_{Da}) \times P_W \times L_W \quad (A.12)$$

If the line has more than one section, the values of R_U , R_V and R_W are the sum of the R_U , R_V and R_W values relevant to each section of the line. The sections to be considered are those between the structure and the first distribution node.

In the case of a structure with more than one connected line with different routing, the calculations shall be performed for each line.

A.3.5 Assessment of risk component due to flashes near a line connected to the structure (S4)

For evaluation of the risk component related to lightning flashes near a line connected to the structure, the following relationship applies:

- component related to failure of internal systems (D3)

$$R_Z = (N_I - N_L) \times P_Z \times L_Z \quad (A.13)$$

If the line has more than one section, the value of R_Z is the sum of the R_Z components relevant to each section of the line. The sections to be considered are those between the structure and the first distribution node.

In the case of a structure with more than one connected line with different routing, the calculations shall be performed for each line.

For the purpose of this assessment, if $(N_I - N_L) < 0$, then assume $(N_I - N_L) = 0$.

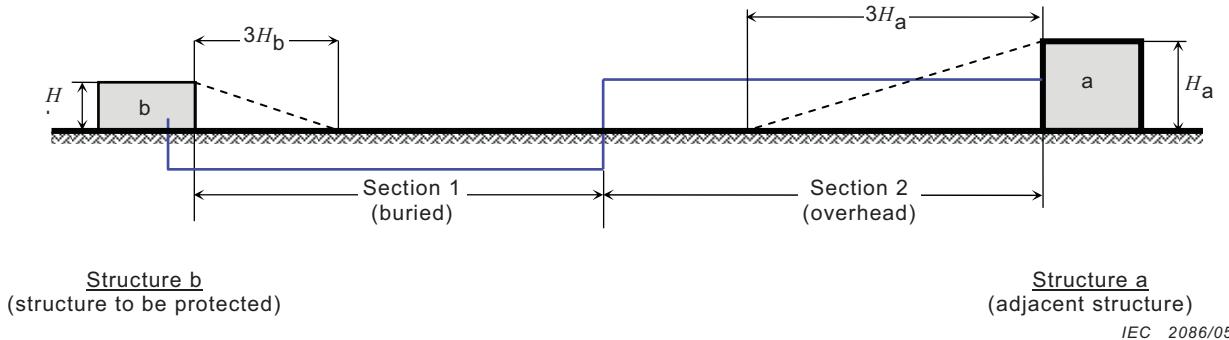


Figure A.2 – Structures at line ends: at “b” end the structure to be protected (structure b) and at “a” end an adjacent structure (structure a)

A.3.6 Summary of risk components in a structure

Risk components for structures are summarized in Table A.4, according to different types of damage and different sources of damage.

Table A.4 – Risk components for a structure for different types of damage caused by different sources

Source of damage Damage	S1 Lightning flash to a structure	S2 Lightning flash near a structure	S3 Lightning flash to an incoming service	S4 Lightning flash near a service
D1 Injury to living beings	$R_A = N_D \times P_A \times r_a \times L_t$		$R_U = (N_L + N_{Da}) \times P_U \times r_u \times L_t$	
D2 Physical damage	$R_B = N_D \times P_B \times r_p \times h_z \times r_f \times L_f$		$R_V = (N_L + N_{Da}) \times P_V \times r_p \times h_z \times r_f \times L_f$	
D3 Failure of electrical and electronic systems	$R_C = N_D \times P_C \times L_o$	$R_M = N_M \times P_M \times L_o$	$R_W = (N_L + N_{Da}) \times P_W \times L_o$	$R_Z = (N_I - N_L) \times P_Z \times L_o$

If the structure is partitioned in zones Z_S (see A.3.7), each risk component shall be evaluated for each zone Z_S .

The total risk R of the structure is the sum of risks components relevant to the zones Z_S which constitute the structure.

A.3.7 Partitioning of a structure in zones Z_S

To assess each risk component, a structure could be divided into zones Z_S each having homogeneous characteristics. However, a structure may be, or may be assumed to be, a single zone.

Zones Z_S are mainly defined by

- type of soil or of floor (risk components R_A and R_U),
- fire proof compartments (risk components R_B and R_V),
- spatial shields (risk components R_C and R_M).

Further zones may be defined according to

- layout of internal systems (risk components R_C and R_M),
- protection measures existing or to be provided (all risk components),
- losses L_X values (all risk components).

Partitioning of the structure in zones Z_S should take into account the feasibility of the implementation of the most suitable protection measures.

A.3.8 Assessment of risk components in a structure with zones Z_S

Rules to evaluate the risk components depends on the type of risk.

A.3.8.1 Risks R_1 , R_2 , R_3 and R_4

A.3.8.1.1 Single zone structure

In this case only one zone Z_S made up of the entire structure is defined. According to A.3.7, the risk R is the sum of risk components R_X in the structure. For the evaluation of risk components and the selection of the relevant parameters involved, the following rules apply:

- parameters relevant to the number N of dangerous events shall be evaluated according to A.4 ;
- parameters relevant to the probability P of damage shall be evaluated according to A.5.

Moreover:

- For components R_A , R_B , R_U , R_V , R_W and R_Z , only one value is to be fixed for each parameter involved. Where more than one value is applicable, the highest one shall be chosen ;
- For components R_C and R_M , if more than one internal system is involved in the zone, values of P_C and P_M are given by:

$$P_C = 1 - (1 - P_{C1}) \times (1 - P_{C2}) \times (1 - P_{C3}) \quad (\text{A.14})$$

$$P_M = 1 - (1 - P_{M1}) \times (1 - P_{M2}) \times (1 - P_{M3}) \quad (\text{A.15})$$

where P_{Ci} , and P_{Mi} are parameters relevant to internal system i.

- Parameters relevant to the amount L of loss shall be evaluated according to A.6.

The typical mean values derived from A.6 may be assumed for the zone, according to the use of the structure.

With the exception made for P_C and P_M , if more than one value of any other parameter exists in a zone, the value of the parameter leading to the highest value of risk is to be assumed.

Defining the structure with a single zone may lead to expensive protection measures because each measure must extend to the entire structure.

A.3.8.1.2 Multi-zone structure

In this case, the structure is divided into multiple zones Z_s . The risk for the structure is the sum of the risks relevant to all zones of the structure; in each zone, the risk is the sum of all relevant risk components in the zone.

For the evaluation of risk components and the selection of the relevant parameters involved, the rules of A.3.8.1.1 apply.

Dividing a structure into zones allows the designer to take into account the peculiar characteristics of each part of the structure in the evaluation of risk components and to select the most suitable protection measures tailored zone by zone, reducing the overall cost of protection against lightning.

A.4 Assessment of annual number N of dangerous events

A.4.1 General

The average annual number N of dangerous events due to lightning flashes influencing an object to be protected depends on the thunderstorm activity of the region where the object is located and on the objects physical characteristics. To calculate the number N , it is generally accepted to multiply the lightning ground flash density N_g by an equivalent collection area of the object and by taking into account correction factors for objects physical characteristics.

The lightning ground flash density N_g is the number of lightning flashes per km^2 per year. This value is available from ground flash location networks in many areas of the world.

NOTE If a map of N_g is not available, in temperate regions it may be estimated by:

$$N_g \approx 0,1 T_d \quad (\text{A.16})$$

where T_d is the thunderstorm days per year (which can be obtained from isokeraunic maps).

Events that may be considered as dangerous for a structure to be protected are

- flashes to the structure;
- flashes near the structure;
- flashes to a service entering the structure;
- flashes near a service entering the structure;
- flashes to a structure to which a service is connected.

A simplified method could be apply only for the structure where :

- fire risk is low or ordinary;
- fire risk is high but with low level of panic;
- there is no explosion risk;
- there is no environmental risk;
- it's not an hospital.

A.4.2 Assessment of the average annual number of dangerous events due to flashes to a structure N_D and to a structure connected at “a” end of a line N_{Da}

A.4.2.1 Determination of the collection area A_d

For isolated structures on flat ground, the collection area A_d is the area defined by 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. Determination of the value of A_d may be performed graphically or mathematically.

A.4.2.1.1 Rectangular structure

For an isolated rectangular structure with length L , width W , and height H on a flat ground, the collection area is then equal to

$$A_d = L \times W + 6 \times H \times (L + W) + 9 \times \pi \times (H)^2 \quad (\text{A.17})$$

with L , W and H expressed in metres (see Figure A.3).

NOTE A more precise evaluation could be obtained considering the relative height of the structure with respect to the surrounding objects or the soil within a distance of $3H$ from the structure.

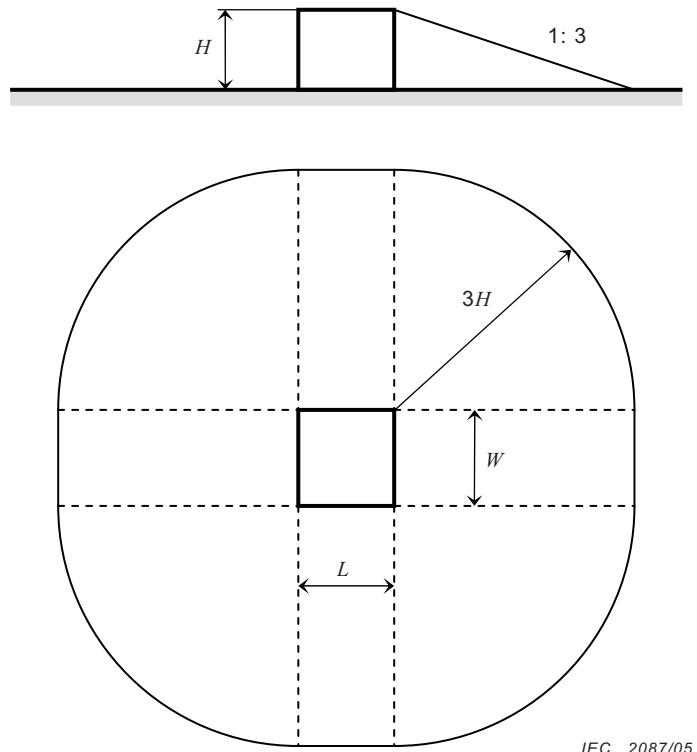


Figure A.3 – Collection area A_d of an isolated structure

A.4.2.1.2 Complex shaped structure

If the structure has a complex shape such as elevated roof protrusions (see Figure A.5), a graphic method should be used to evaluate A_d (see Figure A.6), because the differences may be too great if the maximum ($A_{d\max}$) or minimum ($A_{d\min}$) dimensions are used.

An acceptable approximate value of the collection area is the maximum between Admin and the collection area attributed to the elevated roof protrusion A_d' . A_d' may be calculated by:

$$A_d' = 9\pi \times (H_p)^2 \quad (\text{A.18})$$

where H_p is the height of protrusion.

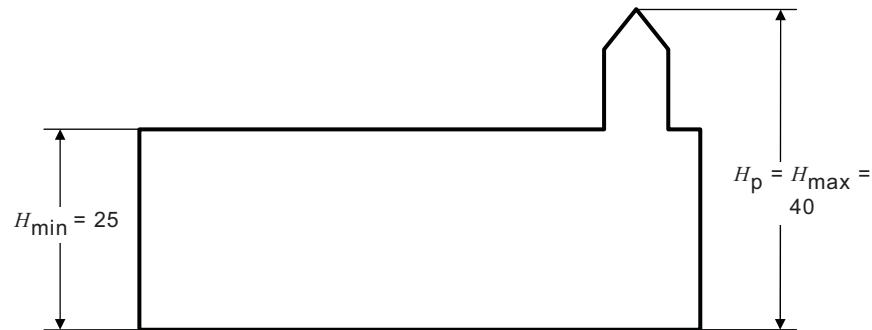
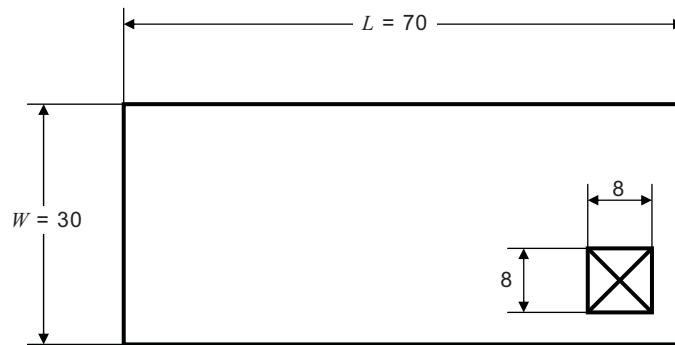


Figure A.4 – Complex shape structure

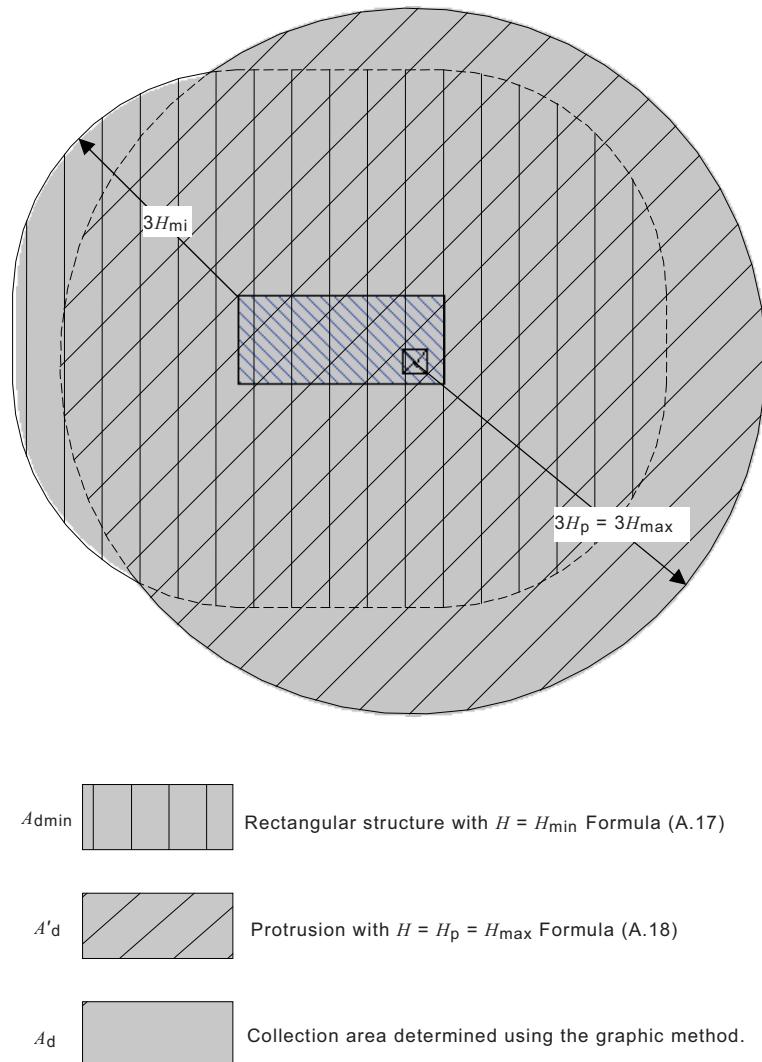


Figure A.5 – Different methods to determine the collection area for the structure of Figure A.4

A.4.2.1.3 Structure as a part of a building

Where the structure S to be considered consists of only a part of a building B, the dimensions of structure S may be used in evaluation of Ad provided that the following conditions are fulfilled (see Figure A.6):

- the structure S is a separated vertical part of the building B;
- the building B does not have a risk of explosion;
- propagation of fire between the structure S and other parts of the building B is avoided by means of walls with resistance to fire of 120 min (REI 120) or by means of other equivalent protection measures;
- propagation of overvoltages along common lines, if any, is avoided by means of SPD installed at the entrance point of such lines in the structure or by means of other equivalent protection measure.

NOTE For definition and information on REI see Official Journal of European Union, 1994/28/02, n. C 62/63.

Where these conditions are not fulfilled, the dimensions of the whole building B should be used.

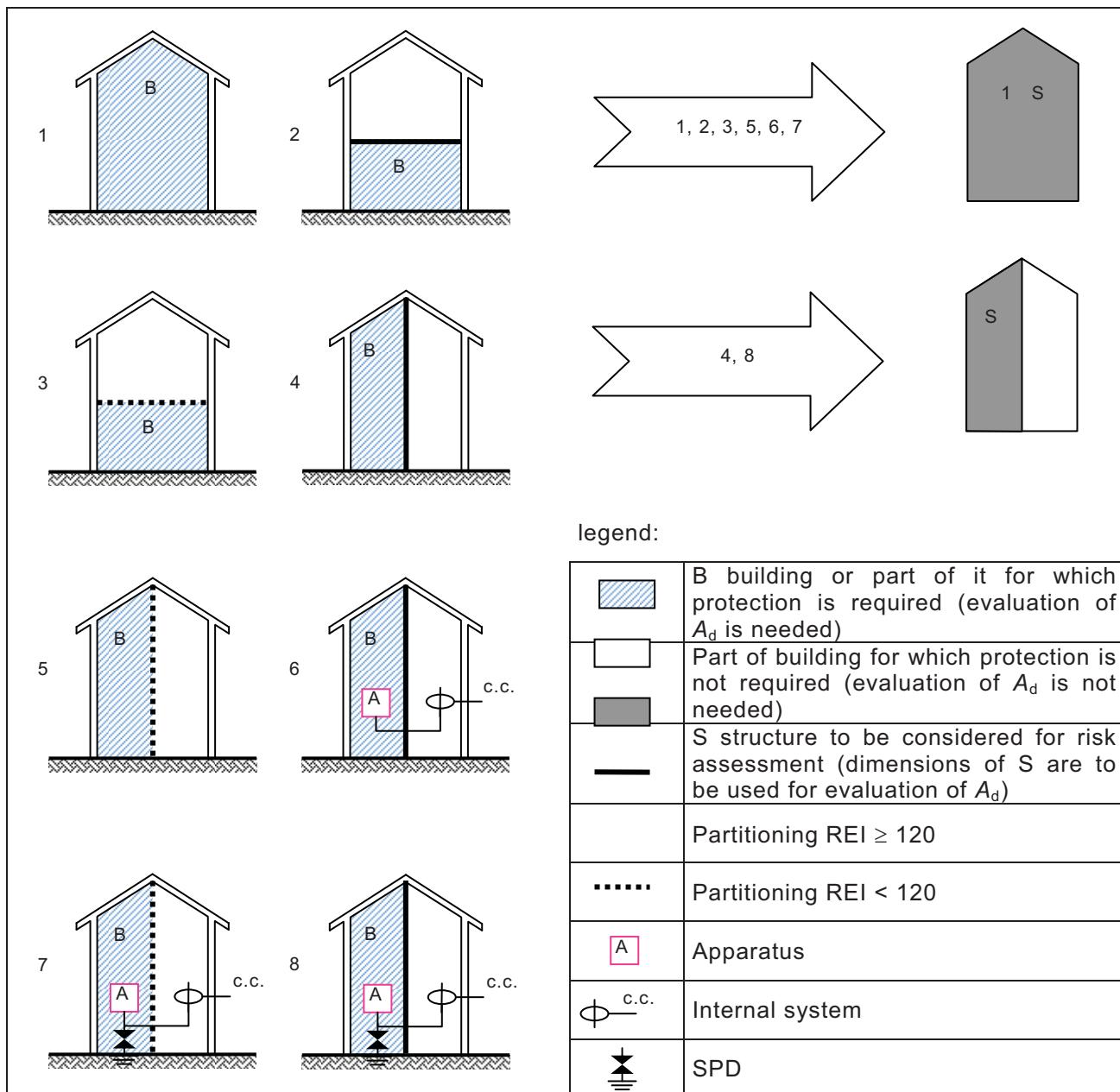


Figure A.6 – Structure to be considered for evaluation of collection area A_d

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A.4.2.2 Relative location of the structure

The relative location of the structure, compensating for surrounding objects or an exposed location, will be taken into account by a location factor C_d (see Table A.5).

Table A.5 – Location factor C_d

Relative location	C_d
Object surrounded by higher objects or trees	0,25
Object surrounded by objects or trees of the same heights or smaller	0,5
Isolated object: no other objects in the vicinity	1
Isolated object on a hilltop or a knoll	2

A.4.2.3 Number of dangerous events N_D for a structure (“b” end of a service)

N_D may be evaluated as the product:

$$N_D = N_g \times A_{d/b} \times C_{d/b} \times 10^{-6} \quad (\text{A.19})$$

where

- N_g is the lightning ground flash density (1/km²/year);
- $A_{d/b}$ is the collection area of the isolated structure (m²) (see Figure A.3);
- $C_{d/b}$ is the location factor of the structure (see Table A.5).

A.4.2.4 Number of dangerous events N_{Da} for an adjacent structure (“a” end of a service)

The average annual number of dangerous events due to flashes to a structure at “a” end of a line N_{Da} (see A.3.5 and Figure A.2) may be evaluated as the product:

$$N_{Da} = N_g \times A_{d/a} \times C_{d/a} \times C_t \times 10^{-6} \quad (\text{A.20})$$

where

- N_g is the lightning ground flash density (1/km²/year);
- $A_{d/a}$ is the collection area of the isolated adjacent structure (m²) (see Figure A.3);
- $C_{d/a}$ is the location factor of the adjacent structure (see Table A.2);
- C_t is the correction factor for the presence of a H_V/L_V transformer on the service to which the structure is connected, located between the point of strike and the structure (see Table A.4). This factor applies to line sections upstream from the transformer with respect to the structure.

A.4.3 Assessment of the average annual number of dangerous events due to flashes near a structure N_M

N_M may be evaluated as the product:

$$N_M = N_g \times (A_m - A_{d/b} C_{d/b}) \times 10^{-6} \quad (\text{A.21})$$

where

- N_g is the lightning ground flash density (flash/km²/year);
- A_m is the collection area of flashes striking near the structure (m²).

The collection area A_m extends to a line located at a distance of 250 m from the perimeter of the structure (see Figure A.7).

If $N_M < 0$, $N_M = 0$ shall be used in the assessment.

A.4.4 Assessment of the average annual number of dangerous events due to flashes to a service N_L

For a one-section service, N_L may be evaluated by:

$$N_L = N_g \times A_l \times C_d \times C_t \times 10^{-6} \quad (\text{A.22})$$

where

- N_g is the lightning ground flash density (flash/km²/year);
- A_l is the collection area of flashes striking the service (m²) (see Table A.3 and Figure A.7);
- C_d is the location factor of service (see Table A.2);
- C_t is the correction factor for the presence of a HV/LV transformer located between the point of strike and the structure (see Table A.4). This factor applies to line sections upstream from the transformer with respect to the structure.

Table A.6 – Collection areas A_l and A_i depending on the service characteristics

	Aerial	Buried
A_l	$(L_c - 3(H_a + H_b)) 6 H_c$	$(L_c - 3(H_a + H_b)) \sqrt{\rho} +$
A_i	$1\ 000 L_c$	$25 L_c \sqrt{\rho} +$

where

A_l is the collection area of flashes striking the service (m^2);
 A_i is the collection area of flashes to ground near the service (m^2);
 H_c is the height of the service conductors above ground (m);
 L_c is the length of the service section from the structure to the first node (m). A maximum value $L_c = 1\ 000 \text{ m}$ should be assumed;
 H_a is the height of the structure connected at end "a" of service (m);
 H_b is the height of the structure connected at end "b" of service (m);
 ρ is the resistivity of soil where the service is buried (Ωm). A maximum value $\rho = 500 \Omega\text{m}$ should be assumed.

For the purposes of this calculation:

- where the value of L_c is unknown, $L_c = 1\ 000 \text{ m}$ is to be assumed;
- where the value of soil resistivity is unknown, $\rho = 500 \Omega\text{m}$ is to be assumed;
- for underground cables running entirely within a highly meshed earth termination, $A_i = A_l = 0$ may be assumed for the equivalent collection area;
- the structure to be protected shall be assumed to be the one connected at "b" end of service.

NOTE More information on the collection areas A_l and A_i can be found in ITU Recommendations K.46 and K.47.

Table A.7 – Transformer factor C_t

Transformer	C_t
Service with two winding transformer	0,2
Service only	1

A.4.5 Assessment of average annual number of dangerous events due to flashes near a service N_l

For a one-section (overhead, underground, screened, unscreened, etc.) service, the value of N_l may be evaluated by:

$$N_l = N_g \times A_i \times C_e \times C_t \times 10^{-6} \quad (\text{A.23})$$

Where

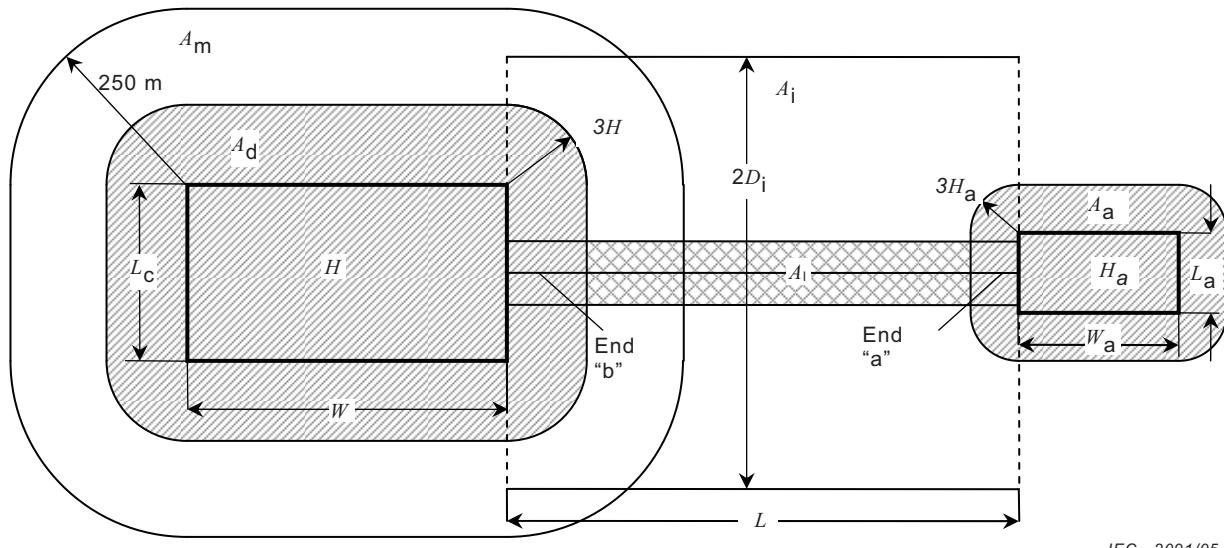
N_g is the lightning ground flash density (flash/km²/year);
 A_i is the collection area of flashes to ground near the service (m^2) (see Table A.3 and Figure A.7);
 C_e is the environmental factor (see Table A.8);
 C_t is the correction factor for the presence of a HV/LV transformer located between the point of strike and the structure (see Table A.4). This factor applies to line sections upstream from the transformer with respect to the structure.

Table A.8 – Environmental factor C_e

Environment	C_e
Urban with tall buildings ¹⁾	0
Urban ²⁾	0,1
Suburban ³⁾	0,5
Rural	1

1) Height of buildings higher than 20 m.
 2) Height of buildings ranging between 10 m and 20 m.
 3) Height of buildings lower than 10 m.

NOTE The collection area A_i of the service is defined by its length L_c and by the lateral distance D_i (see Figure A.7) at which a flash near the service may cause induced overvoltages not lower than 1,5 kV.

Figure A7 – Collection areas (A_d , A_m , A_i , A_l)

A.5 Assessment of probability P_x of damage for a structure

The probabilities given in this annex are valid if protection measures conform to their standards.

Values of probabilities P_x less than 1 may only be selected if the measure or characteristic is valid for the entire structure or zone of structure (Z_s) to be protected and for all relevant equipment.

A.5.1 Probability P_A that a flash to a structure will cause injury to living beings

The values of probability P_A of shock to living beings due to touch and step voltage by a lightning flash to the structure, as a function of typical protection measures, are given in Table A.9.

Table A.9 – Values of probability P_A that a flash to a structure will cause shock to living beings due to dangerous touch and step voltages

Protection measure	P_A
No protection measures	1
Electrical insulation of exposed down-conductor (e.g. at least 3 mm cross-linked polyethylene)	10^{-2}
Effective soil equipotentialization	10^{-2}
Warning notices	10^{-1}

If more than one provision has been taken, the value of P_A is the product of the corresponding P_A values.

NOTE Where the structure is reinforcing members or framework is used as a down-conductor system, or where physical restrictions are provided, the value of probability P_A is negligible.

A.5.2 Probability P_B that a flash to a structure will cause physical damage

The values of probability P_B of physical damage by a flash to a structure, as a function of lightning protection level (LPL), is given in Table A.10.

Table A.10 – Values of P_B depending on the protection measures to reduce physical damage

Characteristics of structure	Class of ESESystem	P_B
Structure not protected by ESESystem	–	1
Structure protected by ESESystem	IV	0,2
	III	0,1
	II	0,05
	I	0,02
Level I ⁺		0,01
Level I ⁺⁺		0,001

A.5.3 Probability P_C that a flash to a structure will cause failure of internal systems

The probability P_C that a flash to a structure will cause a failure of internal systems depends on the adopted coordinated SPD protection:

$$P_C = P_{SPD} \quad (A.24)$$

Values of P_{SPD} depend on lightning protection level (LPL) for which SPD are designed, as shown in Table A.11.

Table A.11 – Value of the probability P_{SPD} as a function of LPL for which SPDs are designed

LPL	P_{SPD}
No coordinated SPD protection	1
III-IV	0,03
II	0,02
I	0,01
NOTE 3	0,005 – 0,001

NOTE 1 Only “coordinated SPD protection” is suitable as a protection measure to reduce P_C . Coordinated SPD protection is effective to reduce P_C only in structures protected by an ESESystem or structures with continuous metal or reinforced concrete framework acting as a natural ESESystem, where bonding and earthing requirements are satisfied.

NOTE 2 Shielded internal systems connected to external lines consisting of lightning protective cable or systems with wiring in lightning protective cable ducts, metallic conduit, or metallic tubes; may not require the use of coordinated SPD protection.

NOTE 3 Smaller values of P_{SPD} are possible in the case of SPDs having better protection characteristics (higher current withstand capability, lower protective level, etc.) compared with the requirements defined for LPL I at the relevant installation locations.

A.5.4 Probability P_M that a flash near a structure will cause failure of internal systems

The probability P_M that a lightning flash near a structure will cause failure of internal systems depends on the adopted lightning protection measures (LPM), according to a factor K_{MS} .

When coordinated SPD protection meeting the requirements of NFEN 61643-11 and CLC/TS 61643-12 is not provided, the value of P_M is equal to the value of P_{MS} .

The values of P_{MS} as a function of K_{MS} are given in Table A.12, where K_{MS} is a factor related to the performances of the adopted protection measures.

When coordinated SPD protection according to NF EN 61643-11 and CLC/TS 61643-12 is provided, the value of P_M is the lower value between P_{SPD} and P_{MS} .

Table A.12 – Value of the probability P_{MS} as a function of factor K_{MS}

K_{MS}	P_{MS}
$\geq 0,4$	1
0,15	0,9
0,07	0,5
0,035	0,1
0,021	0,01
0,016	0,005
0,015	0,003
0,014	0,001
$\leq 0,013$	0,000 1

For internal systems with equipment not conforming to the resistibility or withstand voltage level given in the relevant product standards $P_{MS} = 1$ shall be assumed.

The values of factor K_{MS} are obtained from the product:

$$K_{MS} = K_{S1} \times K_{S2} \times K_{S3} \times K_{S4} \quad (A.25)$$

where

- K_{S1} takes into account the screening effectiveness of the structure, ESESystem or other shields at boundary $L_{PZ} 0/1$;
- K_{S2} takes into account the screening effectiveness of shields internal to the structure at boundary $L_{PZ} X/Y (X>0, Y>1)$;
- K_{S3} takes into account the characteristics of internal wiring (see Table A.13);
- K_{S4} takes into account the impulse withstand voltage of the system to be protected.

Inside an L_{PZ} , at a safety distance from the boundary screen at least equal to the mesh width w , factors K_{S1} and K_{S2} for ESESystem or spatial grid-like shields may be evaluated as

$$K_{S1} = K_{S2} = 0,12 \times w \quad (A.26)$$

where w (m) is the mesh width of grid-like spatial shield, or of mesh type ESESystem down-conductors or the spacing between the structure metal columns, or the spacing between a reinforced concrete framework acting as a natural ESESystem.

For continuous metal shields with thickness of 0,1 mm to 0,5 mm, $K_{S1} = K_{S2} = 10^{-4}$ to 10^{-5} .

Where the induction loop is running close to the LPZ boundary screen conductors at a distance from the shield shorter than the safety distance, the values of K_{S1} and K_{S2} will be higher. For instance, the values of K_{S1} and K_{S2} should be doubled where the distance to the shield ranges from 0,1 w to 0,2 w.

For a cascade of LPZ the resulting K_{S2} is the product of the relevant K_{S2} of each LPZ.

NOTE 1 The maximum value of K_{S1} is limited to 1.

Table A.13 – Value of factor K_{S3} depending on internal wiring

Type of internal wiring	K_{S3}
Unshielded cable – no routing precaution in order to avoid loops 1)	1
Unshielded cable – routing precaution in order to avoid large loops 2)	0,2
Unshielded cable – routing precaution in order to avoid loops 3)	0,02
Shielded cable with shield resistance 4) $5 < RS \leq 20 \Omega / km$	0,001
Shielded cable with shield resistance 4) $1 < RS \leq 5 \Omega / km$	0,000 2
Shielded cable with shield resistance 4) $RS \leq 1 \Omega / km$	0,000 1

¹⁾ Loop conductors with different routing in large buildings (loop area in the order of 50 m²).
²⁾ Loop conductors routing in the same conduit or loop conductors with different routing in small buildings (loop area in the order of 10 m²).
³⁾ Loop conductors routing in the same cable (loop area in the order of 0,5 m²).
⁴⁾ Cable with shield of resistance RS (Ω/km) bonded to equipotential bonding bar at both ends and equipment connected to the same bonding bar.

For wiring running in continuous metal conduit bonded to equipotential bonding bars at both ends, K_{S3} values shall be multiplied by 0,1.

The factor K_{S4} is evaluated as:

$$K_{S4} = 1,5/U_w \quad (A.27)$$

where U_w is the rated impulse withstand voltage of system to be protected, in kV.

If there are apparatus with different impulse withstand levels in an internal system, the factor K_{S4} relevant to the lowest impulse withstand level shall be selected.

A.5.5 Probability P_U that a flash to a service will cause injury to living beings

The values of probability P_U of injury to living beings due to touch voltage by a flash to a service entering the structure depends on the characteristics of the service shield, the impulse withstand voltage of internal systems connected to the service, the typical protection measures (physical restrictions, warning notices, etc. (see Table A.9) and the SPD(s) provided at the entrance of the service.

When SPD(s) are not provided for equipotential bonding, the value of P_U is equal to the value of P_{LD} , where P_{LD} is the probability of failure of internal systems due to a flash to the connected service. Values of P_{LD} are given in Table A.14.

When SPD(s) are provided for equipotential bonding, the value of P_U is the lower value between P_{SPD} (Table A.11) and P_{LD} .

NOTE Coordinated SPD protection according to NF EN 61643-11 and CLC/TS 61643-12 is not necessary to reduce P_U in this case. SPD(s) are sufficient.

Table A.14 – Values of the probability P_{LD} depending on the resistance R_S of the cable screen and the impulse withstand voltage U_w of the equipment

U_w kV	$5 < R_S \leq 20$ Ω/km	$1 < R_S \leq 5$ Ω/km	$R_S \leq 1$ Ω/km
1,5	1	0,8	0,4
2,5	0,95	0,6	0,2
4	0,9	0,3	0,04
6	0,8	0,1	0,02

R_S (Ω/km): resistance of the cable shield.

For unshielded service $P_{LD} = 1$ shall be taken.

When protection measures, such as physical restrictions, warning notices, etc. are provided, probability P_U shall be further reduced by multiplying it by the values of probability P_A given in Table A.9.

A.5.6 Probability P_V that a flash to a service will cause physical damage

The values of probability P_V of physical damage by a flash to a service entering the structure depend on the characteristics of service shield, the impulse withstand voltage of internal systems connected to the service and the SPDs provided.

When $SPD(s)$ are not provided for equipotential bonding, the value of P_V is equal to the value of P_{LD} , where P_{LD} is the probability of failure of internal systems due to a flash to the connected service.

Values of P_{LD} are given in Table A.14.

When SPD(s) are provided for equipotential bonding, the value of P_V is the lower value between P_{SPD} (see Table A.11) and P_{LD} .

NOTE Coordinated SPD protection according to NF EN 61643-11 and CLC/TS 61643-12 is not necessary to reduce P_V in this case. SPD(s) are sufficient.

A.5.7 Probability P_W that a flash to a service will cause failure of internal systems

The values of probability P_W that a flash to a service entering the structure will cause a failure of internal systems depend on the characteristics of service shielding, the impulse withstand voltage of internal systems connected to the service and the SPDs installed.

When coordinated SPD protection conforming to NF EN 61643-11 and CLC/TS 61643-12 is not provided, the value of P_W is equal to the value of P_{LD} , where P_{LD} is the probability of failure of internal systems due to a flash to the connected service.

Values of P_{LD} are given in Table A.14.

When coordinated SPD protection conforming to NF EN 61643-11 and CLC/TS 61643-12 is provided, the value of P_W is the lower value between P_{SPD} (see Table A.11) and P_{LD} .

A.5.8 Probability P_Z that a lightning flash near an incoming service will cause failure of internal systems

The values of probability P_Z that a lightning flash near a service entering the structure will cause a failure of internal systems depend on the characteristics of the service shield, the impulse withstand voltage of the system connected to the service and protection measures provided.

When coordinated SPD protection conforming to NF EN 61643-11 and CLC/TS 61643-12 is not provided, the value of P_Z is equal to the value of P_{LI} , where P_{LI} is the probability of failure of internal systems due to flash to the connected service.

Values of P_{LI} are given in Table A.15.

When coordinated SPD protection conforming to NF EN 61643-11 and CLC/TS 61643-12 is provided, the value of P_Z is the lower value between P_{SPD} (see Table A.11) and P_{LI} .

Table A.15 – Values of the probability P_{LI} depending on the resistance R_s of the cable screen and the impulse withstand voltage U_w of the equipment

U_w kV	No shield	Shield not bonded to equipotential bonding bar to which equipment is connected	Shield bonded to equipotential bonding bar and equipment connected to the same bonding bar		
			$5 < R_s \leq 20$ Ω/km	$1 < R_s \leq 5$ Ω/km	$R_s \leq 1$ Ω/km
1,5	1	0,5	0,15	0,04	0,02
2,5	0,4	0,2	0,06	0,02	0,008
4	0,2	0,1	0,03	0,008	0,004
6	0,1	0,05	0,02	0,004	0,002

R_s : resistance of the cable shield (Ω/km).

NOTE More precise evaluation of K_s for shielded and unshielded sections can be found in ITU Recommendation K.46.

A.6 Assessment of amount of loss L_x in a structure

A.6.1 Average relative amount of loss per year

The loss L_x refers to the mean relative amount of a particular type of damage which may be caused by a lightning flash, considering both its extent and effects.

Its value depends on:

- the number of persons and the time for which they remain in the hazardous place;
- the type and importance of the service provided to the public;
- the value of the goods affected by the damage.

The loss L_x varies with the type of loss (L1, L2, L3, L4) considered and, for each type of loss, with the type of damage (D1, D2 and D3) causing the loss. The following symbols are used:

- + L_t is the loss due to injury by touch and step voltages;
- + L_f is the loss due to physical damage;
- + L_o is the loss due to failure of internal systems.

A.6.2 Loss of human life

The value of L_t , L_f and L_o may be determined in terms of the relative number of victims from the following approximate relationship:

$$L_x = (n_p / n_t) \times (t_p / 8\,760) \quad (\text{A.28})$$

where

- n_p is the number of possible endangered persons (victims);
- n_t is the expected total number of persons (in the structure);
- t_p is the time in hours per year for which the persons are present in a dangerous place, outside of the structure (L_t only) or inside the structure (L_t , L_f and L_o).

Typical mean values of L_t , L_f and L_o , for use when the determination of n_p , n_t and t_p is uncertain or difficult, are given in Table A.16.

Table A.16 – Typical mean values of L_t , L_f and L_o

Type of structure	L_t
All types – (persons inside the building)	10^{-4}
All types – (persons outside the building)	10^{-2}

Type of structure	L_f
Hospitals, hotels, civil buildings	10^{-1}
Industrial, commercial, school	5×10^{-2}
Public entertainment, churches, museum	2×10^{-2}
Others	10^{-2}

Type of structure	L_o
Structure with risk of explosion	10^{-1}
Hospitals	10^{-3}

Loss of human life is affected by the characteristics of a structure. These are taken into account by increasing (h_z) and decreasing (r_f , r_p , r_a , r_u) factors as follows:

$$L_A = r_a \times L_t \quad (A.29)$$

$$L_U = r_u \times L_t \quad (A.30)$$

$$L_B = L_V = r_p \times h_z \times r_f \times L_f \quad (A.31)$$

$$L_C = L_M = L_W = L_Z = L_o \quad (A.32)$$

where

r_a is a factor reducing the loss of human life depending on the type of soil (see Table A.17);
 r_u is a factor reducing the loss of human life depending on the type of floor (see Table A.17);
 r_p is a factor reducing the loss due to physical damage depending on the provisions taken to reduce the consequences of fire (see Table A.18);
 r_f is a factor reducing the loss due to physical damage depending on the risk of fire of the structure (see Table A.19);
 h_z is a factor increasing the loss due to physical damage when a special hazard is present (see Table A.20).

Table A.17 – Values of reduction factors r_a and r_u as a function of the type of surface of soil or floor

Type of surface	Contact resistance $k\Omega^{1)}$	r_a and r_u
Agricultural, concrete	≤ 1	10^{-2}
Marble, ceramic	1 – 10	10^{-3}
Gravel, moquette, carpets	10 – 100	10^{-4}
Asphalt, linoleum, wood	≥ 100	10^{-5}

¹⁾ Values measured between a 400 cm^2 electrode compressed with force of 500 N at a point of infinity.

Table A.18 – Values of reduction factor r_p as a function of provisions taken to reduce the consequences of fire

Provisions	r_p
No provisions	1
One of the following provisions: extinguishers; fixed manually operated extinguishing installations; manual alarm installations; hydrants; fire proof compartments; protected escape routes	0,5
One of the following provisions: fixed automatically operated extinguishing installations; automatic alarm installations ¹⁾	0,2

¹⁾ Only if protected against overvoltages and other damages and if firemen can arrive in less than 10 min.

If more than one provision has been taken, the value of r_p shall be taken as the lowest of the relevant values.

In structures with risk of explosion, $r_p = 1$ for all cases.

Table A.19 – Values of reduction factor r_f as a function of risk of fire of structure

Risk of fire	r_f
Explosion	1
High	10^{-1}
Ordinary	10^{-2}
Low	10^{-3}
None	0

NOTE 1 In the cases of a structure with risk of explosion and a structure containing explosive mixtures a more detailed evaluation of r_f may be necessary.

NOTE 2 Structures with a high risk of fire may be assumed to be structures made of combustible materials, structures with roof made of combustible materials or structures with a specific fire load larger than 800 MJ/m².

NOTE 3 Structures with an ordinary risk of fire may be assumed to be structures with a specific fire load between 800 MJ/m² and 400 MJ/m².

NOTE 4 Structures with a low risk of fire may be assumed to be structures with a specific fire load less than 400 MJ/m², or structures containing combustible materials only occasionally.

NOTE 5 Specific fire load is the ratio of the energy of the total amount of the combustible material in a structure and the overall surface of the structure.

Table A.20 – Values of factor h_z increasing the relative amount of loss in presence of a special hazard

Kind of special hazard	h_z
No special hazard	1
Low level of panic (e.g. a structure limited to two floors and the number of persons not greater than 100)	2
Average level of panic (e.g. structures designed for cultural or sport events with a number of participants between 100 and 1 000 persons)	5
Difficulty of evacuation (e.g. structures with immobilized persons, hospitals)	5
High level of panic (e.g. structures designed for cultural or sport events with a number of participants greater than 1 000 persons)	10
Hazard for surroundings or environment	20
Contamination of surroundings or environment	50

A.6.3 Unacceptable loss of service to the public

The values of L_f and L_o can be determined in term of the relative amount of possible loss from the following approximate relationship:

$$L_x = n_p / n_t \times t / 8\ 760 \quad (\text{A.33})$$

where

n_p is the mean number of possible endangered persons (users not served);
 n_t is the total number of persons (users served);
 t is the annual period of loss of service (in hours).

Typical mean values of L_f and L_o , for use when the determination of n_p , n_t and t is uncertain or difficult, are given in Table 21.

Table A.21 – Typical mean values of L_f and L_o

Type of service	L_f	L_o
Gas, water	10^{-1}	10^{-2}
TV, TLC, power supply	10^{-2}	10^{-3}

Loss of service to the public is affected by structure characteristics and by a reduction factor (r_p) as follows:

$$L_B = L_V = r_p \times r_f \times L_f \quad (\text{A.34})$$

$$L_C = L_M = L_W = L_Z = L_o \quad (\text{A.35})$$

Values for factors r_p and r_f are given in Tables A.18 and A.19 respectively.

A.6.4 Loss of irreplaceable cultural heritage

The value of L_f can be determined in terms of the relative amount of possible loss from the following approximate relationship:

$$L_x = c / c_t \quad (\text{A.36})$$

where

c is the mean value of possible loss of the structure (i.e. the insurable value of possible loss of goods) in currency;
 c_t is the total value of the structure (i.e. the total insured value of all goods present in the structure) in currency.

A typical mean value of L_f , when the determination of c and c_t is uncertain or difficult, is:

$$L_f = 10^{-1} \quad (\text{A.37})$$

Loss of irreplaceable cultural heritage is affected by the characteristics of the structure by reduction factor r_p as follows:

$$L_B = L_V = r_p \times r_f \times L_f \quad (\text{A.38})$$

Values for factors r_p and r_f are given in Tables A.18 and A.19, respectively.

A.6.5 Economic loss

The value of L_t , L_f and L_o can be determined in terms of the relative amount of possible loss from the following approximate relationship:

$$L_x = c / c_t \quad (\text{A.39})$$

where

c is the mean value of possible loss of the structure (including its content and relevant activities and its consequences) in currency;
 c_t is the total value of the structure (including its content and relevant activities) in currency.

Typical mean values of L_t , L_f and L_o for all types of structures, for use when the determination of c and c_t is uncertain or difficult, are given in Table A.22.

Table A.22 – Typical mean values of L_t , L_f and L_o

Type of structure	L_t
All types – Inside buildings	10^{-4}
All types – Outside buildings	10^{-2}

Type of structure	L_f
Hospital, industrial, museum, agriculture	0,5
Hotel, school, office, church, public entertainment, economic building	0,2
Others	0,1

Type of structure	L_o
Risk of explosion	10^{-1}
Hospital, industrial, office, hotel, economic building	10^{-2}
Museum, agriculture, school, church, public entertainment	10^{-3}
Others	10^{-4}

Loss of economical value is affected by the characteristics of the structure. These are taken into account by increasing (h_z) and decreasing (r_p , r_a , r_f , r_u) factors as follows:

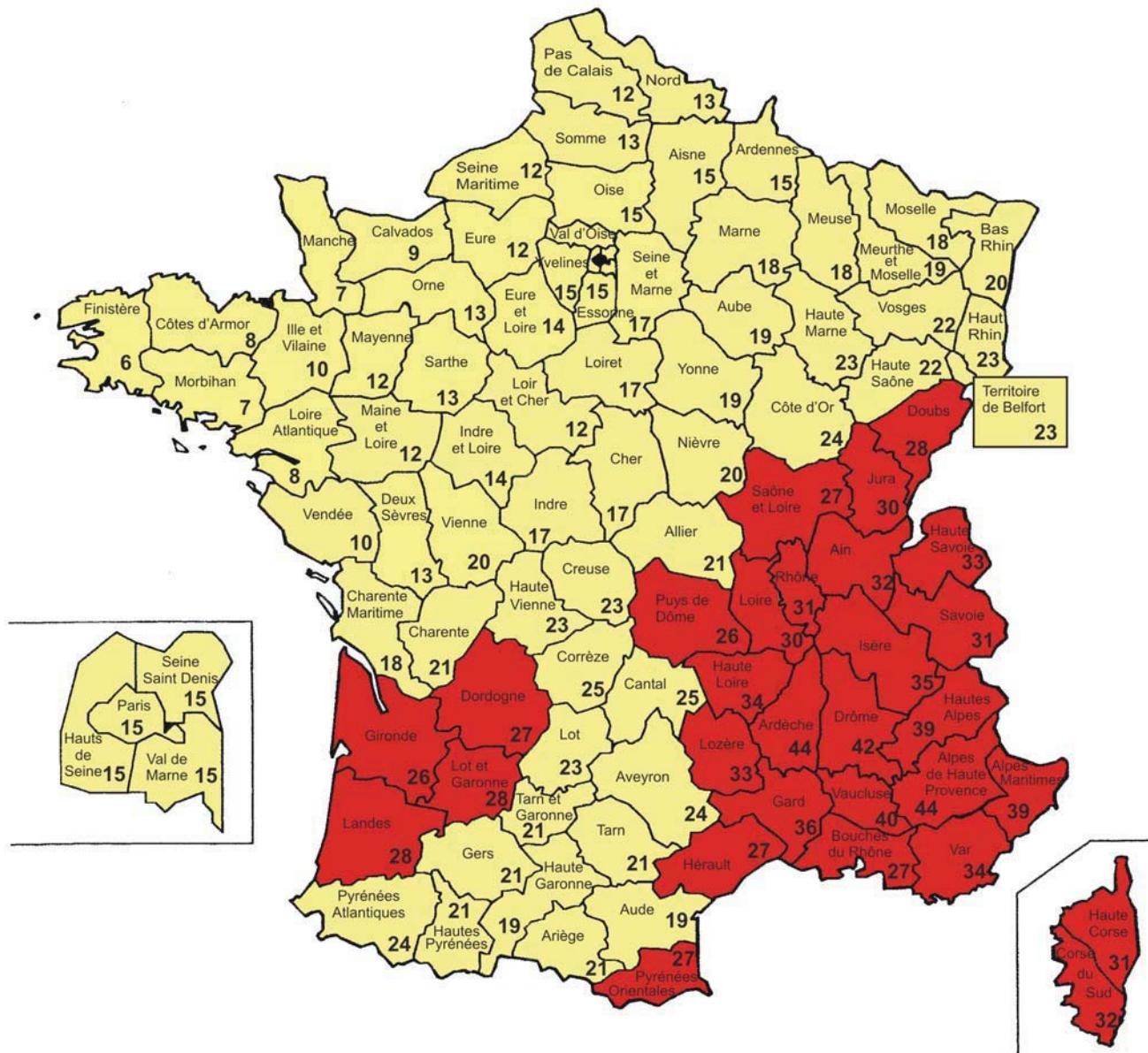
$$L_A = r_a \times L_t \quad (\text{A.40})$$

$$L_U = r_u \times L_t \quad (\text{A.41})$$

$$L_B = L_V = r_p \times r_f \times h_z \times L_f \quad (\text{A.42})$$

$$L_C = L_M = L_W = L_Z = L_o \quad (\text{A.43})$$

ANNEXE B (normative) N_g maps



Réunion : $N_k = 20$

Guyane/Martinique/Guadeloupe : $N_k = 40$

Saint-Pierre et Miquelon : $N_k = 1$

Figure B.1 – Map of N_k level, ($N_k=10 \times N_g$) for France

ANNEXE C(Normative)
ESEAT testing procedures and requirements

C.1	Operation conditions
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C.1.1 Normal conditions

The normal operating conditions are as follows:

- operating temperature -20°C to 60°C;
- wind speed lower than 122 km/h.

C.1.2 Abnormal conditions

The abnormal operation conditions are as follows:

- operating temperature lower than -20°C or higher than 60°C;
- wind speed higher than 122 km/h;
- snow and ice;
- site with highly polluted atmosphere.

C.2 Requirements

C.2.1 General requirements

C.2.1.1 Identification and documentation

The ESEAT is identified by the following information indicated on the product (marking):

- name, logo or trade mark of the manufacturer;
- product reference;
- early streamer emission efficiency : ΔT (in μ s);
- serial number.

C.2.1.2 Marking

The information shall be marked legibly and indelibly. It shall include at least the name, logo or trade mark of the manufacturer, the reference of the product and the serial number. Checked by the tests in § C.2.6.2.

C.2.2 Requirements for early streamer emission

The early streamer emission of the ESEAT (ΔT) shall be determined according to the procedures of clause C.3.5.

It shall range between 10 μ s and 60 μ s.

If the result of ΔT is lower than 10 μ s, then the air terminal will not be considered as an ESEAT.

If the result of ΔT is higher than 60 μ s, then all the calculations will be made considering $\Delta T = 60 \mu$ s.

C.2.3 Electrical requirements

The ESEAT shall be resistant to a lighting impulse of 100 kA (10/350 wave). This is verified by the tests defined in C.3.5.

C.2.4 Mechanical requirements

The parts of the ESEAT through which the lightning current transits shall have a section compliant NF EN 50164-2 (possible spark gaps used in the design of the ESEAT are tested during the current withstanding tests and do not require mechanical requirements).

The parts of the ESEAT that shall capture the lightning shall have dimensional characteristics compliant with the table below.

Table C.1 – Material, setup and minimum area of the striking point part's body

Material	Setup	Minimum area	Comments
Copper, Aluminium, Aluminium alloy, hot dip galvanised steel (note 1), stainless steel (note 2),	Full solid	200 mm ²	16 mm diameter

NOTE 1: coating shall be smooth and continuous and shall not have any flux tarnishing. Minimum thickness shall be 50 µm.

NOTE 2: Chromium 16 %, nickel 8 %, carbon 0.07 %.

C.2.5 Environmental requirements

C.2.5.1 Climate conditions

The ESEAT shall resist environmental constraints such as salt spray and sulphide atmospheres characteristic of seaside pollution and industrial pollution. This is checked by carrying out tests described in C.3.

C.2.6 Electromagnetic compatibility

C.2.6.1 Electromagnetic immunity

The ESEATs without an electronic system or for which all components are passive (e.g. diodes, resistors, capacitors, inductances, varistors and other protective components) are not sensitive to the electromagnetic waves of industrial environments. Thus, no immunity tests are required.

The other ESEATs shall be subjected to testing. These ESEATs shall be compliant with the NF EN 61000-6-2 immunity for industrial environments standard for applicable tests. The operation of the early streamer emission device and of the testing device possibly integrated into the ESEAT shall not be disturbed during the test. This is verified by the absence of sparks detected visually.

C.2.6.2 Electromagnetic emission

The ESEATs without an electronic system or for which all components are passive (e.g. diodes, resistors, capacitors, inductances, varistors and other protective components) do not generate any signals outside of stormy conditions. Thus, no emission tests are required.

ESEATs with electronic circuits shall be compliant with the NF EN 61000-6-3 emission standard for residential environments.

For ESEATs that meet these conditions but include radio modules, all requirements described in the RTTE 1999/5/CE directive shall be met.

C.3 Type test

The tests shall be carried out on a sample according to the flowchart in figure C.1.

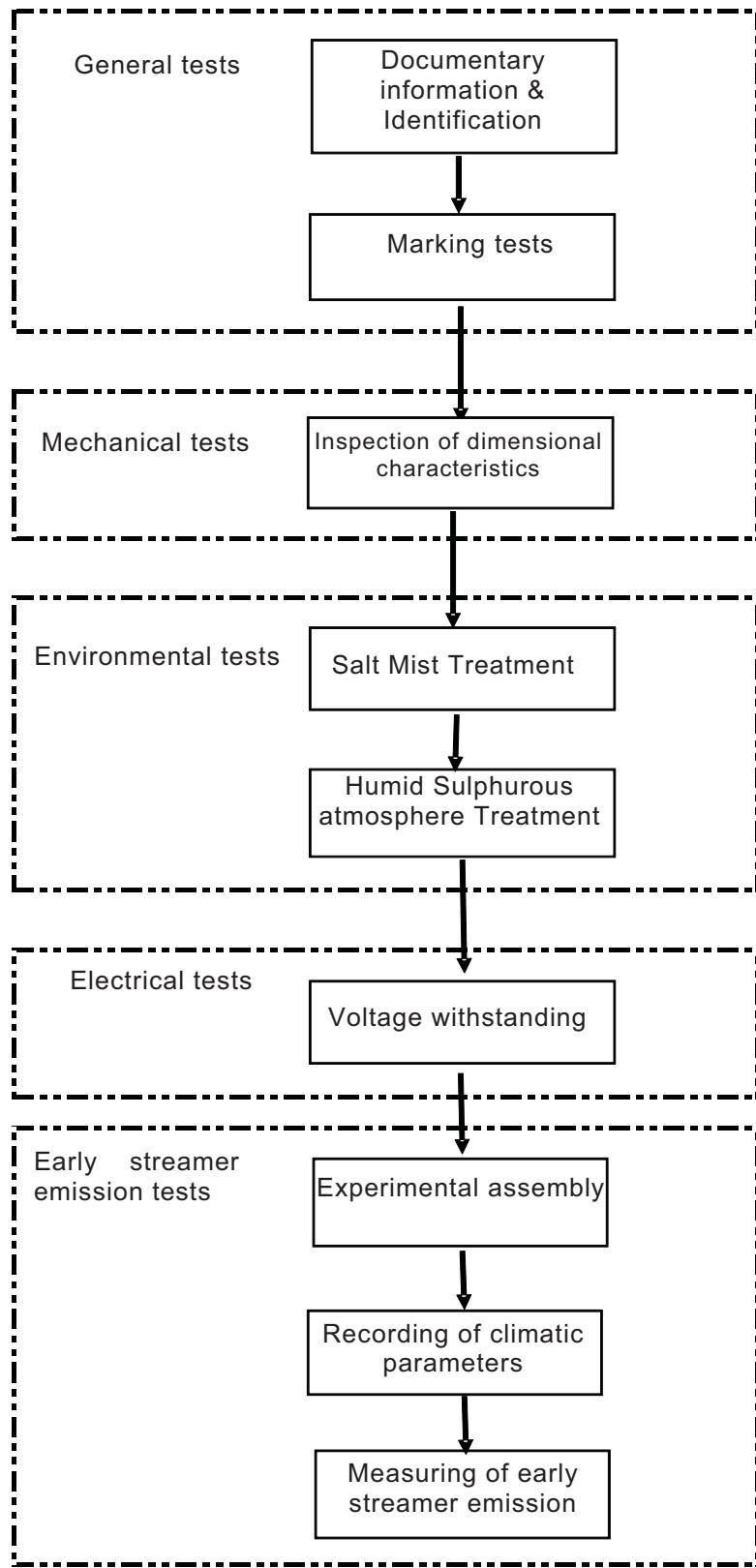


Figure C.1: Sequence of testing

C.3.1 General tests

C.3.1.1 Documentary information and identification

The checking via examination of the identification of markings shall be carried out according to the requirements of C.2.1.2 Compliance is checked by visual inspection.

C.3.1.2 Marking

A test shall be carried out on all types of markings except those carried out via pressure casting or engraving.

The test is carried out by rubbing the marking by hand for 15 s with a cotton rag dipped in water and for 15 s more with a cotton rag dipped in hexane aliphatic.

NOTE Hexane aliphatic is defined by a 0.1 % maximum content of aromatic carbide in volume, a kauributanol index of 29, an initial boiling temperature of approx. 65°C, a final boiling temperature of approx. 69°C and a specific mass of 0.68 g/cm³

After this test, the marking shall be legible.

C.3.2 Mechanical tests

The checking of the dimensional characteristics with their tolerances is carried out according to manufacturer drawings and data:

- determination of the sensor part,
- Calculation of the bore of the sensor part's body,
- Calculation of the bore of the parts through which the current shall transit.

C.3.3 Environmental conditioning

C.3.3.1 Salt mist treatment

Salt spray test according to the NF EN 60068-2-52 standard, except articles 7, 10 and 11 that are not applicable.

The test is carried out with level 2 severity.

C.3.3.2 Humid Sulphurous atmosphere Treatment

Test in a humid sulphurous atmosphere according to the NF EN ISO 6988 standard with seven cycles and a sulphur dioxide concentration of 667 ppm (in volume).

Each cycle lasts 24 hours and includes an 8-hour heating period at a temperature of 40°C ± 3 °C in a saturated humid environment followed by a 16-hour standing period. After this standing period, the humid sulphide atmosphere is restored.

C.3.4 Current withstand tests

After environmental pre-conditioning and without the sample being cleaned, the ESEAT is subjected to the following tests.

I_{imp} Impulse current test

The I_{imp} test impulse is defined by I_{peak} , Q and W/R . A unipolar current impulse shall reach these parameters within 10 ms.

A typical wave shape able to achieve these parameters is the 10/350 wave. The relationship between I_{peak} , Q and W/R is given in the following formulas:

$$Q (\text{As}) = 0.5 I_{peak} (\text{kA}) \quad (\text{C.1})$$

$$W/R (\text{kJ}/\Omega^\circ) = Q^2 (\text{As}) \quad (\text{C.2})$$

The tolerances on the peak value of the I_{peak} current, I_{oad} Q and specific energy W/R are:

- I_{peak} $\pm 10\%$
- Q $\pm 20\%$
- W/R $\pm 35\%$

The sample shall be subjected three times to a test current given in table C.2. The time-slot between each test shall enable the sample to cool down at room-temperature.

Table C.2 – Value of current I_{imp}

I_{peak} (kA)	Q (A.s)	W/R (kJ/Ω)
100	50	2 500

Test endorsement

The sample passes the test if the voltage/current recordings and the visual inspection do not reveal any indications of deterioration or perforation of the sample, except the parts that drain off the lighting current where traces of emission and superficial fusion can appear.

C.3.5 Early streamer emission tests

The reference standard for testing procedures is NF EN 61180-1. The ESEAT shall be installed and connected electrically according to manufacturer instructions.

During the tests, no maintenance or disassembly of the ESEAT is authorised.

It shall be seen that appropriate testing techniques are necessary for crash tests and measurements, in order to ensure that the correct test values are recorded. Experimental set-up.

C.3.5.1.1 Characterisation of the reference single rod air terminal

The reference single rod air terminal (SRAT) shall respect the dimensions indicated in the drawing below.

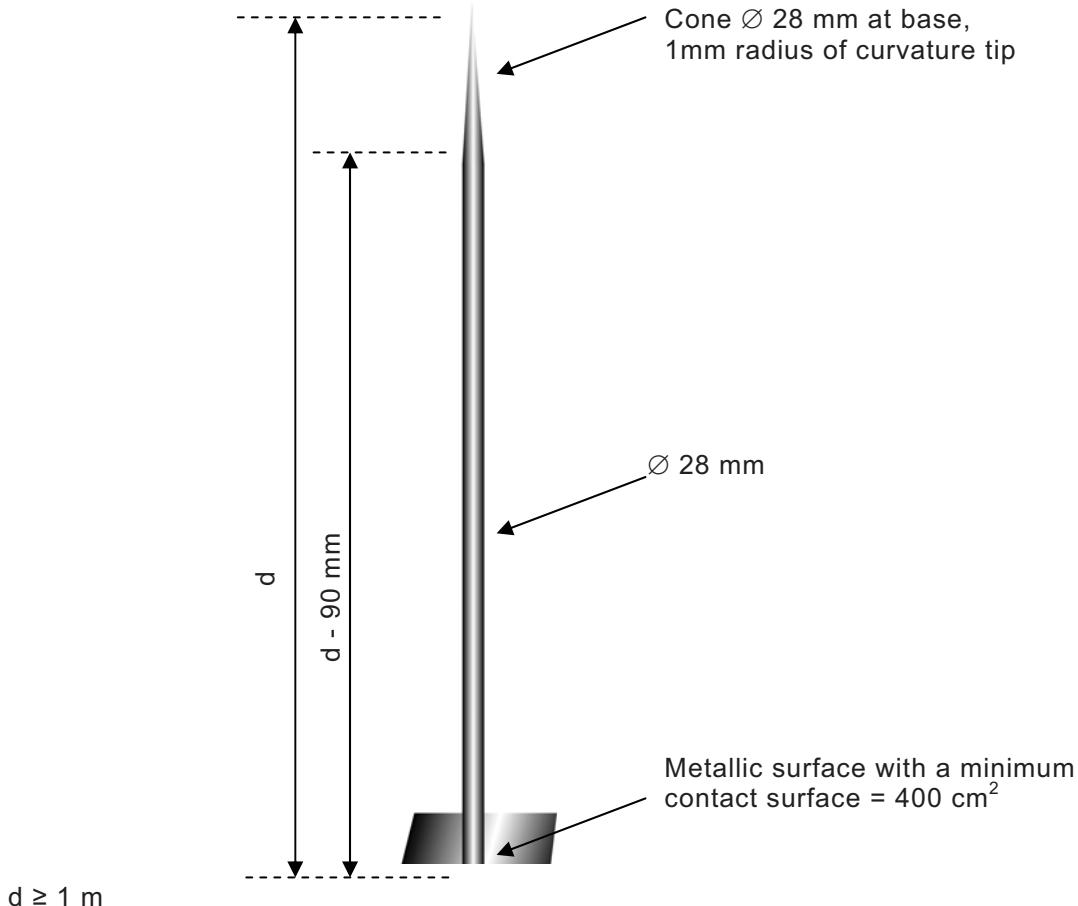


Figure C.2 - Reference single rod air terminal (SRAT)

C.3.5.1.2 Dimensions of the test assembly

The dimensions of the test assembly are as follows:

- the height of the air terminals (h) exceeds or equals 1 m. The difference of height between the two terminals shall be less than 1%;
- the distance between the upper plate and the ground (H) shall exceed 2 m. The h/H ratio shall range between 0.25 and 0.5;
- the smallest horizontal dimension of the upper plate is the distance between platen and ground (H);
- the 28 mm diameter rod, the air terminal support, rests on a square support with a 0.2 m side.

The following figures represent the two test configurations that correspond respectively with the testing of the reference SRAT (defined in Figure C.2) and the testing of the ESEAT.

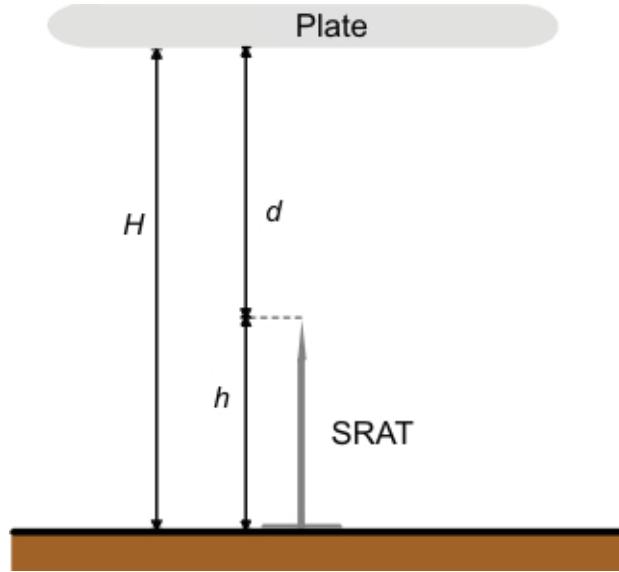


Figure C.3 – Experimental set-up of the SRAT

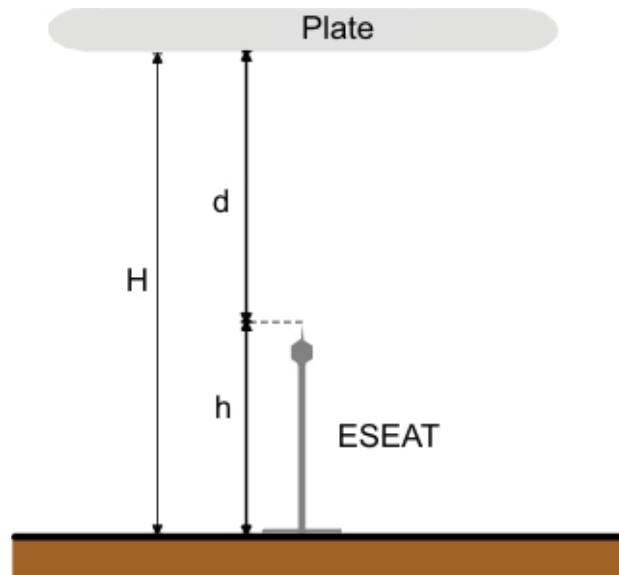


Figure C.4 – Experimental set-up of the ESEAT

C.3.5.2 Experiment conditions

The effectiveness of the ESEAT is assessed by comparing, in a high voltage laboratory, the emission time of the ascending tracer which it emits with the one an SRAT emits.

To achieve this, the SRAT and the ESEAT are assessed one after the other under the same electrical and geometrical conditions during laboratory tests that simulate natural discharge capturing start-up conditions (ascending positive tracer).

C.3.5.2.1 Wave simulation

The natural wave that exists before a lightning strike has consequences on the forming conditions of the corona and the pre-existing space-charge. It is therefore necessary to simulate it by applying a direct current that creates an electric fields between the plate and the ground ranging between -20 kV/m and -25 kV/m.

C.3.5.2.2 Impulse field simulation

The impulse field may be simulated by a switching impulse which rise time ranging between 100 μ s to 1000 μ s. The waveform slope when the upward initiates should be between 2·108 and 2·109 V/m/s. A typical waveshape is 250/2500 as per NF EN 60060-1 (only the tolerance on the front is important).

C.3.5.2.3 Quantities to be inspected – Measurement to be carried out

C.3.5.2.3.1 Electrical parameters

The electrical parameters to be inspected and recorded are the shape and the magnitude of the voltages applied (calibration of the ambient field, impulse voltage wave, associated current) for the SRAT and the ESEAT.

To achieve this, the following shall be adjusted:

- the continuous polarizing voltage;
- the impulse wave that triggers the emission on the single rod air terminal: the voltage to be applied is determined using a simplified “up and down” procedure so as to obtain the value U100 with a final precision of 1%.

C.3.5.2.3.2 Geometrical conditions

Distance d shall be strictly the same (+/- 1 mm) for each test configuration; it is inspected before each configuration (see figure C.3).

C.3.5.2.3.3 Climatic parameters

The climatic conditions (pressure, temperature, relative humidity) shall be recorded at the beginning and the middle of the tests of each series and at the end of the tests for the test configuration.

In order for the test configurations of the SRAT and the ESEAT to be considered identical (same U100 voltage), the variations of the climatic parameters shall comply with the values defined in the table below. Otherwise, it is necessary to re-measure the U100 voltage before the next configuration.

Table C.3 – Variation of the climatic parameters during the tests

Parameter	Variation for both test configurations
Pressure	+/- 2%
Temperature	+/- 10°C
Relative humidity	+/- 20%

The values are recorded in the test report but do not lead to corrections.

C.3.5.2.3.4 Number of impacts per configuration

For each configuration, the first 50 usable impacts will be recorded. (Example of a non-useful impact: pre-starting of the generator). The standing time between two impacts shall equal 2 minutes. This value should be maintained throughout the tests.

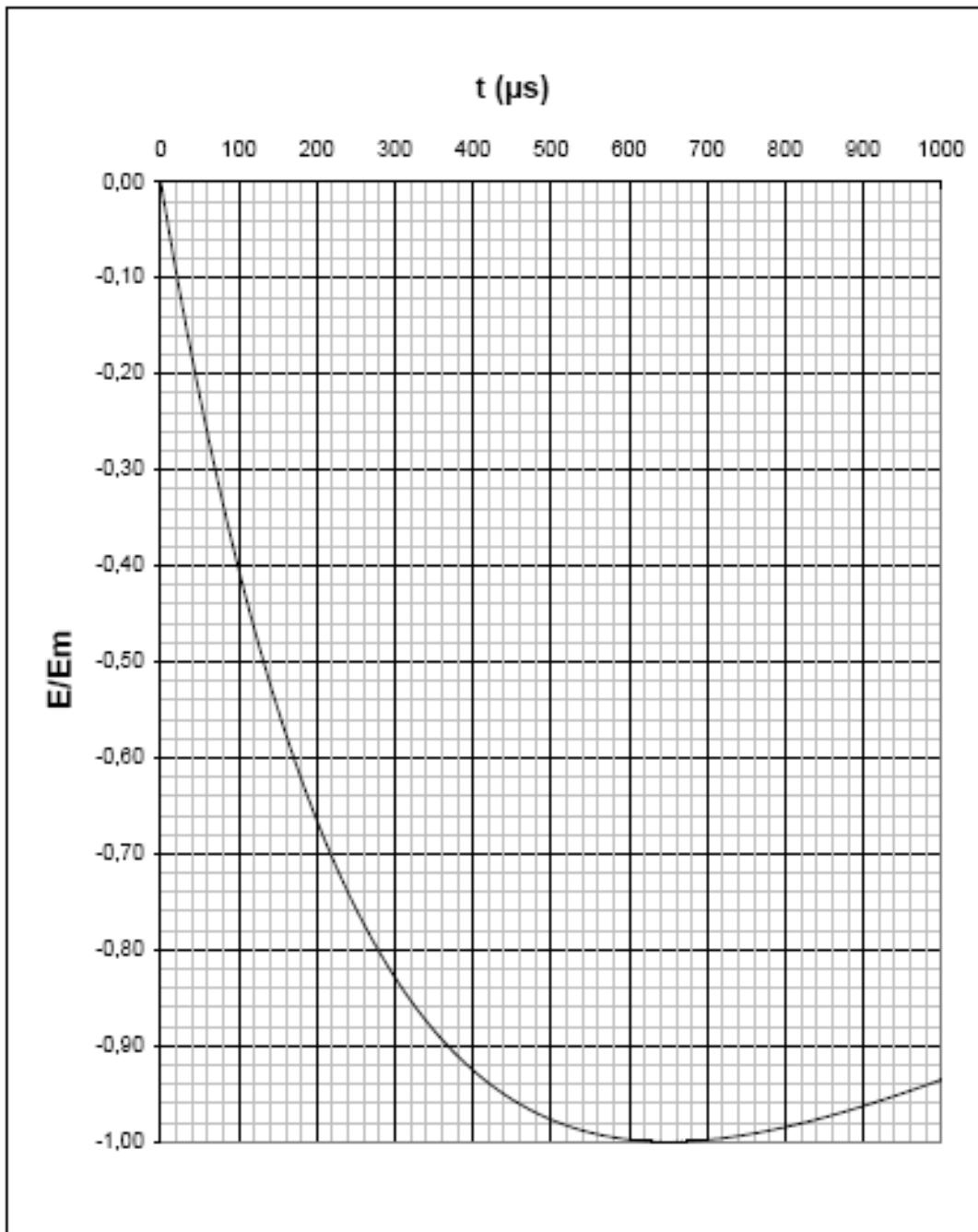
C.3.5.2.3.5 Measuring the early streamer emission of the ESEAT

The chosen criterion for assessing the effectiveness of an ESEAT is its ability to repeatedly emit an ascending tracer before an SRAT placed in the same conditions. For each usable impact on the SRAT and on the ESEAT, we measure the value T of the emission time of the ascending tracer. Time T is measured between the point of intersection of the time axis with the impulse voltage curve and the time corresponding to the sudden change of the impulse voltage slope corresponding to an emission.

Based on the measurements of the ascending tracer's emission times taken from an SRAT and an ESEAT, the average emission times $T_{\text{moy,SRAT}}$ and $T_{\text{moy,ESEAT}}$ are calculated based on the usable impacts, while respecting the parameters). The standard deviation of the two distributions are also calculated (σ_{SRAT} et σ_{ESEAT}).

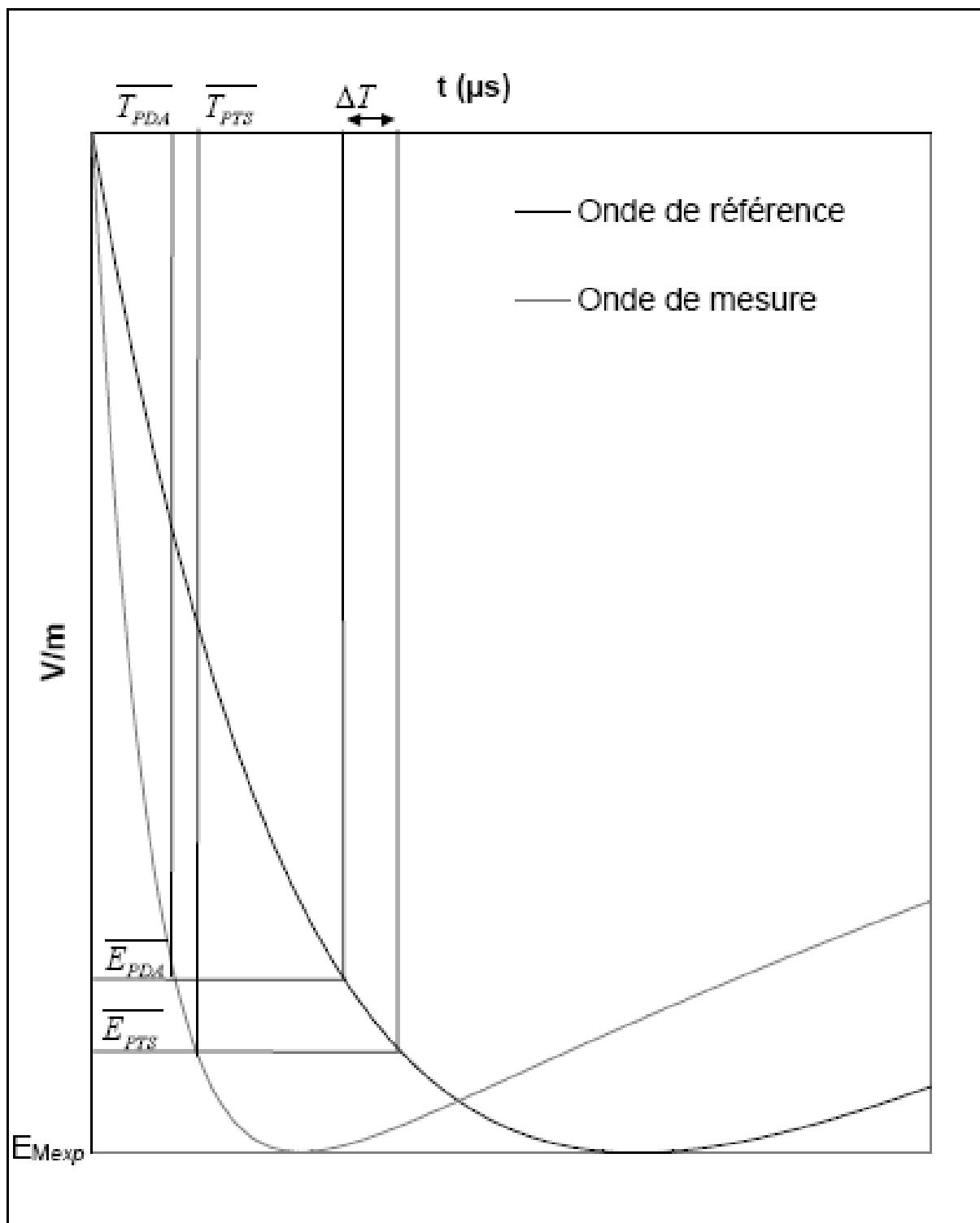
C.3.5.2.4 Determination of the early streamer emission of the ESEAT

The early streamer emission is determined in relation to a reference wave defined by a build up time $T_m = 650\mu\text{s}$ and the shape defined by Figure C.5.

**Figure C.5 – Reference wave**

On top of the reference wave shape, for which the value of the field E_m is set to the maximum experimental field value E_{Mexp} the experimental curve is juxtaposed.

$T_{\text{moy ESEAT}}$ and $T_{\text{moy SRAT}}$ are related to E fields by way of the experimental curve. From these E fields, using the reference wave shape, we deduce the emission times related to the reference curve T_{SRAT} and T_{ESEAT} used for calculating the early streamer emission $\Delta T(\mu\text{s}) = T_{\text{SRAT}} - T_{\text{ESEAT}}$.

**Figure C.6 - Graphic correction principle**

Onde de référence	Reference wave
Onde de mesure	Measuring wave

C.3.5.2.5 Validation of the ESEAT effect

Average values T_{ESEAT} and T_{SRAT} and standard deviations σ_{ESEAT} and σ_{SRAT} are calculated.

The tested lighting conductor is an ESEAT if both the following conditions are met:

- $T_{ESEAT} < T_{SRAT}$
- $\Sigma_{ESEAT} < 0,8 \sigma_{SRAT}$
- $T_{PTS} - T_{PDA} > 10 \mu\text{s}$

C.4 Structure and content of the test report

The purpose of this instruction is to provide general requirements for laboratory test reports. This document is intended to promote clear, complete reporting procedures for laboratories submitting test reports.

The results of each test carried out by the laboratory shall be reported accurately, clearly, unambiguously and objectively, in accordance with any instructions in the test methods. The results shall be reported in a test report and shall include all the information necessary for the interpretation of the test results and all information required by the method used.

Particular care and attention shall be paid to the arrangement of the report, especially with regard to presentation of the test data and ease of assimilation by the reader. The format shall be carefully and specifically designed for each type of test carried out, but the headings shall be standardized as indicated herein.

The structure of each report shall include at least the following:

- Report Identification;
- A title or subject of the report;
- Name, address and telephone number of the test laboratory;
- Name, address and telephone number of the sub test laboratory where the test was carried out if different from company which has been assigned to perform the test;
- Unique identification number (or serial number) of the test report;
- Name and address of the vendor/manufacturer;
- Report shall be paginated and the total number of pages indicated;
- Date of issue of report;
- Date(s) of performance of test(s);
- Signature and title, or an equivalent identification of the person(s) authorized to sign for the testing laboratory for the content of the report;
- Signature and title of person(s) conducting the test;
- Specimen description;
- Sample Description;
- Detailed description and unambiguous identification of the test sample and/or test assembly;
- Characterization and condition of the test sample and/or test assembly;
- Photographs, drawings or any other visual documentation, if available;
- Standards and References;
- Identification of the test standard used and the date of issue of the standard;
- Other relevant documentation with the documentation date;
- Test Procedure;
- Description of the test procedure;
- Justification for any deviations from, additions to or exclusions from the referenced standard;
- Any other information relevant to a specific test such as environmental conditions;
- Configuration of testing assembly;
- Location of the arrangement in the testing area and measuring techniques;
- Testing Equipment, description;
- Description of equipment used for every test conducted i.e. generator etc.;
- Measuring Instruments description;

- Characteristics and calibration date of all instruments used for measuring the values specified in the standard;
- Results and parameters recorded;
- The measured, observed or derived results shall be clearly identified;
- The above shall be presented by tables, graphs, drawings, photographs or other documentation of visual observations as appropriate;
- A statement of pass/fail identifying the part of the test for which the specimen has failed and also a description of the failure. This shall be illustrated by drawings, photographs or other documentation of visual observations as appropriate.

C.5 Care and maintenance of the ESEATs

In order to ensure the ESEATs are working correctly, the manufacturer shall describe, in an inspection and maintenance note, the measures to be taken in order ensure the upkeep and maintenance of its product.

This note shall contain at least the following information:

- The operation(s) to be carried out during the visual inspection of the lightning protection system;
- The operation(s) to be carried out during the full inspection of the lightning protection system;
- The testing equipment which may be necessary for carrying out product inspection;
- Correct operating criteria for the product;
- The approach in case of product malfunction.

When the ESEAT requires specific periodic maintenance (for example the replacing of a battery), this shall be specified in the note provided with the product.

Annexe D
(Normative)**Protection of people against electrical shocks caused by lightning****D.1 Protection measures against injury to living beings due to touch and step voltages****D.1.1 Protection measures against touch voltages**

In certain conditions, the vicinity of the down-conductors of an ESESystem, outside the structure, may be hazardous to life even if the ESESystem has been designed and constructed according to the above-mentioned requirements.

The hazard is reduced to a tolerable level if one of the following conditions is fulfilled:

- a) the probability of persons approaching, or the duration of their presence outside the structure and close to the down-conductors, is very low;
- b) the natural down-conductor system consists of typically more than ten columns of the extensive metal framework of the structure or of several pillars of interconnected steel of the structure, with the electrical continuity assured;
- c) the contact resistance of the surface layer of the soil, within 3 m of the down-conductor, is not less than 100 kΩ.

NOTE A layer of insulating material, e.g. asphalt, of 5 cm thickness (or a layer of gravel 15 cm thick) generally reduces the hazard to a tolerable level.

If none of these conditions is fulfilled, protection measures shall be adopted against injury to living beings due to touch voltages as follows:

- insulation of the exposed down-conductor is provided giving a 100 kV, 1,2/50 µs impulse withstand voltage, e.g. at least 3 mm cross-linked polyethylene;
- physical restrictions and/or warning notices to minimize the probability of down-conductors being touched.

D.1.2 Protection measures against step voltages

In certain conditions, the vicinity of the down-conductors outside the structure may be hazardous to life even if the ESESystem has been designed and constructed according to the above-mentioned rules.

The hazard is reduced to a tolerable level if one of the following conditions is fulfilled:

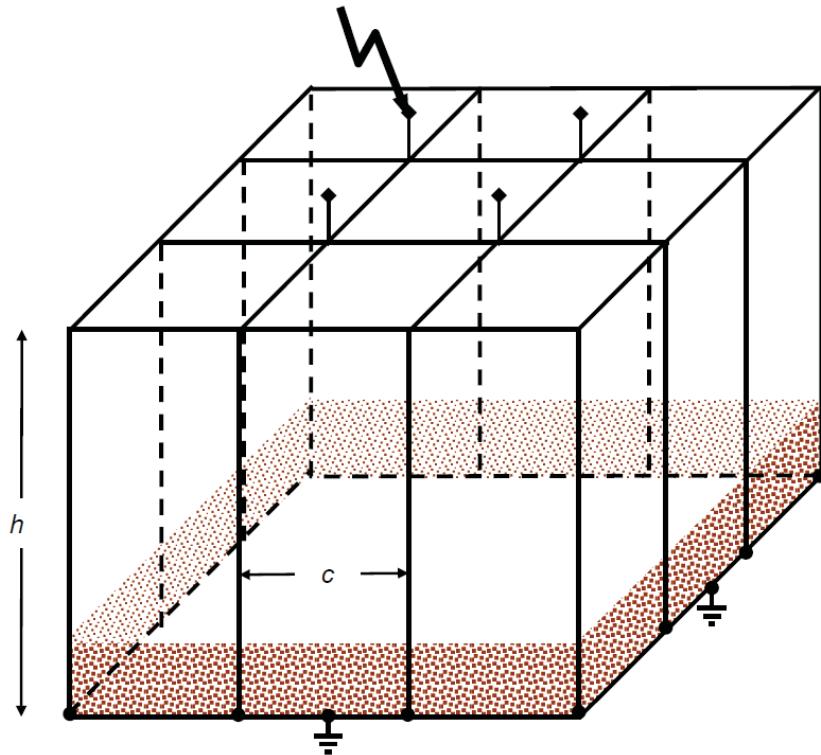
- a) the probability of persons approaching, or the duration of their presence in the dangerous area within 3 m from the down-conductors, is very low;
- b) the natural down-conductor system consists of typically more than ten columns of the extensive metal framework of the structure or of several pillars of interconnected steel of the structure, with the electrical continuity assured;
- c) the contact resistance of the surface layer of the soil, within 3 m of the down-conductor, is not less than 100 kΩ.

NOTE A layer of insulating material, e.g. asphalt, of 5 cm thickness (or a layer of gravel 15 cm thick) generally reduces the hazard to a tolerable level.

If none of these conditions is fulfilled, protection measures shall be adopted against injury to living beings due to step voltages as follows:

- equipotentialization by means of a meshed earth termination system;
- physical restrictions and/or warning notices to minimize the probability of access to the dangerous area, within 3 m of the down-conductor.

Annexe E
(Informative)
Example of values of coefficient k_c



$$k_c = \frac{1}{2n} \quad 0,1 \quad 0,2 \times \sqrt{3} \frac{c}{h}$$

Key

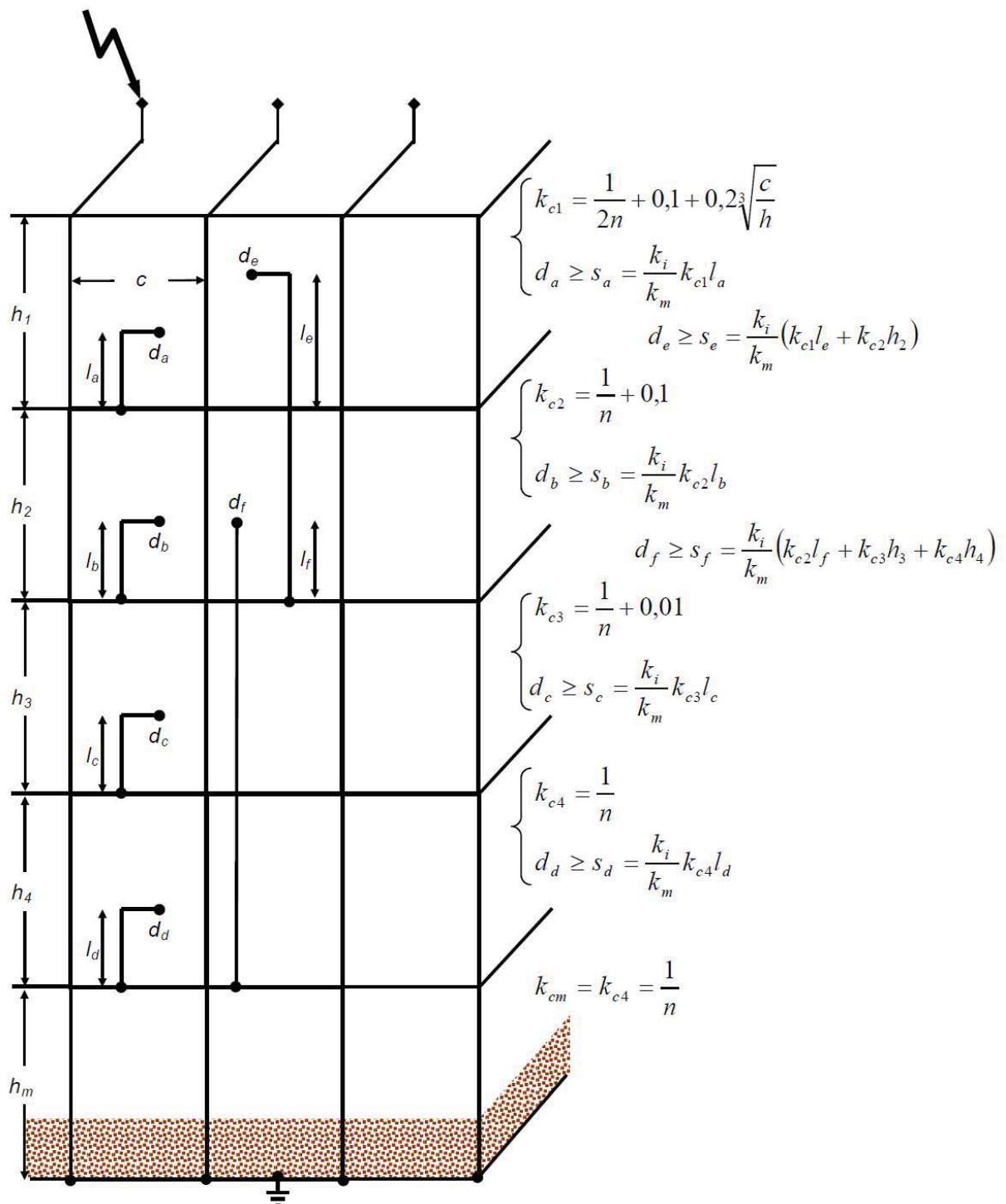
n total number of down-conductors
 c distance of a down-conductor to the next down-conductor
 h spacing (or height) between ring conductors

Figure E.1 – In the case of numerous ESE interconnected at roof level and type B earth-termination system

When intermediate additional rings are used to better balance the lightning current or as additional striking elements, the separation distance is improved (lowered, see Figure E.3). However, for very tall structures, to maintain the separation distance in a realistic is not really possible.

NOTE In that later case, it is then needed to interconnect at roof level the LPS to the metallic structure of the building.

It is possible to calculate the current distribution at each level from 1 to m beginning by the roof, from k_{c1} to k_{cm} . From this value of current distribution, we can determine the separation distance at each level, from s_a to s_f at the illustrated example of the Figure E.2.



Key

<i>n</i>	total number of down-conductors
<i>c</i>	distance of a down-conductor to the next down-conductor
<i>h</i>	spacing (or height) between ring conductors
<i>m</i>	total number of level
<i>d</i>	distance to the nearest down-conductor
<i>l</i>	height above the equipotential point

Figure E.2 – Examples of calculation of the separation distance in the case of downconductors an interconnected by rings.

Bibliographie

- [1] NF EN 61643-21, Low voltage surge protective devices - Part 21: Surge protective devices connected to telecommunications and signalling networks - Performance requirements and testing methods
- [2] IEC 61643-22, Low-voltage surge protective devices - Part 22: Surge protective devices connected to telecommunications and signalling networks - Selection and application principles
- [3] UTE C 17-108, *Analyse simplifiée du risque foudre*
- [4] Arrêté du 31 décembre 1999, *fixant la réglementation technique générale destinée à prévenir et limiter les nuisances et les risques externes résultant de l'exploitation des installations nucléaires de base (version consolidée au 25 mars 2011).*
- [5] *Arrêté du 19 novembre 2001, portant approbation de dispositions complétant et modifiant le règlement de sécurité contre les risques d'incendie et de panique dans les établissements recevant du public.*
- [6] Arrêté du 5 août 2002, *relatif à la prévention des sinistres dans les entrepôts couverts soumis à autorisation sous la rubrique 1510.*
- [7] Circulaire du 24 avril 2008, *relative à l'arrêté du 15 janvier 2008 relatif à la protection contre la foudre de certaines installations classées.*
- [8] ITU K.46, Protection of telecommunication lines using metallic symmetric conductors against Recommendations lightning-induced surges
- [9] ITU K.47, Protection of telecommunication lines using metallic conductors against direct lightning Recommendations discharges
- [10] Directive RTTE 1999/5/CE, concernant les équipements hertziens et les équipements terminaux de télécommunications et la reconnaissance mutuelle de leur conformité.

List of organizations participating in the standardization committee

Secretariat : UTE

ADEME (AGENCE DE L'ENVIRONNEMENT & DE LA MAITRISE DE L'ENERGIE)

COPREC

EDF (ELECTRICITE DE FRANCE)

FFIE (FEDERATION FRANCAISE DES ENTREPRISES DE GENIE ELECTRIQUE ET ENERGETIQUE)

FRANCE TELECOM

GIMELEC (GROUPEMENT DES INDUSTRIES DE L'EQUIPEMENT ELECTRIQUE, DU CONTRÔLE-COMMANDE ET DES SERVICES ASSOCIES)

IGNES (Groupement des Industries du Génie Numérique Energétique et Sécuritaire)

INERIS (INSTITUT NATIONAL DE L'ENVIRONNEMENT INDUSTRIEL ET DES RISQUES)

LCPP (LABORATOIRE CENTRAL DE LA PREFECTURE DE POLICE)

MINISTÈRE DU TRAVAIL, DES RELATIONS SOCIALES, DE LA FAMILLE, DE LA SOLIDARITÉ ET DE LA VILLE

SUPELEC (ECOLE SUPERIEURE D'ELECTRICITE)

SYCABEL (SYNDICAT PROFESSIONNEL DES FABRICANTS DE FILS ET CABLES ELECTRIQUES ET DE COMMUNICATION)

TOTAL