

AS 1768:2021



Lightning protection



AS 1768:2021

This Australian Standard® was prepared by EL-024, Protection Against Lightning. It was approved on behalf of the Council of Standards Australia on 23 November 2021.

This Standard was published on 3 December 2021.

The following are represented on Committee EL-024:

- Australian Chamber of Commerce and Industry
- Australian Industry Group
- Clean Energy Council
- Communications, Electrical and Plumbing Union — Electrical Division
- Consult Australia
- Department of Regional NSW
- Electric Energy Society of Australia
- Energy Networks Australia
- Engineers Australia
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This Standard was issued in draft form for comment as DR AS 1768:2021.

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ISBN 978 1 76113 625 2

Lightning protection

Originated in Australia as AS MC1—1969.
Revised and redesignated as AS 1768—1975.
Third edition 1991.
Jointly revised and redesignated as AS/NZS 1768(Int):2003.
Jointly revised and redesignated as AS/NZS 1768:2007.
Revised and redesignated as AS 1768:2021.

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Preface

This Standard was prepared by the Australian members of the Joint Standards Australia/Standards New Zealand Committee EL-024, Protection Against Lightning, to supersede AS/NZS 1768:2007.

After consultation with stakeholders in both countries, Standards Australia and Standards New Zealand decided to develop this document as an Australian Standard rather than an Australian/New Zealand Standard.

The objective of this document is to provide requirements for and guidance on lightning protection for a wide range of structures and systems.

This document is a major revision of previous versions, which seeks to align with IEC standards. The major change is to recognize modern building practices and acknowledge that many modern buildings are inherently self-protecting.

This document is accompanied by a spreadsheet to be used to calculate the risk index for lightning protection.

The spreadsheet can be obtained on purchase of the document as a zip file for PDF purchasers, to be downloaded from the website of purchase. Delivery methods for any additional files may change over time.

The spreadsheet can only be used or reproduced by an authorized user in a way that meets the requirements of this document. It cannot be used for any other purpose.

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The terms “normative” and “informative” are used in Standards to define the application of the appendix to which they apply. A “normative” appendix is an integral part of a Standard, whereas an “informative” appendix is for information and guidance only.

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Introduction

Thunderstorms and lightning are natural phenomena and are largely unpredictable. As such, there are no proven devices or methods capable of preventing, deflecting or attracting lightning flashes. Direct and nearby cloud-to-ground lightning discharges can be hazardous to people, structures and installations. Conformance with this document will not necessarily prevent damage to assets or personal injury but will reduce the probability of damage and injuries.

A lightning protection system is designed to intercept a lightning strike, by placing air terminals at the points on a structure most likely to be struck, conduct the energy safely to earth and dissipate the energy into the ground. Additional measures aim to safely dissipate any energy impressed onto power or data lines, which would otherwise damage equipment within a structure.

NOTES

Australian Standard®

Lightning protection

Section 1 Scope and general

1.1 Scope and application

1.1.1 Scope

This document specifies requirements for the design, installation, maintenance and testing of lightning protection on common structures, and for electrical and electronic systems within those structures.

These requirements cover the following:

- (a) Assessment of risk.
- (b) Protection of structures.
- (c) Protection of electrical and electronic equipment.
- (d) Testing and maintenance.
- (e) Personal safety.

1.1.2 Application

This document applies to conventional lightning protection systems (LPSs) that comprise air terminals, downconductors, earth termination networks and surge protective devices (SPDs).

This document does not endorse nor imply the endorsement of non-conventional LPSs that comprise air terminals which claim enhanced performance, or downconductors which claim enhanced magnetic screening over conventional systems. The performance of such systems is outside the scope of this document.

For conformance to this document, air terminals shall be placed in accordance with [Section 3](#).

The protection of specific occupancies is provided for in the following appendices:

- (a) [Appendix I](#) for specific structures.
- (b) [Appendix J](#) for structures with explosive or flammable contents.
- (c) [Appendix K](#) for wind turbines.
- (d) [Appendix L](#) for high voltage power systems.
- (e) [Appendix M](#) for lightning risk in mines.
- (f) [Appendix N](#) for solar photovoltaic installations.

1.2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document.

NOTE Documents referenced for informative purposes are listed in the Bibliography.

AS/NZS 3000, *Electrical installations (known as the Australian/New Zealand Wiring Rules)*

AS/NZS 3008.1.1, *Electrical installations — Selection of cables, Part 1.1: Cables for alternating voltages up to and including 0.6/1 kV — Typical Australian installation conditions*

AS/NZS 4065, *Concrete utility services poles*

1.3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

1.3.1

air terminal

conductor or natural element positioned to intercept a lightning discharge which establishes a zone of protection

1.3.2

air terminal network

network of air terminals and interconnecting conductors, either specifically installed or natural elements, which form the part of an LPS that is intended to intercept lightning discharges

1.3.3

arc distance

air clearance path

straight-line distance from metal to metal across the insulator

1.3.4

basic impulse level

BIL

standard lightning impulse test value for substation primary plant which has a 10 % probability of insulation damage for a lightning impulse wave shape of 1.2/50 μ s

Note 1 to entry: Also known as “lightning impulse withstand voltage” in other standards.

1.3.5

bond

bonding conductor

conductor providing electrical connection between the LPS and other metalwork or between earthing systems, not intended to carry the full discharge current

1.3.6

compact earth termination network

special earthing design for lightning transients that takes into account the critical length, ensuring the value of impedance does not exceed the low-frequency resistance value

1.3.7

covered conductor thick

CCT

unscreened conductor around which a specified thickness of insulating material for the nominal working voltage is applied

1.3.8**critical flashover voltage****CFO**

50 % probability flashover voltage for lightning impulse wave shape of 1.2/50 μ s

1.3.9**currents and voltages****1.3.9.1****impulse discharge current** **I_{imp}**

peak value of a 10/350 μ s current waveform that any one branch of an SPD can withstand after a graduated test sequence

1.3.9.2**maximum continuous operating voltage** **U_c**

maximum r.m.s. or d.c. voltage that can be continuously applied to the SPD's mode of protection

1.3.9.3**maximum discharge current** **I_{max}**

peak value of an 8/20 μ s current waveform that any one branch of an SPD can withstand at least once

1.3.9.4**nominal surge current** **I_n**

peak value of an 8/20 μ s current waveform that any one branch of an SPD can withstand at least 15 times

1.3.9.5**rated impulse withstand voltage** **U_w**

highest peak value of impulse voltage of prescribed form and polarity which does not cause breakdown of insulation to earth under specified conditions

Note 1 to entry: AS/NZS 61439.1:2016 Appendix G provides a table of typical values of U_w .

1.3.9.6**rated load current** **I_L**

maximum continuous rated r.m.s. or d.c. current that can be supplied to a resistive load connected to the protected output of a two port SPD

1.3.9.7**voltage protection level** **U_p**

maximum voltage to be expected at the SPD terminals due to an impulse stress with defined voltage rise time and/or with a current of defined amplitude and wave shape

Note 1 to entry: The test conditions for parameters I_{imp} , I_{max} , I_n and U_p are defined in IEC 61643-11.

1.3.10**distributed facilities**

standalone structures that are interconnected with electrically conductive services within a facility boundary

1.3.11**downconductor**

conductor or natural element that connects an air terminal network with an earth termination network

1.3.12**earth conductor**

conductor that connects to an earth termination network

1.3.13**earth electrode**

portion of the earth termination network that makes direct electrical contact with the general mass of earth

1.3.14**earth potential rise****EPR**

increase in electrical potential of a structure, with respect to remote earth, caused by the discharge of current through the earth termination network of the structure

1.3.15**earth resistance**

resistance of the earth termination network to the general mass of earth

1.3.16**earth termination network**

network of conductors and electrodes intended to discharge lightning current into the general mass of the earth

1.3.17**electricity supply service earth electrode**

earth electrode as defined in AS/NZS 3000

1.3.18**hazardous area**

area in which an explosive atmosphere is present, or may be expected to be present, in quantities such that special precautions for the construction, installation and use of equipment are required

Note 1 to entry: Explosive atmospheres may be due to flammable gases or vapours, where hazardous areas would be classified according to AS/NZS 60079.10.1, or due to combustible dusts, where hazardous areas would be classified according to AS/NZS 60079.10.2.

1.3.19**immunity**

ability of electronic equipment and systems to withstand voltage and current surges without damage

1.3.20**incoming service**

any conductive service entering a structure

Note 1 to entry: Examples of an incoming service are electricity lines, data signalling and control lines, gas, water and other services.

1.3.21**indirect lightning flash**

lightning discharge that impresses a voltage on incoming services

1.3.22**joint**

mechanical and electrical connection between elements of an LPS

1.3.23**life hazard**

permanent injury, including loss of life, to people or animals resulting from a direct strike or by electric shock, resulting from touch and step voltages caused by lightning

1.3.24**lightning flash****lightning discharge**

electrical discharge in the atmosphere involving one or more electrically charged regions taking either of the following forms —

- (a) *ground flash (earth discharge)* — a lightning flash in which at least one lightning discharge channel reaches the ground; or
- (b) *cloud flash (cloud to cloud)* — a lightning flash in which the lightning discharge channels do not reach the ground

1.3.25**lightning ground flash density**

N_g

number of ground flashes per square kilometre per annum

1.3.26**lightning protection system**

LPS

complete system, inclusive of air terminals, downconductors, earth network and bonding, used to reduce physical damage due to lightning flashes to a structure or its contents

1.3.27**lightning protection zone**

LPZ

zone where the lightning electromagnetic environment is defined

Note 1 to entry: The zone boundaries of an LPZ are not necessarily physical boundaries.

1.3.28**lightning strike**

general term for a ground flash

1.3.29**lightning strike attachment point**

point where the ground flash connects

1.3.30**lightning stroke**

individual current impulse in a lightning flash

1.3.31**loss**

due to lightning strike, loss of human life, loss of service to the public, or economic loss

1.3.32**main earthing bar**

MEB

metallic bar installed in the main switchboard that provides a termination point for the main earthing conductor, equipotential bonding conductors, and protective earthing conductors

1.3.33**main switchboard**

MSB

location of electricity supply service to the building that contains the MEB, main neutral earth link and has a connection to the electricity supply service earth electrode

Note 1 to entry: Where the multiple earthed neutral (MEN) system of earthing is employed, a link exists between the MEB and the main neutral link (MEN link).

1.3.34**may**

indicates the existence of an option

1.3.35**metal oxide varistor****MOV**

discrete electronic component with voltage dependent resistance that is a basic building block of many SPDs

1.3.36**multiple earthed neutral system****MEN system**

power distribution system where the neutral is connected to the earth at the main switchboard, as described in AS/NZS 3000

Note 1 to entry: This is also known as TN-C-S.

1.3.37**natural component**

electrically conductive component of a structure, not specifically installed for lightning protection, which may be suitable to provide the function of one or more parts of the LPS

1.3.38**open air facilities**

sparsely placed standalone structures that are not interconnected with electrically conductive services within a facility boundary

1.3.39**primary plant**

substation equipment connected to HV conductors

Note 1 to entry: Examples of primary plant are transformers and disconnectors.

1.3.40**protection level****LPL I to IV**

set of maximum (sizing criteria) and minimum (interception criteria) lightning current parameters used to determine the rolling sphere radius

1.3.41**protection measures**

measures taken to reduce the probability of damage and/or loss which may include protection of the structure and/or surge protection

1.3.42**ring conductor**

above ground conductor around the perimeter of a structure that interconnects downconductors to equalize earth potential

1.3.43**ring electrode**

bare conductor buried around the perimeter of a structure that interconnects downconductors to equalize earth potential

1.3.44**risk assessment**

process of estimating the probability of damage and/or loss

1.3.45**secondary systems**

substation a.c. and d.c. supplies, control, protection, metering and communications equipment and cabling

1.3.46**shall**

indicates that a statement is mandatory

1.3.47**should**

indicates a recommendation

1.3.48**side flash**

discharge from the LPS to nearby objects

1.3.49**step voltage**

difference in the earth surface potential experienced by a person bridging a distance of 1 m with their feet without contacting any earthed object

1.3.50**striking distance** **d_s**

distance between the tip of the downward leader and the eventual lightning strike attachment point at the moment of initiation of an upward intercepting leader

1.3.51**substation**

site for power system equipment, a pole mounted transformer, ground mounted transformer or a pad-mount transformer

Note 1 to entry: A pad-mount transformer is also known as a kiosk substation.

1.3.52**surge protective device****SPD**

device that is intended to mitigate overvoltages caused by lightning currents and other sources, in order to prevent equipment damage

1.3.53**taut string distance**

distance between two parts measured along a taut string stretched the shortest way between those parts

1.3.54**test link**

joint to enable resistance or continuity measurements to be made

1.3.55**tolerable risk****acceptable risk** **R_a**

maximum value of the risk that can be tolerated

1.3.56**touch voltage**

potential difference between an earthed structure and the earth surface at the point (nominally 1 m away) where a person is standing, while touching the earthed structure

1.3.57**zone of protection**

portion of space within which an object or structure is considered to be protected by an LPS at the desired protection level from a direct strike

Section 2 Risk assessment

2.1 Scope of section

This section provides a lightning risk assessment method for structures.

The lightning risk assessment covers the following:

- (a) Potential differences causing death or injury from step and touch voltages.
- (b) Death due to fire, explosion, mechanical and chemical effects caused by a lightning strike.
- (c) Mechanical damage of the structure and contents.
- (d) Damage and failure of equipment within the structure.
- (e) Fire damage that may result from the lightning strike.

The lightning risk assessment procedure compares the calculated risk to a tolerable risk level. The tool which is provided as part of the risk assessment procedure recommends the minimum protective measures required to reduce the risk to below the tolerable limit.

The risk assessment process is applicable to standalone structures and does not consider the hazard scenarios associated with cases including the following:

- (i) Risk to people outdoors.
NOTE 1 For recommendations regarding public safety, see [Section 6](#).
- (ii) Any structures where a decision to apply lightning protection has been made independently by the customer, asset owner, or facility management.
- (iii) Small structures which by virtue of their size may appear not to need lightning protection (e.g. shelters, shade structures and rotundas where people may gather during a storm).

NOTE 2 [Appendix I](#) discusses cases where lightning protection may be warranted.

NOTE 3 For information on managing lightning strike related risk associated with non-standalone structures such as distributed and open-air facilities (e.g. sports fields, golf courses, schools, mine sites, and wastewater treatment plants), see [Clause 2.5.4](#).

2.2 General

Lightning protection measures are installed to reduce the risk of lightning damage and its consequential effects. The need for protection and the level of protection applied should be evaluated in terms of the assessed risk of a lightning strike and the effects of the strike upon people, plant and equipment. The spreadsheet provided with this document (see [Clause 2.5.3](#)) allows users to estimate the relative lightning risk for standalone structures and recommended protection measures. The calculations used in the spreadsheet are from IEC 62305-2 and have been adjusted for Australian conditions.

The decision to provide lightning protection requires judgement on the part of the user. The spreadsheet provides guidance to support this process. Factors such as the risk to people or the value of the site and its operation may determine that there needs to be minimal avoidable risk. Therefore protection measures may be justified regardless of the outcome of any risk assessment.

2.3 Risk management principles

Those involved in the design, installation and maintenance of structures and facilities carry common law and legislative obligations to manage risks to health and safety of personnel and the public. The

mitigation of lightning related risk should follow the principle of the hierarchy of risk controls which defines the order of preference for risk mitigation measures:

- (a) *Elimination of the hazard* — Physically remove the hazard.
- (b) *Minimization of the risk* by the following means:
 - (i) *Substitution* — Replace the hazard to get a lower hazard.
 - (ii) *Isolation* — Separate the hazard from people.
 - (iii) *Engineering controls* — Add physical safety features to plant or equipment.
- (c) *Administrative controls* — Change the way people work or move.
- (d) *Personal protective equipment (PPE)*.

While elimination of all hazards caused by direct and indirect lightning strikes is rarely achievable, implementation of lightning protection will reduce the risk. Administrative controls may be required to achieve the appropriate level of risk (e.g. stopping a sporting event and arranging for the public to relocate to safe locations with adequate time).

NOTE For guidance on risk management, see AS ISO 31000.

2.4 Tolerable levels of risk

Up to 10 people are killed by lightning in Australia each year. This is equivalent to a probability of death of about 5×10^{-7} per year. Moreover, up to 100 people are seriously injured by lightning in Australia each year. This is equivalent to a probability of serious injury of about 5×10^{-6} per year.

Generally, for a single human fatality associated with an involuntary hazard, risks of greater than 10^{-3} per year (i.e. chance of 1 in 1 000 of occurrence in a year) are considered intolerable. Money would normally be spent to eliminate or reduce to a level as low as reasonably practicable, the causes of risks greater than 10^{-4} per year (i.e. chance of 1 in 10 000 of occurrence). Risks less than 10^{-5} per year (i.e. chance of 1 in 100 000 of occurrence) are generally considered tolerable, although public money may still be spent on an education campaign to reduce those risks regarded as avoidable.

NOTE For situations such as public group events (e.g. large sporting events, outdoor concerts, theme parks) where it is likely that more than one person could be killed in the event of a lightning strike, see [Section 6](#) for measures to manage the risk.

Indicative values for tolerable risk due to lightning for four types of losses are presented in [Table 2.1](#).

Table 2.1 — Typical values of tolerable risk

Type of loss	Tolerable risk per year (R_a)
Loss of human life	10^{-5}
Loss of service to the public	10^{-3}
Loss of cultural heritage	10^{-4}
Loss of economic value	10^{-3}
[SOURCE: IEC 62305-2:2010 Table 4. © 2010 IEC Geneva, Switzerland. www.iec.ch] NOTE For a loss of economic value, the tolerable risk may be selected based on economic or cost/benefit considerations by the facility owner or user, often in consultation with the designer of the protection measures. If the data for this analysis are not available, the value of tolerable risk of 10^{-3} may be used as a starting point. For example, a more stringent tolerable risk may be selected if the economic impact of damage due to a strike is very high.	

2.5 Assessment of risk due to lightning

2.5.1 Risk components

Strikes to a structure or connected line(s) may cause physical damage and life-threatening hazards. Strikes near a structure or line, as well as strikes to a structure or line, may cause failure of electrical and electronic systems due to overvoltage resulting from resistive and inductive coupling of these systems with the lightning current. Moreover, failures caused by lightning overvoltage in users' installations and in power supply lines may also generate switching type overvoltage in the installations.

For each type of loss relevant to the structure, the relative risk due to lightning is the probability of that loss occurring over the period of a year. The total risk is made up of the sum of a number of risk components associated with the four possible sources of hazard, according to the point of strike, as listed below:

- (a) Lightning strikes directly to the structure (S1). These may generate hazards due to:
 - (i) Step and touch voltages, or side strike contact outside the structure resulting in electric shock to living beings.
 - (ii) Mechanical and thermal effects of the lightning current or by dangerous sparking causing fire, explosion, mechanical and chemical effects inside the structure.
 - (iii) Overvoltage on internal installations and incoming services causing failure of electrical and electronic systems.
- (b) Lightning strikes to ground near the structure (S2). These may generate hazards due to overvoltage on internal installations and equipment, mainly induced by the magnetic field associated with the lightning current, causing failure of electrical and electronic systems.
- (c) Lightning strikes directly to conductive services (S3) may generate risk due to:
 - (i) Overvoltages transmitted through incoming lines causing electric shock or injury to people inside the structure.
 - (ii) Mechanical and thermal effects including dangerous sparking between external installation and metallic parts (generally at the point-of-entry of the incoming line into the structure) causing fire, explosion, mechanical and chemical effects on the structure and/or its content.
 - (iii) Overvoltage, transmitted through incoming lines to the structure, causing failure of electrical and electronic systems.
- (d) Lightning strikes to ground near conductive services (S4) may generate hazards due to induced overvoltage, transmitted through incoming lines to the structure, causing failure of electrical and electronic systems.

2.5.2 Risk assessment process

The risk assessment approach is based on the principles of the management of risk due to lightning presented in IEC 62305-2.

The lightning risk assessment process calculates risk factors based on the construction, usage and exposure to lightning strikes. The risk is assessed against the tolerable limits given in [Clause 2.4](#). Mitigation measures based upon an integrated approach are recommended to reduce the risk below the tolerable limits. The integrated approach requires coordination of the following aspects:

- (a) Direct strike interception (see [Section 3](#)).
- (b) Surge protection (see [Section 4](#)).
- (c) Earthing and bonding (see [Section 3](#) and [Appendix E](#)).

The risk assessment process is summarized in [Figure 2.1](#).

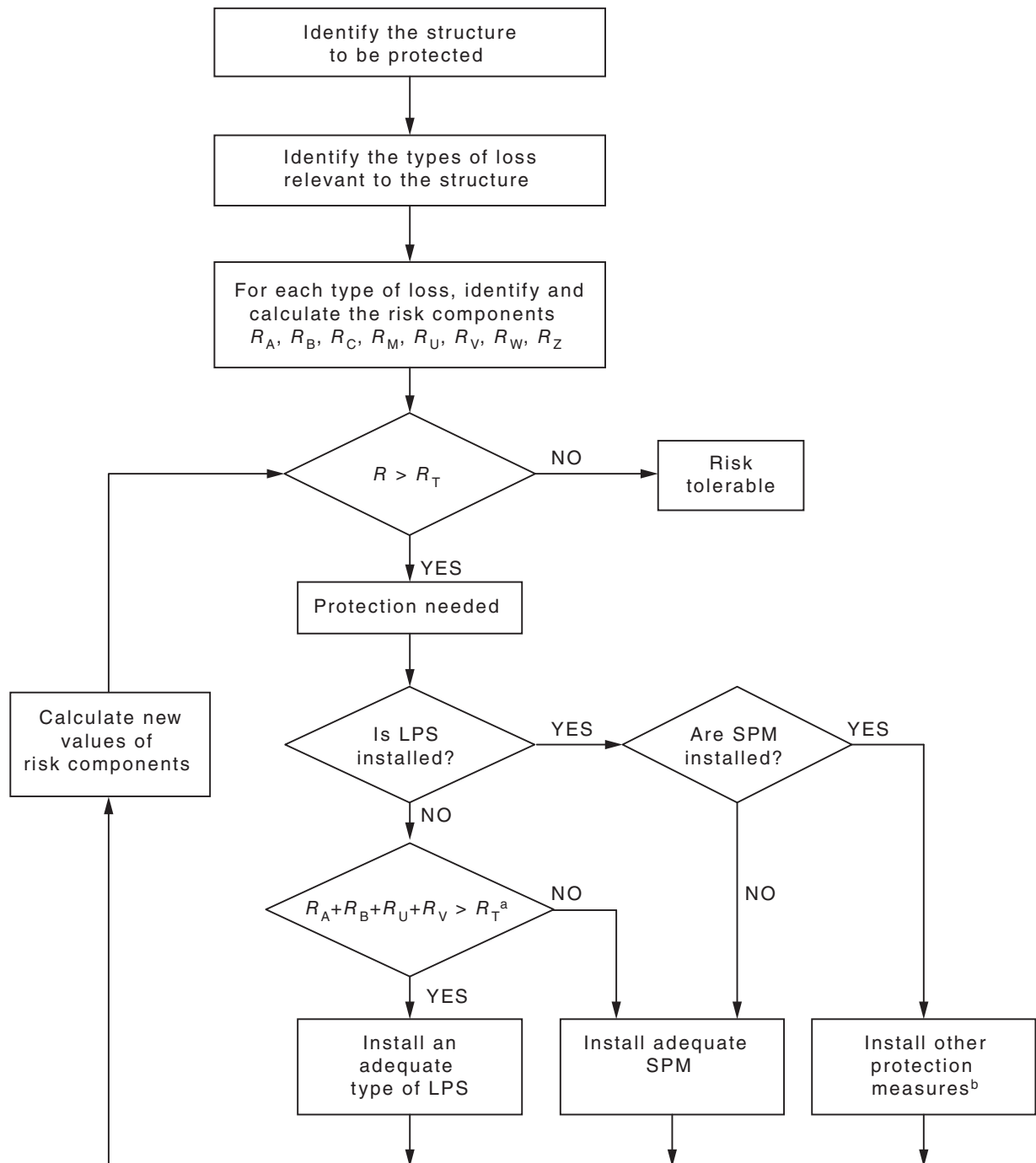
NOTE 1 [Appendix B](#) provides a description of the components within the risk assessment process.

NOTE 2 [Appendix C](#) provides case studies with explanation regarding each of the required inputs.

Where other relevant information exists, such as a history of damage to existing similar structures or equipment in the nearby area, this should be taken into account when deciding whether or not to install lightning protection. For instance, if there is a history of damage to the site then a higher level of protection should be considered.

The risk assessment process calculates a level of assessed risk (R) for comparison with the tolerable risk levels (R_T). [Table 2.2](#) provides a description of the risk factors involved in calculating the assessed risk level (R).

The selection of the most suitable protection measures needs to be made according to the contribution of each risk component to the total risk, and according to the technical and economic aspects of the different protection measures available. Technical considerations include the highest risk components while economic considerations involve minimizing the total cost to achieve a suitable level of protection.



^a If $R_A + R_B < R_T$, a complete LPS is not necessary; in this case, surge protection measures are sufficient.

^b See [Section 3](#) for a list of protection measures.

NOTE SPM = Surge protection measures.

Figure 2.1 — Risk assessment and lightning protection selection process

Table 2.2 — Risk factors

Risk	Strike to structure (S1)	Strike near structure (S2)	Strike to connected service ^a (S3)	Strike near connected service ^a (S4)
Injury to people	R_A		R_U	
Damage to structure	R_B		R_V	
Failure of internal systems	R_C	R_M	R_W	R_Z
^a Conductive services entering the structure including power, telecommunications, gas and water.				

2.5.3 Risk assessment spreadsheet

A spreadsheet is provided with this document to assist in carrying out a lightning risk assessment for standalone structures. It applies the methodology outlined in [Appendix B](#). Worked case studies are provided in [Appendix C](#). The approach used in [Appendix B](#) has been simplified from the approach in IEC 62305-2 by reducing the number of variables and options requiring selection, based on assumptions for general conditions in Australia. First issued in AS/NZS 1768:2007, the spreadsheet has been enhanced to provide clarity and improved functionality.

The calculations made assume that an all metal or reinforced concrete structure will be electrically continuous and that it will be adequately earthed. It also assumes that the structure provides adequate air terminations. Although the spreadsheet may report that a structure does not require direct strike lightning protection, continuity and earthing shall be in accordance with [Sections 3](#) and [5](#), and the presence of air terminations confirmed.

2.5.4 Multiple structures

2.5.4.1 General

The spreadsheet applies to standalone structures. Distributed and open air facilities require a different approach.

2.5.4.2 Distributed facilities

Standalone structures that are interconnected with electrically conductive services within a facility boundary are defined as distributed facilities. Examples of distributed facilities include water and wastewater treatment plants, petrochemical plants, mine sites, and ground mounted photovoltaic arrays.

As the spreadsheet is not applicable to such facilities as a whole, the following method is recommended:

- Use the facility boundary to calculate the area.
- Multiply this area by the ground flash density (N_g) to obtain the expected number of flashes per year.
- Use this information to determine protective measures in accordance with the hierarchy of controls described in [Clause 2.3](#).

The above method gives an indication of the risk of a lightning strike to the facility as a whole. Should this calculation indicate a strike to the facility during its projected life, then lightning protection measures should be considered.

Although it is not practicable to provide direct strike protection to a large open facility, the standalone structures within the facility such as metal tanks and pipework are normally self-protecting. However, to ensure continued operation of the plant, the protection of equipment and cables interconnecting the standalone structures should be carried out in accordance with [Section 4](#).

Apply the spreadsheet to individual structures, to determine protection requirements for each structure.

This multi-stage approach provides guidance only and may require additional calculations to take into account services external to the facility (e.g. pipelines and powerlines).

2.5.4.3 Open air facilities

Sparsely placed standalone structures that are not interconnected with electrically conductive services within a facility boundary are defined as open air facilities. Examples include golf courses, school grounds, sporting facilities and outdoor swimming pools.

As the spreadsheet is not applicable to such facilities, the following method is recommended:

- (a) Use the facility boundary to calculate the area. Multiply this area by the ground flash density (N_g), to obtain the expected number of flashes per year.
- (b) Apply the spreadsheet to individual structures, to determine protection requirements for each structure.

NOTE Often the only practical protection methods are administrative controls (see [Section 6](#)).

Section 3 Protection of structures

3.1 General

This section sets out requirements for the design and installation of a lightning protection system (LPS) for common structures. The requirements cover the placement of air terminals, downconductors, design of earthing systems, conductor sizing and materials to be used for the protection of those structures.

For structures with explosive or flammable contents, see the additional requirements in [Appendix J](#).

The reason for installing an LPS on a structure is to intercept a pre-determined portion of lightning stroke currents. This concept is described by the term lightning protection level (LPL). Four LPLs (I, II, III, IV) are used to define the efficiency with which the LPS is designed to protect the structure against physical damage and life hazards. The interception efficiency is 99 %, 97 %, 91 % and 84 % for LPLs I, II, III and IV respectively (see [Table 3.1](#)).

Table 3.1 — LPL interception efficiencies

LPL	Efficiency	Note
I	99 %	Often used for hazardous or sensitive sites
II	97 %	
III	91 %	Often used for common structures
IV	84 %	

Direct strike protection shall be provided when the risk assessment deems it necessary.

Direct strike protection should be provided when the —

- (a) consequences of a lightning flash could affect public service utilities;
- (b) economic consequences of lightning damage are unacceptable; or
- (c) consequences of a lightning flash could affect human safety (occupancy).

An LPS may comprise natural components, specifically installed (dedicated) components or a combination of both. Irrespective of the form of the LPS, the requirements of this section shall be followed.

The components of an LPS shall —

- (i) be electrically continuous (including from air terminal to earth termination);
- (ii) be positioned/spaced in accordance with [Clauses 3.2](#) and [3.3](#); and
- (iii) meet the material and sizing requirements outlined in [Clause 3.7](#).

Careful coordination between electrical, structural and architectural designers and contractors is essential to ensure these requirements are met.

3.2 Air terminals

3.2.1 General

Interception of lightning flashes relies on two key aspects —

- (a) air terminals used to capture the flash; and
- (b) method by which the air terminals are positioned on structures to achieve the desired protection level (LPL).

An air terminal may consist of a vertical rod, a raised horizontal conductor, or natural component of the structure.

NOTE 1 Examples of natural components include metal roofs, parapet railings or poles.

The rolling sphere method (RSM) is used for the positioning of dedicated air terminals, and checking the sufficiency of any natural components used as air terminals (see [Appendix D](#)).

Air terminals shall be provided in accordance with the requirements in [Clause 3.2.2.2](#) when the roof type is not capable of performing the role of an air terminal.

NOTE 2 Common examples are reinforced concrete structure or masonry tile roof.

3.2.2 Air terminal requirements

3.2.2.1 General

The minimum requirements for air terminals shall be as specified in [Clauses 3.2.2.2](#) and [3.2.2.3](#).

3.2.2.2 Use of dedicated air terminals

Where dedicated air terminals are necessary, the following shall apply:

- (a) Air terminals shall be positioned on or close to the most vulnerable parts of the structure (typically points and corners) and —
 - (i) when a raised horizontal conductor is used, it shall be positioned directly above the part it is to protect; and
 - (ii) when a vertical rod is used, its length shall be not less than 500 mm. It shall be mounted on or above the part it is to protect, and not more than half the height of the rod from the edge to be protected.
- (b) The rolling sphere method (RSM) shall be used to check the protection in accordance with [Appendix D](#).

Conductors at or near roof level shall interconnect all air terminals to ensure multiple paths to earth. These conductors could carry full lightning current and shall be sized accordingly, including natural components used as conductors.

The upper portions of dedicated downconductors on the exterior of tall structures shall be regarded as a continuation of the air terminal network. These shall be placed as near as practicable to the exposed outer vertical corners of a structure.

Non-conventional LPSs using air terminals that claim enhanced performance are outside the scope of this document. To conform to this document and irrespective of claimed performance, air terminals shall be placed in accordance with the relevant clauses of this section.

3.2.2.3 Use of the structure as air terminals (natural components)

Where the upper parts of a structure are conductive and of sufficient size, they shall be bonded to the LPS and form part of the air terminal network.

The following components of a structure may be considered to be part of the air terminal network, removing the need for dedicated air terminals, provided they meet the requirements outlined in [Clause 3.1](#) and the dimensions specified in [Table 3.3](#):

- (a) Sheet metal covering the structure to be protected.
- (b) Metal parts, such as ornamentation, handrails, pipes, tanks, parapets, roof.

NOTE The roof of a reinforced concrete structure in itself is not capable of performing the role of an air terminal network. It requires other metallic items such as those listed above, or dedicated air terminals.

3.2.3 Air terminal positioning

This document specifies the rolling sphere method (RSM) for the placement of air terminals, as outlined in [Appendix D](#).

NOTE 1 [Section 2](#) provides guidance as to which LPL (sphere radius) is appropriate.

NOTE 2 The most vulnerable parts of a structure, associated with over 90 % of observed instances of lightning strike damage, are located on the upper parts. Field data of damage caused by lightning strikes identified the following parts as being the most vulnerable:

- (a) Pointed apex roofs, spires and protrusions.
- (b) Gable roof ridge ends.
- (c) Outer roof corner.

NOTE 3 Other areas of vulnerability, in decreasing order, are:

- (a) Exposed edges of horizontal roofs, and the slanting and horizontal edges of gable roofs (< 10 %).
- (b) Lower horizontal and vertical edges on outer sides just below corners (< 5 %).
- (c) Flat surfaces near points and corners (< 3 %).
- (d) Intruding surfaces and other surfaces, particularly flat surfaces (< 1 %).

NOTE 4 Vulnerability is caused by the electric field intensification associated with exposed points and corners on the upper surfaces of structures. Therefore, air terminals should be positioned to intercept lightning strikes to vulnerable parts.

3.2.4 Side strike protection

An air terminal network shall be provided on the vertical sides of tall structures as follows:

- (a) Structures of height between 60 m and 75 m — On that part of the structure greater than 60 m.
- (b) Structures of height greater than 75 m — On the top 20 % of the structure.

Side strike protection to those areas specified above shall take into consideration protection to protruding parts, such as corners and edges of facades, balconies, and viewing platforms (see Note 1).

NOTE 1 Side strike protection may cover less of the structure than if the rolling sphere were strictly applied. Side strike protection can be provided by natural elements such as the metallic cladding.

NOTE 2 Where there is uncertainty regarding the flammability of metallic cladding used on the exterior of a structure, it should be bonded to the LPS regardless of the height of the structure.

3.3 Downconductors

3.3.1 General

Downconductors consist of dedicated conductors and/or natural components of the structure.

3.3.2 Downconductor requirements

The following requirements apply to downconductors:

- (a) Downconductors shall be placed around the external perimeter (using the taut string distance) of the structure at intervals not exceeding 20 m.
- (b) An LPS shall be provided with at least two downconductors.
- (c) Downconductors shall not be installed in lift shafts or service ducts.

Downconductors should —

- (i) follow the most direct path between the air terminal and the earth termination;
- (ii) be equally spaced; and
- (iii) not be located in areas where people congregate.

Downconductors that claim enhanced magnetic screening or shielding over conventional systems are outside the scope of this document. To conform to this document and irrespective of claimed performance, downconductors shall be placed in accordance with the relevant clauses of this section.

3.3.3 Natural components

The following parts of a structure may be used as natural downconductors forming part of the LPS, provided they meet the requirements of [Clauses 3.1](#) and [3.7.3](#) and the dimensions specified in [Table 3.3](#):

- (a) Structural steel framing, including steel within concrete.
- (b) Metal cladding, excluding cladding with combustible cores.
- (c) Curtain wall systems. In a concrete reinforced structure with a curtain wall, it is recommended that it be bonded to the reinforcing steel at intervals of 20 m horizontally and 10 m vertically.
- (d) Steel reinforcing within concrete (cast *in situ* or precast).

NOTE 1 Care should be taken where post-tensioned cables and chemical anchors are used in construction, as they may not provide adequate electrical connection.

- (e) Metallic structures such as lighting towers, communications towers, and roadway gantries are inherently conductive and require no additional downconductors.

NOTE 2 For bonding and surge protection of equipment mounted on these structures, see [Clause 3.5](#).

NOTE 3 For information on SPD components, including their performance and application, see [Appendix G](#).

3.3.4 Test points

Test points should be installed where there is an ongoing need for a downconductor to be tested.

NOTE Test points constructed as test links allow for isolation during testing.

3.4 Strike counters

Devices to record lightning strikes may be installed on downconductors. These devices should record a lightning impulse of greater than 1 kA when tested with an 8/20 μ s wave shape. They should be weatherproof and, if battery powered, run for at least 5 years. The battery replacement date should be noted on the exterior of the device.

NOTE Refer to IEC 62561-6 for more details.

3.5 Earth termination network

3.5.1 General

The primary purpose of the earth termination network is to safely dissipate the lightning energy. The earth termination network should also reduce step and touch voltages in and around the structure.

The earth termination network consists of conductors and earth electrodes and/or natural components of the structure below ground.

In most structures, foundations comprised of concrete and steelwork are conductive and are suitable to be used as the earth termination network when they meet the requirements of [Clause 3.5.3](#). Where the foundations are not suitable, dedicated earth electrodes should be installed to supplement the foundation earth. The dedicated electrodes should be bonded to the foundation steelwork.

Aluminium conductors shall not be directly buried.

3.5.2 Earthing requirements

The following requirements apply:

- (a) All earthing systems associated with a structure shall be bonded to the earth termination network either directly or via gas discharge devices.
- (b) Where dedicated downconductors are installed, they shall be bonded to an earth electrode.
- (c) Horizontal earth electrodes shall be buried at least 500 mm below finished level.
- (d) All metallic services shall be electrically bonded to the earth termination network.
- (e) The earth termination network shall be bonded to the electrical earth electrode where present.

NOTE Typical bonding configurations are shown in [Appendix E](#).

The following should be taken into consideration:

- (i) Multiple vertical electrodes should be interconnected.
- (ii) Where dedicated earth electrodes are used and are accessible, they should include labelling similar to the following:

WARNING: LIGHTNING EARTH — DO NOT DISCONNECT.

The following parts of a structure may be deemed to be natural components for the earth termination network, provided they are not impeded by a continuous isolating barrier:

- (A) Reinforced concrete footings.
- (B) Steel piles, screw anchors, and other substantial conductive structure supports.

Where multiple natural components are used as part of the earthing system and they are not bonded together, an interconnecting horizontal electrode shall be installed to bond these together. This conductor should be buried at least 500 mm below finished level.

3.5.3 Earth resistance

The earth termination network should have a resistance to earth not exceeding 10 Ω before any bonding to services that are not part of the LPS.

At some sites, the soil resistivity and composition is such that achieving a resistance to earth less than 10 Ω is not feasible. In these instances, the lowest practical value should be sought, using the impedance reduction measures outlined in [Clause E.3.7](#).

Equipotential bonding shall be installed directly or by the application of SPDs. Guidance is provided in [Appendix E](#).

Where structural footings are used, resistance measurements shall be taken and values recorded during construction, when individual footings can be tested. Measurements and recording of resistance values shall also be completed for installation using dedicated earth electrodes.

The fall-of-potential (FOP) method is most commonly used for making earth resistance measurements (see [Clause E.5.5](#)).

3.6 Prevention of side flashing

3.6.1 General

When the LPS intercepts a lightning flash, its electric potential with respect to earth is raised and, unless suitable precautions are taken, the discharge may seek alternative paths to earth by side flashing to other nearby conductors.

To prevent side flashing, equipotential bonding (see [Clause 3.6.2](#)) or protection by isolation (see [Clause 3.6.3](#)) shall be used.

3.6.2 Equipotential bonding

Equipotential bonding connects metal parts to prevent uncontrolled discharge. Bonding eliminates local potential differences between the bonded metal parts (see [Clause E.3.9](#) for more details). It is still possible to incur significant potential differences if the bonding conductors are long. Any part that is bonded into the LPS could carry a proportion of the lightning current; the bond and bonded element shall be capable of carrying such current.

NOTE 1 For bonding conductor minimum section dimensions, see [Clause 3.7.2](#).

Bonding, as a minimum, shall conform to the following:

- (a) Prominent metal plant on the roof shall be bonded to the LPS.
- (b) Metal components that pose a life hazard shall be bonded to the LPS (e.g. balcony rails, ladders, walkway gantries, and screens).
- (c) Metallic services (e.g. gas and water) entering a structure shall be bonded to the earth termination at the point-of-entry.

The following should be taken into consideration:

- (i) Metal that is running vertically through a structure for a considerable length (> 10 m) and in close proximity (< 1 m) to a downconductor should be bonded to the LPS at each end and at vertical intervals of not more than 10 m.
- (ii) In curtain wall construction, where the curtain wall would otherwise be electrically isolated from the structure, it should be made electrically continuous and be bonded to the LPS at intervals not exceeding 20 m around the perimeter of the building. This should occur at the top and bottom of each curtain wall and at vertical intervals of not more than 10 m.
- (iii) The effects bonding may have on any metal that is cathodically protected.

NOTE 2 For more details, refer to the AS 2832 series.

3.6.3 Protection by isolation

Isolation is the separation or insulation of metal parts in such a way that electrical breakdown to them is prevented. Isolation may be achieved by separation of the LPS from the structure protected using an air clearance or insulating materials. The necessary separation distance from any point on the LPS depends on the electric potential generated at that point by the lightning discharge.

To achieve a sufficiently low probability of side flash, the responses of the protection system to a range of severe stroke current wave shapes shall be accounted for. To calculate the necessary separation distance (S), the following [Equation 3.6.3](#) may be used:

$$S = \frac{k_i k_c}{k_m} l \quad 3.6.3$$

where

l = length, in metres, along the air-terminal network and the downconductor from the point where the separation distance is to be considered, to the nearest equipotential bonding point or the earth termination

k_i = LPS factor

k_c = downconductor factor

k_m = insulation factor

Simplified values for the k factors in [Equation 3.6.3](#) are given in [Table 3.2](#).

Isolation may be provided by appropriate air clearance from bare downconductors or by appropriately insulated downconductors.

NOTE For additional information for protection by isolation and insulated downconductors, refer to IEC 62305-3.

Table 3.2 — Factors k_i , k_c and k_m for common (simplified) application scenarios of the separation distance formula of [Equation 3.6.3](#)

LPS factor		Downconductor factor		Insulation factor	
LPL	k_i	No. DC	k_c	Material	k_m
I	0.08	1	1.0	Air	1.0
II	0.06	2	0.66	Masonry	0.5
III	0.04	≥ 3	0.44		
IV	0.04				
NOTE For examples of separation distance, refer to IEC 62305-3:2010 Annex C.					

3.7 Materials

3.7.1 General

Materials shall be chosen for their conductivity, strength and durability.

Materials shall be capable of minimizing corrosion of both the component and the structure.

3.7.2 Form and size of conductors

The form and size of conductors shall be in accordance with [Table 3.3](#).

3.7.3 Joints

Joints shall be mechanically and electrically effective (e.g. clamped, screwed, bolted, crimped, riveted or welded). Where reinforcing bars are used as conductors, they shall be —

- (a) overlapped by a minimum of 20 times the reinforcing bar diameter;
- (b) touching over the length of the overlap; and
- (c) secured by a minimum of two tie wires (located at each end of the overlap).

Joints shall not reduce the conductor cross-sectional area below the minimum value specified in [Table 3.3](#).

The LPS should be designed to have as few joints as practicable.

3.7.4 Fasteners

Fasteners secure the LPS to the structure.

The following requirements apply to fasteners:

- (a) LPS components shall be securely attached to the structure.
- (b) Fasteners shall be compatible from a corrosion perspective with the materials they contact, see [Clause 3.7.5](#).
- (c) Fasteners shall be adequately spaced to support the component.

NOTE 1 For dedicated components, recommended fastener spacing is ≤ 1.0 m on horizontal runs and ≤ 1.5 m on vertical runs.

- (d) Fasteners shall be suitable for long-term exposure to the environment (e.g. stabilized and protected against UV and corrosion).

NOTE 2 Where LPS components such as air terminals are subject to vibration caused by wind, measures to mitigate the effects of vibration are recommended.

Fastening shall not result in a reduction of the conductor cross-sectional area below the minimum value specified in [Table 3.3](#).

Table 3.3 — Minimum section dimensions for LPS components

Component	Minimum section dimensions	Examples of typical component dimension
Air terminals	35 mm ²	Strip: 25 mm × 3 mm Solid rod: 8 mm diameter Stranded conductor: 35 mm ² Metal sheeting: 0.45 mm (5 mm) thickness (see Note 1)
Downconductors	35 mm ²	Strip: 25 mm × 3 mm Solid rod: 8 mm diameter Stranded conductor: 35 mm ² Metal sheeting: 0.5 mm (5 mm) thickness (see Note 1)
Earth electrodes and buried conductors	35 mm ²	Earth rods: 12 mm diameter Galvanized star stakes (star pickets): Y: 25 mm × 19 mm × 19 mm Galvanized steel water pipe: 25 mm diameter Galvanized steel strip: 50 mm × 3 mm Copper strip: 25 mm × 3 mm Stranded conductor: 70 mm ²
Major bonding conductors	16 mm ²	Stranded conductors: 16 mm ² Strip: 25 mm × 3 mm
Minor bonding conductors	6 mm ²	Stranded conductors: 6 mm ²

NOTE 1 For metal sheets, standard sheets with a thickness of 0.45 mm would be determined to be within the nominal thickness range identified. The first thickness shown is suitable where it is not important to prevent puncture and possible fire resulting from molten metal splatter. The thickness in brackets will minimize the risk of puncture and hotspots.

NOTE 2 While earth electrodes are only required to be 35 mm², they are often oversized to allow for corrosion and also to be more resilient to mechanical damage (such as can occur from digging equipment).

NOTE 3 Earth electrodes should be made of metals not liable to be adversely affected by corrosion over their lifetime. Stainless steel electrodes should be used in harsh environments, such as saline conditions, as they provide excellent corrosion performance.

NOTE 4 A major bonding conductor interconnects bonding bars, and connects bonding bars to the earth termination system. It may carry the full or a significant part of the lightning current.

NOTE 5 A minor bonding conductor connects internal metal installations to bonding bars. It may carry partial lightning current. It is used to bond metallic objects that could cause touch voltage hazards to people.

3.7.5 Galvanic corrosion

Galvanic corrosion is an electrochemical process in which one metal corrodes preferentially when it is in electrical contact with another, in the presence of an electrolyte. Dissimilar metals and alloys have different electrode potentials, and when two or more come into contact in an electrolyte, one metal acts as anode and the other as cathode. All metals may be classified into a galvanic series (commonly called the anodic index), representing the electric potential they develop in a given electrolyte against a standard reference electrode. The relative position of two metals in the anodic index gives a good indication of which metal will corrode more quickly. An indicative anodic index is shown in [Table 3.4](#).

The materials used to build the structure and the lightning protection system components mounted thereon shall be selected for galvanic compatibility. Compatibility is checked between any of the following items where they are in contact with each other:

- (a) Building materials.
- (b) Conductors.
- (c) Fixings.
- (d) Any other element of the LPS.

The potential difference in the anodic series index, between the materials used to build the structure, and the mounted lightning protection system components, shall not exceed 0.5 V.

Where transitioning from one material to another, such as from aluminium conductors to copper earthing conductors, measures shall be taken to protect the joint from corrosion.

NOTE 1 Examples of measures include the use of bi-metallic connectors, mastic or other waterproofing measures.

NOTE 2 For example, copper has an anodic index of 0.35 V, and aluminium has an anodic index of 0.90 V, giving a potential difference of 0.55 V, which exceeds the value specified above.

NOTE 3 In harsh environments, such as coastal locations, the potential difference in the anodic series index between any of these touching metals should not exceed 0.15 V.

Table 3.4 — Indicative anodic index for metals

Metal	Index (V)
Gold, solid and plated and gold-platinum alloy	0.00
Rhodium plated on silver-plated copper	0.05
Silver, solid or plated; nickel-copper alloys with high tensile strength and resistance to corrosion	0.15
Nickel, solid or plated, titanium and alloys and nickel-copper alloys with high tensile strength and resistance to corrosion	0.30
Copper, solid or plated; low brasses or bronzes; silver solder and German silvery high copper-nickel alloys; nickel-chromium alloys	0.35
Brass and bronzes	0.40
High brasses and bronzes	0.45
18 % chromium type corrosion-resistant steels (e.g. 304 SS)	0.50
Chromium plated; tin plated; 12 % chromium type corrosion-resistant steels	0.60
Tin-plate; tin-lead solder	0.65
Lead, solid or plated; high lead alloys	0.70
Aluminium, wrought alloys of the 2000 Series	0.75
Iron, wrought, grey or malleable, plain carbon and low alloy steels (e.g. rebar)	0.85
Aluminium, wrought alloys other than 2000 Series Aluminium, cast alloys of the silicon type	0.90
Aluminium, cast alloys other than silicon type, cadmium, plated and chromate	0.95
Hot-dip-zinc plate; galvanized steel	1.20
Zinc, wrought; zinc-base die-casting alloys; zinc plated	1.25
Magnesium and magnesium-base alloys, cast or wrought	1.75
Beryllium	1.85

Section 4 Protection of equipment

4.1 General

This section sets out requirements for the installation of surge protection and defines applicable ratings of SPDs suitable for power and signal/data lines.

Earthing, bonding and surge protection are integral parts of an overall lightning protection system (LPS).

Whenever an LPS is fitted to a structure, equipotential bonding shall be applied to incoming metallic and electrical services. For electrical services, equipotential bonding is achieved through the application of SPDs. The need for secondary protection to equipment contained within the structure should be considered through the risk assessment process.

4.2 Surge protection installation

4.2.1 General

While people and equipment within buildings may be protected from a direct lightning strike, many circumstances arise where the effects of lightning are transmitted within the building, placing people and equipment at risk.

Surge protection shall be installed —

- (a) where the risk assessment deems it necessary; and
- (b) where the facility is to be protected from direct lightning strikes.

Surge protection should be installed where the —

- (i) value of N_g is greater than 2 flashes/km²/year and the conductive services are overhead;
- (ii) consequences of surge damage could affect human safety;
- (iii) consequences of surge damage could affect public service utilities; and
- (iv) economic consequences of surge damage are intolerable.

4.2.2 Introduction to SPDs

SPDs are intended to mitigate transient overvoltages and fall into the following three general categories:

- (a) *Voltage-limiting* — An SPD that has a high impedance when no surge is present but will reduce impedance continuously with increased surge current and voltage.

NOTE 1 Common examples of voltage limiting SPD components include metal oxide varistors (MOV) and avalanche breakdown diodes.

- (b) *Voltage-switching* — An SPD that has a high impedance when no surge is present but will have a sudden change in impedance to a low value in response to a voltage surge.

NOTE 2 Common examples of voltage-switching SPD components include spark gaps, gas discharge tubes and thyristors.

- (c) *Combination type* — An SPD that incorporates both voltage-switching and voltage-limiting components.

SPDs are referred to as either of the following:

- (i) *One-port SPD* — An SPD having no intended series impedance.
NOTE 3 A one-port SPD may have separate input and output connections.
- (ii) *Two-port SPD* — An SPD having a specific series impedance connected between separate input and output connections.

4.3 Transient overvoltages

Lightning induces transient overvoltages into conductive services, including power, communications, data and control lines. These overvoltages may be caused by the following:

- (a) Lightning striking the LPS, resulting in earth potential rise (EPR), e.g. across a process plant or up a multistorey building (see [Figure 4.1 S1](#)). This EPR creates earth potential differences across the plant or building, resulting in equipment damage.
- (b) Direct conduction of lightning current on the conductors entering the building (see [Figure 4.1 S3](#)).
- (c) Indirect effects, where lightning strikes the ground or nearby objects causing local EPR, or transient overvoltages which are induced on the conductors entering the building (see [Figure 4.1 S2 and S4](#)).

The strategies to deal with these overvoltages involve the following:

- (i) Ensuring correct earthing and equipotential bonding is installed (see [Section 3](#)).
- (ii) Provision of SPDs. The aim of any SPD protection scheme is to ensure that the resultant voltage protection level (U_p) of the primary and/or secondary protection is less than that which will damage the equipment to be protected.

NOTE For guidance on impulse withstand and immunity of equipment, see [Appendix H](#).

4.4 Temporary overvoltages

When the voltage of an a.c. power system rises above its normal value, a temporary overvoltage (TOV) is created. This may be caused by poor regulation, faults on the LV or HV distribution system (including phase to neutral or earth short-circuit), loss of neutral conductor, capacitor switching, sudden load rejection, and HV contact on LV circuits. These events typically last from 0.2 s up to 5 s. On the MEN system, LV faults can result in these overvoltages being up to 1.7 times the nominal system voltage, due to the phase-to-phase voltage appearing between phase and neutral. In the case of HV contact on LV circuits, the TOV will be much higher.

The effect of these TOVs on SPDs may be catastrophic. For this reason, SPDs shall be protected by an upstream overcurrent protective device capable of isolating the SPD.

NOTE IEC 61643-11 has specific TOV tests to verify safe operation.

4.5 Lightning protection zones

Previous editions of this document defined lightning location categories. This edition uses lightning protection zones (LPZ) which provide a similar categorization of locations within a typical structure. SPDs are placed at the boundaries of these zones to reduce the likelihood of damage to downstream equipment.

Protection measures such as the LPS, shield wires, magnetic shielding and SPDs determine the LPZ. With respect to the threat of lightning, the following LPZ are defined (see [Figure 4.1](#)):

- (a) Outside zones are as follows:
 - (i) LPZ0_A — A zone where the threat is due to direct lightning flashes and the full lightning electromagnetic field. Without SPDs, equipment beyond this boundary may be subjected to full or partial lightning current.
 - (ii) LPZ0_B — A zone protected against direct lightning flashes but where equipment is subjected to the full lightning electromagnetic field. Without SPDs, equipment beyond this boundary may be subjected to induced surge current.
- (b) Inside zones are as follows:
 - (i) LPZ 1 — A zone where the surge current is limited by current sharing and isolating interfaces and/or SPDs at the boundary. Spatial shielding may also attenuate the lightning magnetic field.
 - (ii) LPZ 2...n — Zones where the surge current may be further limited by current sharing and isolating interfaces and/or by additional SPDs at the boundary. Additional spatial shielding may also attenuate the lightning magnetic field.

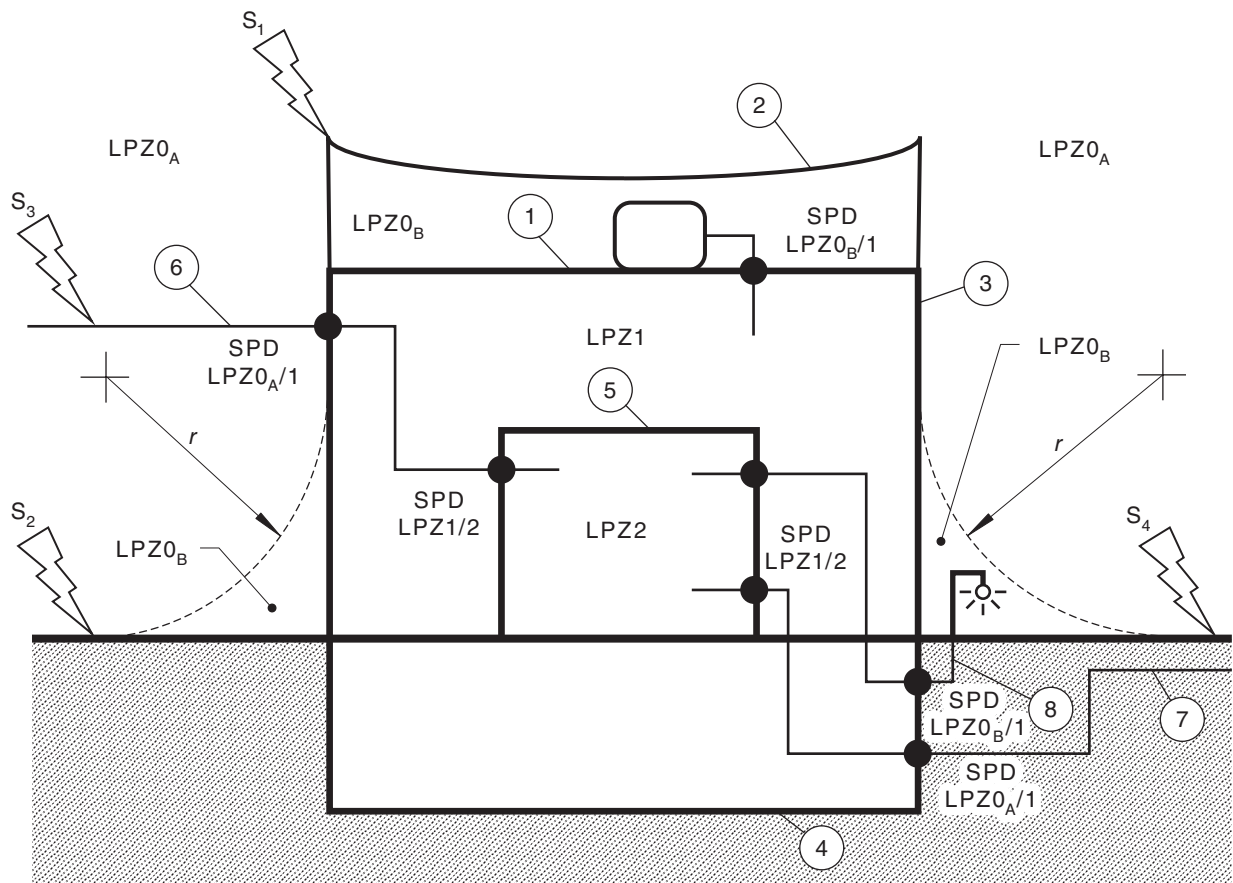
There are four categories of lightning flashes, shown as S1 to S4 in [Figure 4.1](#). These are as follows:

- (a) S1 — Flash to the structure.
- (b) S2 — Flash near the structure.
- (c) S3 — Flash to a service.
- (d) S4 — Flash near a service.

The rolling sphere defines the boundary between LPZ0_A and LPZ0_B.

For effective protection at LPZ0_A/1 and LPZ0_B/1 boundaries, primary SPDs shall be installed. At these points, partial direct lightning current may flow through the primary SPDs. Therefore, these SPDs may have both 8/20 μ s and 10/350 μ s ratings in accordance with [Table 4.1](#).

Secondary SPDs shall be included at the LPZ1/2 and LPZ2/...n boundaries if the risk assessment or factors in [Clause 4.2.1\(i\)](#) to (iv) indicate this requirement. These SPDs have 8/20 μ s ratings.



Key

- 1 Structure, boundary of LPZ0A/1 and/or LPZ0B/1
- 2 Air termination network
- 3 Downconductor network
- 4 Earth termination system
- 5 Boundary of LPZ1/2
- 6 Incoming overhead metallic services to structure
- 7 Incoming underground metallic services to structure
- 8 Outdoor electrical service in LPZ0B

Figure 4.1 — Lightning protection zones (LPZ)

4.6 Power SPD requirements

4.6.1 General

The requirements in [Clauses 4.6.2, 4.6.3](#) and [4.6.4](#) apply to power SPDs installed on the MEN system of wiring, as defined in AS/NZS 3000.

NOTE For other wiring systems, see [Appendix F](#).

4.6.2 Overcurrent protection

SPDs shall be protected against short-circuit by an overcurrent protective device. The short-circuit withstand of the SPD and the overcurrent protective device shall be not less than the prospective short-circuit current at the point of installation.

SPDs should be installed upstream of any residual current device (RCD). Where this cannot be achieved, consideration should be given to the use of type S RCDs with their enhanced immunity to impulse energy. Use of such devices shall not compromise electrical safety.

The rating of the overcurrent protective device should be as specified by the SPD manufacturer. The rating shall be not greater than the manufacturer's maximum backup fuse rating.

In all cases, the SPD backup fuse shall discriminate with the power authority supply fuse.

NOTE 1 For information on fuse discrimination, refer to AS/NZS 3000:2018 Clause 2.5.7.

NOTE 2 Although circuit-breakers are suitable for overcurrent protection of SPDs, fuses or dedicated SPD disconnectors should be used due to their lower series impedance.

NOTE 3 For additional information on the installation of SPDs, refer to AS/NZS 3000:2018 Clause F.1.2.2.

4.6.3 Primary SPDs (LPZ0/LPZ1)

Primary protection SPDs shall be installed at the LPZ0 and LPZ1 boundaries to protect downstream equipment.

The following requirements shall apply to the installation of primary SPDs:

- (a) SPDs shall be rated in accordance with [Table 4.1](#).
- (b) SPDs shall be installed at the Main Switch Board (MSB as defined in AS/NZS 3000).
- (c) SPDs shall be protected by an overcurrent device in accordance with [Clause 4.6.2](#).
- (d) SPDs shall be installed at any distribution board where cabling leaves the structure and is exposed to induced or direct effects of lightning.
- (e) Where there is an LPS installed, the SPD earth shall be bonded to the LPS earth termination network.
- (f) Some SPDs, typically combined types or two-port devices containing a series coordinating impedance, provide both primary and secondary protection. These shall be installed as per the rules for primary protection.
- (g) Primary SPDs shall be installed between each phase conductor and neutral in accordance with [Appendix F](#).
- (h) The U_p of the SPD shall be less than that which will damage the equipment.

NOTE Guidance is provided in [Appendix H](#).

4.6.4 Secondary SPDs (LPZ1/2...n)

Secondary protection SPDs are located downstream of primary protection SPDs at the LPZ1 and LPZ2 boundaries and, similarly, those boundaries subsequent, to protect downstream equipment. Secondary SPDs shall be installed as follows:

- (a) SPDs shall be rated in accordance with [Table 4.1](#).
NOTE 1 [Table 4.1](#) sets out surge ratings for different zone boundaries.
- (b) SPDs shall be installed at the Distribution Board (DB as defined in AS/NZS 3000) or at the equipment to be protected.
- (c) SPDs shall be protected by an overcurrent device in accordance with [Clause 4.6.2](#).

- (d) SPDs shall be installed between each phase conductor and neutral. Additionally, an SPD (preferably comprising a voltage switching component) shall be installed between neutral and DB earth. This installation shall be in accordance with [Appendix F](#).

NOTE 2 The installation between neutral and DB earth provides both common and differential mode protection as required at sub-boards and for other wiring systems.

- (e) U_p of the SPD shall be less than that which will damage the equipment.

NOTE 3 For guidance on voltage protection level (U_p), see [Appendix H](#).

Table 4.1 — Surge ratings for a.c. power system SPDs per phase — MEN (TN-C-S) systems and other TN, TT and IT systems

Zone boundary	Location category ^a	SPD location	$I_{\max}$ rating, 8/20 μ s, kA	I_n rating, 8/20 μ s, kA	I_{imp} rating, 10/350 μ s, kA
LPZ2/...n	A	Long final subcircuits and supply outlets	3 to 10	2 to 5	—
LPZ1/2	B	Major submains, short final subcircuits and load centres	40	20	—
LPZ0 _B /1	C1	Domestic service entrance or external services shielded from direct lightning strike	40	20	5
LPZ0 _A /1	C2	Industrial or commercial service entrance, building fed by long overhead or underground conductive services	100	40	10
LPZ0 _A /1 ^b	C3	Service entrance, building in a high lightning area (N_g greater than 2), or fitted with an LPS	100	40	10

Not all SPDs specify their $I_{\max}$, I_n and I_{imp} ratings. An SPD conforming to any one of these ratings shall be deemed to conform.

^a The term location category has been defined in previous editions of AS/NZS 1768. It is shown here for the purposes of clarity.

^b In high lightning areas (e.g. in tropical regions, at mountaintop telecommunication and broadcasting sites with long overhead powerlines), it may be prudent to consider higher surge ratings for the primary SPD to provide a longer service life.

4.7 Signal/data line SPD requirements

Like power SPDs, signal SPDs are installed at LPZ boundaries to protect downstream equipment. When installing signal SPDs, the following requirements shall apply:

- (a) SPDs shall be rated in accordance with [Table 4.2](#).
- (b) SPDs shall be installed at the first point of termination of the line or as close as practicable to the equipment to be protected.
- (c) Where SPDs are earthed to a dedicated signal earth, this signal earth shall be bonded to site earths as per [Clause 3.5.2\(a\)](#).

NOTE For details installation and configuration requirements for SPDs, see [Appendix F](#).

Table 4.2 — Surge ratings for signal/data line SPDs^a

Zone boundary	Location category	SPD location	I_{TOT} rating, 8/20 μ s, kA	I_{imp} rating, 10/350 μ s, kA
LPZ1/...n	A, B	Internal marshalling cubicle or equipment cabinet	1 to 5	—
LPZ0 _B /1	C1	External signal cables shielded from direct lightning strike	5 to 10	0.5 to 1
LPZ0 _A /1	C2	Point of entry, long overhead or underground signal cables	10 to 20	1 to 2.5
LPZ0 _A /1	C3	Point of entry signal cables, building in a high lightning area (N_g greater than 2), or fitted with an LPS	10 to 20	1 to 2.5
Not all SPDs specify their I_{TOT} and I_{imp} ratings. An SPD conforming to either of these ratings shall be deemed to conform.				
^a Most signal lines are paired cables and the primary protection is frequently provided by gas discharge tubes. The I_{TOT} and I_{imp} ratings here relate to the rating from both lines to earth, referred to as X1/Y1 – C.				

Section 5 Testing and maintenance

5.1 General

A lightning protection system designed and installed in accordance with this document should require little or no maintenance over the life of the structure it is protecting. However, it is important to inspect and verify the LPS on a regular basis to ensure continued effectiveness.

5.2 Testing

Testing of the LPS shall be carried out during the construction of a structure (when utilizing natural components) or upon installation of a system of dedicated components. Testing shall also be carried out over the service life of the LPS to ensure that electrical continuity of components is maintained.

Where the LPS components cannot be inspected following the completion of the structure, records and installation photographs shall show the installation method and connection integrity. This requirement applies to conductors and connections enclosed within concrete, footings used as earth electrodes, or natural components used as air terminations.

Electrical continuity of air termination system, downconductors, base and ring conductors, and bonding conductors shall be demonstrated.

Surge protection devices should also be inspected.

Testing should be as follows:

- (a) Testing of electrical continuity should be carried out during construction if any conductor or joint will not be readily accessible after construction is completed.
- (b) Resistance of the earth termination network should be less than 10 Ω . Non-interconnected earth electrodes should be less than 10 Ω [see Item (c)].
- (c) Individual earth electrodes within the earth termination network may be greater than 10 Ω .

Where uncertainty exists about the validity of test results, comparison with original design figures and data, together with historical test records, will often serve to indicate the extent of deterioration of the earth electrodes. Test methods should be reviewed, and tests repeated if a significant variation is observed in resistance figures.

Testing of the LPS should be undertaken at intervals of not more than two years throughout its service life.

5.3 Records

The following records should be kept and be accessible on site:

- (a) Drawings showing the measurements and details of the LPS.
- (b) Visual inspections conducted and observations made.
- (c) Number of strikes logged on any recording equipment.
If the recording equipment is battery operated, a record of the service life of the battery should also be included.
- (d) Test conditions, date and results, including earth resistance, electrical continuity results, soil conditions and any special earth arrangements.
- (e) Photographs of components, particularly natural components that are not able to be inspected following the completion of the structure.

- (f) Alterations, additions or repairs to the LPS.
- (g) Condition indicator readings of SPDs.
- (h) Name and contact details of the installer.

5.4 Maintenance

5.4.1 General

The physical and electrical characteristics of the LPS shall be maintained to ensure conformity with the requirements of this document.

NOTE Periodic inspections and tests, as detailed within this section, will identify the need for any maintenance, repairs or modifications to the LPS.

5.4.2 Maintenance program

The maintenance program should include the following:

- (a) Inspection of all LPS components, with particular attention given to any evidence of corrosion, either of the system components or the structure upon which the LPS is mounted.
- (b) Checking of all accessible connections.
- (c) Inspection of any strike counters, including recording the number of strikes.
Batteries should be replaced in battery-operated strike counters if the expected remaining service life is less than the date of the next scheduled maintenance visit.
- (d) Measurement of the earth termination system resistance and, where accessible, measurement of the resistance of individual earth electrodes.
- (e) Inspection of SPDs, including recording their status indication information, if possible. The condition of any upstream over current protective devices for the SPD should be assessed.

5.4.3 Alterations or extensions to the structure

As alterations or extensions to the structure may have an impact upon the original LPS design, the effectiveness of the LPS should be reassessed in accordance with this document.

NOTE Examples of such alterations or extensions include —

- (a) changes in the use of a building;
- (b) installation of photovoltaic panels;
- (c) installation of communication antennas; and
- (d) changes to the electrical, telecommunications or computing facilities within the structure.

5.4.4 Inspection

Inspections should be carried out on the LPS at intervals of not more than two years. However, depending on location, more frequent inspections may be required.

NOTE 1 For example, where the system is located in a marine environment and a high rate of corrosion is expected, more frequent inspections may be required.

The LPS should be inspected after alterations to —

- (a) the LPS;
- (b) the structure; or
- (c) after a lightning strike.

The LPS should be visually examined for —

- (i) physical and electrical integrity;
- (ii) corrosion or mechanical damage to the LPS or supporting structures;
- (iii) security of components;
- (iv) burning or pitting of the air termination network;
- (v) condition of accessible joints or connections;
- (vi) condition of SPDs; and
- (vii) condition of strike counters.

NOTE 2 Particular attention should be paid to structures with building maintenance units (BMU), as damage to the air terminal network is prevalent.

5.4.5 Remedial action

All identified defects shall be recorded and rectified.

Problems identified during the inspection or maintenance process may require the LPS design to be reviewed.

Section 6 Personal safety

6.1 General

This section provides direction for personal safety during thunderstorms. Measures for the protection of people located within structures are outlined in [Section 3](#).

NOTE For guidance on the protection of people located within outdoor shelters during a thunderstorm, see [Appendix I](#).

6.2 Need for personal protection

Each year, many people are injured or killed by lightning, particularly when outdoors in open spaces such as a golf course or out on a large body of water. Up to 10 people are killed by lightning in Australia each year. This is equivalent to a probability of death of about 5×10^{-7} per year. However, up to 100 people are seriously injured by lightning in Australia each year. This is equivalent to a probability of serious injury of about 5×10^{-6} per year.

The severity of injuries inflicted on a person by a lightning strike depends upon the proportion of the strike current that flows over the skin and through the body (including its specific path). The worst situation arises when a person is struck directly, typically on the head, in which case the current through the body could cause fatal injuries to the brain, heart and the lungs. A less dangerous situation is where the person is subjected to indirect effects in which only a fraction of the total current passes through the body, although the specific pathway taken by this fraction is still important for determining the severity of injuries.

Significant differences exist with regard to personal protection in outdoor or indoor scenarios. In built-up areas, protection from direct strikes is frequently provided by nearby buildings, electricity supply service lines or public lighting poles. Furthermore, people located within a substantial structure are normally protected from direct strikes but may be exposed to a hazard from conductive services entering the structure or from conductive objects within the structure that may attain different potentials.

In some workplaces, employees who work within larger buildings may be unaware of the external weather conditions and therefore there is a risk if using a fixed communication system. When a thunderstorm is in the vicinity, people indoors should avoid using electrical and electronic equipment that is powered from the mains power supply and also having contact with metallic services.

6.3 Lightning injury mechanisms

6.3.1 General

There are many mechanisms by which lightning can cause injuries and deaths. These mechanisms may be broadly categorized as electrical and non-electrical. While electrical injury mechanisms can result in death, non-electrical injury mechanisms rarely result in death but do constitute a significant percentage of permanent injuries.

6.3.2 Electrical injury and death mechanisms

The four main electrical injury mechanisms by which lightning may cause serious human injuries and deaths are —

- (a) direct strike to the person;
- (b) side flash from an adjacent structure (e.g. while sheltering beneath or near an unearthed or improperly-earthed structure);
- (c) touching a conductor that has risen to a dangerous voltage (known as touch voltage); and

- (d) step voltage, which arises from an indirect cloud-to-ground strike that causes a large voltage in the soil or, in some cases, surface arcing along the ground which can create a voltage difference across the human body.

The effects of these electrical injury mechanisms include —

- (i) burns to the skin;
- (ii) damage to various bodily organs and systems;
- (iii) unconsciousness; and
- (iv) death.

Measures to reduce, and in some cases mitigate, exposure to electrical injury mechanisms include the following:

- (A) Avoiding being outdoors during a thunderstorm.
- (B) Creating sufficient air clearance (separation) from conductors carrying lightning currents.
- (C) Avoiding touching of conductors carrying lightning currents.
- (D) Managing earth potential rise effects, either by insulation or via voltage equalization (the latter is achieved for example through the use of meshes, grading rings and/or bonding).

6.3.3 Non-electrical injury mechanisms

The three main non-electrical mechanisms that can cause serious human injuries are —

- (a) acoustic pressure wave(s) from nearby thunder;
- (b) radiation from the lightning channel; and
- (c) flying or falling debris from trees, buildings or structures struck by lightning.

The sound level experienced by a human ear membrane at the time of a lightning strike is dependent upon the proximity of the strike. Some estimates put this value at around 170 dB, which is greater than the human pain threshold. Acoustic pressure wave(s) are known to affect 50 % or more of people involved in a close lightning incident. Acoustic injuries include ruptured ear membranes, tinnitus and other temporary and permanent hearing impairments. Consequently, this mechanism is a very important consideration when people are in an open-air environment, even if sheltering under a structure.

The other major hazard due to lightning is eye damage. A lightning strike has intense light as well as infrared and ultraviolet radiation which may temporarily blind a person or seriously damage vision.

Measures to reduce the risk of non-electrical injuries include the use of PPE. For mitigation of these injuries, people should remain indoors during thunderstorms and follow the guidance provided in [Clause 6.4](#).

6.4 Personal conduct

6.4.1 General

The threat to personal safety is greatest if a person is outdoors when the thunderstorm is within 15 km. In the absence of specific information from weather radar, lightning location system or a specialized lightning warning device (see [Clause 6.5](#)), and where lightning can be seen or thunder heard, immediate shelter should be sought indoors.

A receding local thunderstorm is not considered to pose a threat to personal safety when more than 30 minutes has elapsed after the last thunder is heard.

6.4.2 Outdoors

When planning and undertaking outdoor activities, particularly those involving groups and large numbers of people, the following checks should be made:

- (a) Check weather reports for likely thunderstorms.
- (b) Monitor the surroundings for indications of the onset of thunderstorms.

If thunderstorms occur, measures for reducing the risk of injury or death include the following:

- (i) Seek shelter in a substantial building.
- (ii) In exposed locations, a metal-bodied vehicle can offer some protection. In these situations, close all windows, avoid contact with metallic parts and avoid operation of the vehicle as a strike to the vehicle may cause a damage to the tyres.
- (iii) Do not stay in open vehicles such as tractors, beach buggies, or any other type of open or enclosed vehicle without a metallic roof.
- (iv) Do not ride or sit on horses, bicycles or motorcycles, or otherwise elevate the body above the local surroundings.
- (v) Do not shelter under trees, particularly an isolated tree. If surrounded by trees, seek a position outside the foliage and crouch, keeping the feet together.
- (vi) Do not shelter in small sheds, pagodas, walkways, or similar, with low unearthed metallic roofs supported on wooden or other electrically insulating materials. Fabric tents do not provide protection.
- (vii) Do not touch or stand close to any metallic structures, including wire fences and clothes lines. Do not stand on or under bridges or other elevated structures. Do not carry metallic objects such as umbrellas or golf clubs and remove metallic chains and other jewellery, particularly from the head and upper parts of the body.
- (viii) If in an open field or on the beach and remote from any shelters, keep a low and small profile (i.e. crouch with feet together and do not touch any objects or people near you). A dry ditch, valley or any depression in the ground is safer than elevated or flat terrain. Do not lie on the ground as this could cause dangerous voltage to develop across the body by earth currents generated by a nearby strike. Footwear, or a layer of non-absorbing, insulating material, such as plastic sheets, can offer some protection against earth voltages.
- (ix) Do not swim or wade in the sea, lake, river, pool or any other body of water. Exit the water and move to a safe place.
- (x) If on a boat deck, keep a low profile and avoid contact with or being close to masts, rails, stay wires or any other metallic objects. Avoid unnecessary contacts with communication or navigation equipment. Do not enter the water, and in general avoid contact with water. Additional protection may be gained by anchoring under relatively high objects such as jetties and bridges, provided that direct contact is not made with them. Isolated buoys and pylons should be avoided.

6.4.3 Swimming pools

Locations containing bodies of water are extremely hazardous during thunderstorms and should be avoided if at all possible. Statistics show that more than 10 % of lightning-related injuries and deaths are water related (e.g. fishing, boating and swimming). Indoor and outdoor pools should be treated with the same regard to lightning dangers.

The following swimming pool safety procedures should be applied:

- (a) A person should be designated as the pool's weather safety lookout. The designated person should keep an eye on the weather and throughout their shift regularly check localized, advanced weather information on specialist websites.
- (b) Identify in advance places that are typically safe and unsafe, such as the following:
 - (i) Safe places are dry areas inside large permanent buildings.
 - (ii) Unsafe places are those near electrical conductors, electrical equipment, metal objects (e.g. lifeguard stands, ladders, diving board stanchions) and water, including showers.
- (c) When thunder and/or lightning are first observed, use the 30/30 rule described in [Clause 6.4.1](#). The pool should be evacuated immediately, and people directed to a safe shelter.

6.4.4 Indoors

Measures for reducing the risk of injury include the following:

- (a) Avoid the use of fixed line telephones. If unavoidable, keep the phone call brief and try not to touch electrical appliances, personal computers, metal pipes, stoves, sinks, and any other metallic objects at the same time. Mobile and cordless telephones are safe to use indoors. Where headsets are used for a large percentage of the time, or where operators may be unaware of local lightning storms, the risk of injury from lightning may be dramatically reduced by the use of wireless headsets.
- (b) Do not take a bath or a shower and do not wash hands or dishes.
- (c) Do not use personal computers and other electronic and electrical equipment, and avoid contact with sinks, stoves, refrigerators, metallic pipes and other large metallic objects in the house.
- (d) Where surge protection is not installed, disconnect (unplug) electronic and electrical appliances from antennas, conductive telecommunication connections and electricity supply outlets to ensure physical separation from surges and to avoid damage to appliances.

NOTE 1 Switching off an appliance does not provide full separation as it does not disconnect (unplug) both neutral and earth wiring.

NOTE 2 Switching off the electricity supply at the switchboard may also reduce the chances of damage to the electrical wiring and to permanently wired electrical appliances.

6.5 Lightning detectors and lightning warning systems

Specially designed lightning detectors may provide warning of approaching electrical storms so that precautions may be taken. None of these systems are 100 % reliable. In particular, portable hand-held detectors are the least reliable.

Lightning detectors are typically electronic devices which measure the unique radio frequency burst associated with lightning and may display an accurate source distance. Such devices provide a warning that thunderstorm conditions are local and that conditions are unsafe. These devices alert after the fact and cannot predict a first flash or measure the conditions that may lead to lightning flashes.

Lightning warning systems monitor the measurable conditions that lead up to the onset of lightning, like the ambient electric field, and are therefore predictive systems.

IEC 62793 provides comprehensive guidance on the types and uses of lightning detectors and lightning warning systems. The following four distinct phases may be identified during the thunderstorm life cycle regarding detectable phenomena:

- (a) Initial phase.
- (b) Growth phase.
- (c) Mature phase.
- (d) Dissipation phase.

For the classification of detectors and warnings systems, the following classes are defined:

- (i) *Class A* — Monitor a thunderstorm over its entire lifecycle (Phases a to d).
- (ii) *Class B* — Detect inter-cloud and cloud-to-ground flashes (Phases b to d).
- (iii) *Class C* — Detect cloud-to-ground flashes only (Phases c and d).
- (iv) *Class D* — Detect cloud-to-ground flashes (Phase c) and other electromagnetic sources with very limited efficiency.

NOTE For further details regarding the application of lightning detectors and lightning warning systems, refer to IEC 62793. In general, these systems may prevent or reduce injuries and loss of life by detecting approaching electrical storms, providing advanced warning which enables temporary precautionary measures to be taken. Such systems are not intended to replace a lightning and surge protection system as outlined in this document. Rather, they may be used to further reduce the overall risk.

Appendix A **(informative)**

The nature of lightning

A.1 Scope

This appendix describes the main characteristics and effects of lightning that relate directly to lightning protection.

A.2 Lightning

A.2.1 General

A lightning flash consists of a complex sequence of processes lasting up to 1 s or more. Lightning discharges may occur between or within thunderclouds (cloud-cloud and intra-cloud flashes), or from the thundercloud to the ground (cloud-to-ground flashes). A cloud-to-ground flash consists of a sequence of one or more high-amplitude, short-duration current impulses, or strokes. Almost half of all cloud-to-ground flashes have more than one ground termination, typically two, separated by distances of up to about 10 km. The term lightning strike is used, colloquially, to describe a cloud-to-ground flash.

A.2.2 Lightning initiation

A lightning flash is generally initiated through electric fields formed in thunderclouds due to the separation of oppositely charged regions of the cloud. Such regions form due to airflow or updrafts within the cloud. Initiation of lightning generally occurs at altitudes colder than freezing, where there is a mixture of hail particles, super-cooled water droplets and various forms of ice crystals, generally in the presence of an updraft, causing particle and charge separation. In the presence of electric fields greater than 2.5 MV/m at atmospheric pressure, electron energies are so large that ionization processes are larger than attachment processes. An avalanche of electrons and positive ions are produced, initiating the lightning discharge. Such high electric fields form initially at points and corners of ice crystals.

It is usual for lower regions of the thundercloud to have net negative charge and upper regions of the thundercloud to be positively charged. Generally, cloud-to-ground discharges carry negative charge to the ground, but in some cases the charge transfer may be positive.

A.2.3 Lightning leaders

A.2.3.1 Downward from the cloud

The initial downward discharges from the cloud, if negative, are called stepped leaders, because they proceed in a sequence of steps. High-speed photography and video footage reveal that each step is generally up to about 50 m in length. These steps, formed within approximately a microsecond, are only faintly luminous and cannot be seen by the naked eye. The pause time between steps is of the order of 50 μ s, and there may be branching, with two steps in different directions being formed at the same time. Generally, only the leading step is luminous, luminosity being extinguished in the pause time between steps. Approximately 95 % of lightning strikes are negative and 5 % are positive, the latter originating from a positively charged region of a cloud.

A.2.3.2 Upward from the ground

When any stepped leader is within the striking distance of a ground object (typically tens to hundreds of metres depending on the height of the prospective strike point), the electric field from the leader induces the formation of upward leaders from structures on the ground.

These leaders commence as corona discharges, progress to corona streamers and finally one streamer channel becomes fully ionized and forms an upward leader channel. These upward leaders propagate toward the downward leaders and, at some point, one upward leader will intercept a downward leader. Upon joining, an electrical connection is completed between the thundercloud and the ground.

The overall aim of lightning protection is to position air terminals in such locations that an upward leader from an air terminal, rather than competing with upward leaders from the protected structure, will intercept the downward leader from the cloud.

A.2.4 Return stroke

Upon connection of the two leaders, the return stroke is produced. The return stroke constitutes an electric arc, which produces an intense flash of light, a current between of about 4 kA and 300 kA, significant heating of the air around the channel to the order of 20 000 K to 30 000 K, and gas expansion of the arc region, which produces a shock wave heard as thunder. If the termination point of the electric arc is a conductive object such as an effectively earthed air terminal, the current may be carried to the ground with little or no damage. However, if the termination point is a tree or a masonry section of a building, the large current may heat the moisture within the object to produce super-heated steam and significant damage. Trees are commonly split and destroyed in this manner, and the building masonry is often cracked, dislodged or detached.

A.2.5 Successive dart leaders and return strokes

If sufficient charge remains in the cloud after the first return stroke, there may be subsequent strokes. These subsequent strokes are also preceded by a leader, in this case called a dart leader. A complete cloud-to-ground flash consists of a sequence of one or more of these high-amplitude current impulses, each current pulse being separated by an average time of 50 ms. The whole process generally lasts less than 1 s. The wave shape and magnitude of these pulses are not affected by the characteristics or impedance of the ground termination.

A.2.6 Lightning characteristics and parameters

[Table A.1](#) shows the statistical distribution of the main parameters of lightning.