Lightning protection systems typically follow two approaches:

Non-isolated system – where potentially damaging voltage differentials are limited by bonding the lightning protection system to the structure

Isolated system – where the lightning protection system is isolated from the structure by a specified separation distance. This distance should be sufficient that energy is contained on the LPS and does not spark to the structure. Isolated systems are well suited to structures with combustible materials such as thatched roofs, or telecommunication sites that want to avoid lightning currents being conducted on masts and antenna bodies

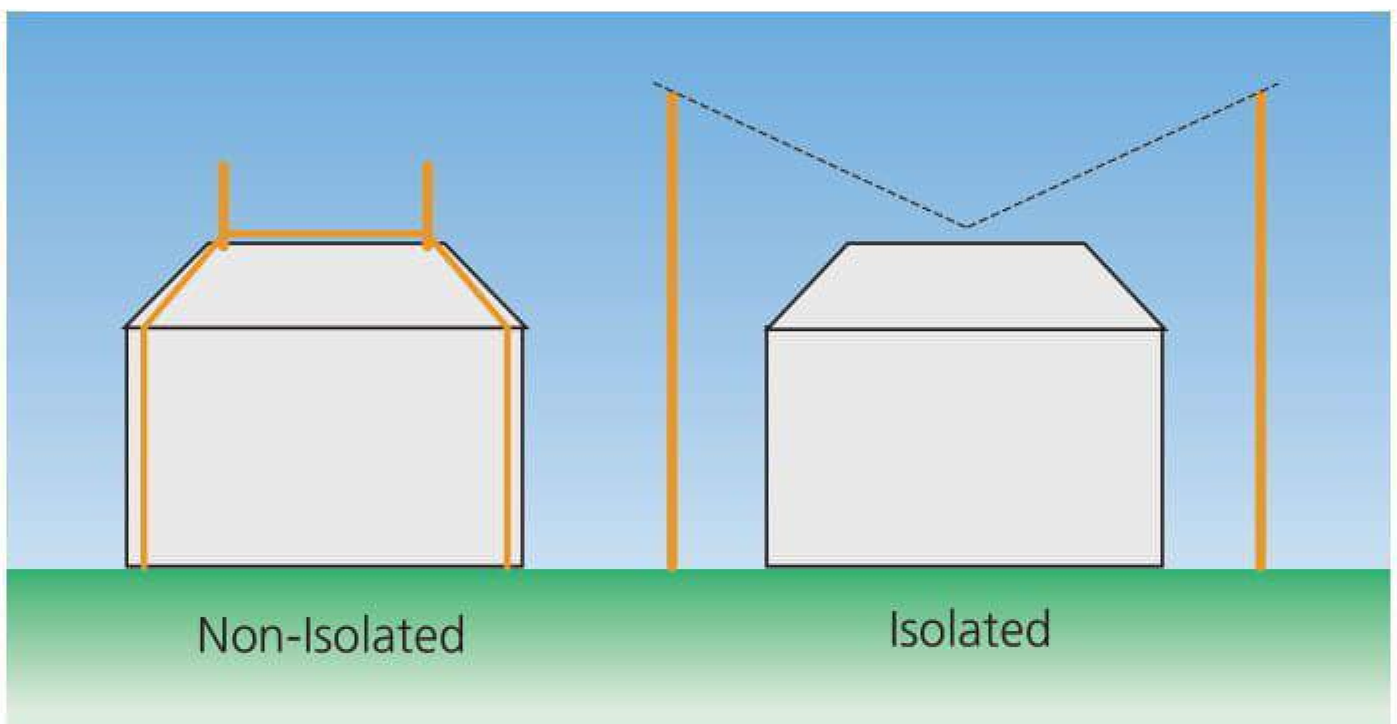

Figure 9. *Non-isolated protection concepts.*

The standard provides simple geometric forms of design which are comprised of cost, effectiveness and simplicity in design. The design methods are:

- Mesh method
- Rolling sphere method (RSM)
- Protection angle method (PAM)

These methods (described in ***Section 9***) are used to determine the optimum location of the air-terminations and the resulting down-conductor and earthing requirements.

A risk assessment is generally undertaken to determine the level of risk for a specific structure, in order to make a comparison with a pre-determined value of "acceptable risk". Protection measures, at an appropriate lightning protection level (LPL), are then implemented to reduce the risk to or below the acceptable risk. The lightning protection level determines the spacing of the mesh, radius of rolling sphere, protective angle, etc.

It should be noted that while lightning protection is typically implemented as a bonded network of air-terminals and down-conductors, other methods are permitted:

- To limit touch and step potential risks:
  - o Insulation of exposed conductive parts
  - o Physical restriction and warning signs
- To limit physical damage:
  - o Fire proofing, fire extinguishing systems, protected escape routes

3.1. Risks

To understand why typical conventional lightning protection systems require rigorous equipotential bonding and earthing, it is important to understand how the risk of injury due to step/touch potentials and side flashing occur.

3.1.1. Step potential

When lightning current is injected into the earth, a large voltage gradient builds up around the earth electrode with respect to a more distant point. The earth can be imagined as a sequence of overlapping hemispheres. The greater the distance from the electrode, the larger the surface area of the hemisphere and the more parallel paths through the soil. Thus the voltage rise is greatest near the electrode where current density is highest.

The normal step distance of a person is near to 1 meter. At the time of discharge being close to the earth electrode means the voltage differential across this distance can be large enough to be lethal – depending upon circumstances such as condition of footwear, etc, substantial current can flow through one lower leg to the other.

In the case of animals, a larger risk exists. The distance between the front and rear legs of larger animals can be in the order of 2 meters, and the current path flows through the more sensitive region of the heart.

The hazard is considered to be reduced to tolerable level if:

- The probability of persons approaching, or duration of presence within 3 m of the down-conductor is very low – limiting access to the area can be a solution
- Step potential is reduced by use of ≥ 5 k ohm.m insulating barrier such as 50 mm of asphalt or 150 mm of gravel within 3 m of the electrode
- An equipotential earthing system such as mesh system is correctly used

It is also good practice for the upper section of the conductor entering into the earth to be insulated. Heat shrink (2 mm polyethylene) or 4 mm thick PVC protecting the first 2-3 m of conductor/electrode is sufficient to reduce step potential hazards. Where a conductor is insulated and buried, any insulated portion should **not** be considered as contributing to the earthing requirements of ***Section 12***.

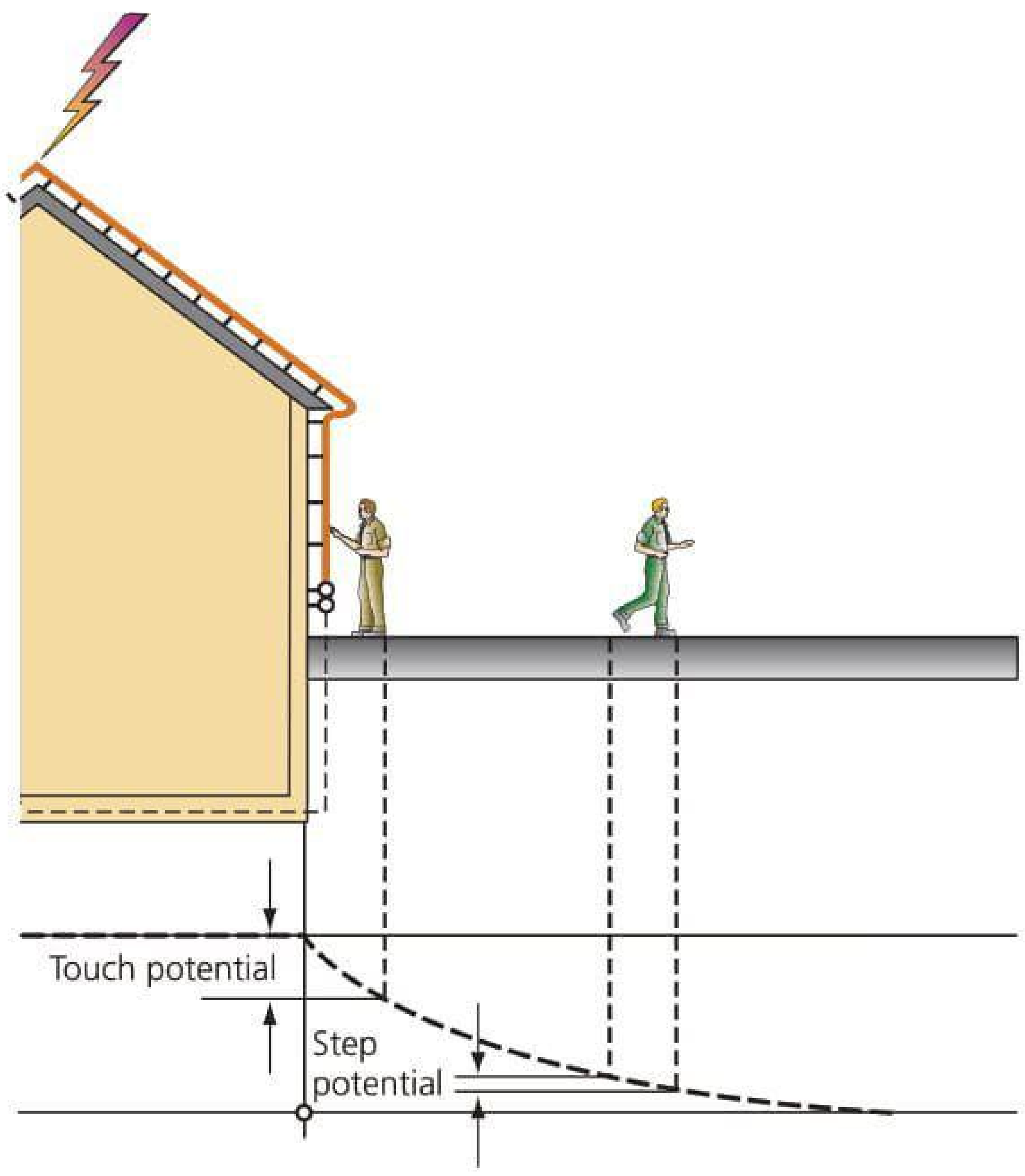

Figure 10. *Step and touch voltage gradients.*

3.1.2. Touch potential

Touch potential is due to a similar reason as step potential, but the voltage differential being considered is that which exists between the hand and (generally) feet. The risk of electrocution due to touch potential is greater than for step potential, as the passage of current flows close to the heart region.

The hazard is considered to be reduced to tolerable level if:

- The probability of persons approaching, or duration of presence is very low – limiting access to the area can be a solution
- Natural down-conductors are used where extensive metal framework or steel work is interconnected
- A surface layer with ≥ 5 k ohm.m insulating barrier such as 50 mm of asphalt or 150 mm of gravel is used
- The down-conductor is insulated with at least 100 kV 1.2/50 μs impulse insulation (3 mm PVC)

3.1.3. Side flashing

All down-conductors have a resistance and, more importantly, inductance. During the lightning flash the rapid rate of current rise can cause the inductive voltage rise of the conductor to reach a magnitude where sufficient voltage exists for the conductor to flashover to a nearby conductive and earthed object.

Side flashing can be controlled by:

- Using a number of parallel down-conductors to reduce the current in each
- Ensuring the separation distance between the two objects is sufficient not to break down the intervening medium; or
- Bonding to the object to eliminate the potential difference (the object may carry a partial lightning current)

The down-conductor and bonding requirements of the standard address these issues.

4. Risk management

IEC 62305-2 provides a lightning risk management procedure that provides a tolerable limit of risk, methods to calculate the actual risk, and then evaluates the protection methods required to reduce the actual risk to be equal or lower than the tolerable risk. The main outcome from this risk assessment is to determine if lightning protection is required and if so, to select the appropriate lightning class. The lightning class determines the minimum lightning protection level (LPL) that is used within the lightning protection design.

Lightning protection can be installed even when the risk management process may indicate that it is not required. A greater level of protection than that required may also be selected.

It should be noted that the IEC 62305-2 document is over 100 pages in length and is extremely comprehensive and complex. A full manual analysis of all risks can take tens of hours to complete. Therefore for most situations a reduced analysis is conducted, preferably with an electronic tool. For this purpose, the IEC standard comes with software, and additional third-party software is also available.

For complex or high risk structures/situations, a more detailed analysis should be considered using the full standard. This would include, but is not limited to:

- Locations with hazardous or explosive materials
- Hospitals or other structures where failure of internal systems may cause a life hazard

Note that with the national implementation of the BS EN 62305-2 Risk Management standard some minor adjustments to the procedures and values has occurred to better reflect the localized conditions and acceptable local tolerable risk. Use the national standard appropriate to the country of installation, or select a national standard where that country experiences similar lightning risk (ground flash density/ thunderdays) and similar social/economic values.

4.1. Overview of risk analysis

It is beyond the scope of this document to describe the full risk management requirements. Conceptually the risk analysis follows the general process of:

1. Identifying the structure to be protected and its environment
2. Evaluating each loss type and associated risk (R_1 to R_3)
3. Comparing R_1 to R_3 to the appropriate tolerable risk R_T to determine if protection is needed
4. Evaluating protection options so R_1 to $R_3 \leq R_T$

Note that separate R_T figures exist for risk of losses R_1 to R_3. Lightning protection is required such that R_1, R_2 & R_3 are all equal or lower than the respective tolerable risk (R_T).

Lightning protection may also be justified upon the economic risk R_4 and the respective economic benefit. A separate procedure in IEC 62305-2 is followed for this analysis.

Each of the following risks are broken down into individual risk components (sub categories), which are then evaluated with regard to direct and indirect lightning effects upon the structure and on the services. This requires the computation of the number of dangerous events, which is related to the structure size and lightning flash density.

The simplified analysis software considers:

- Structure's dimensions
- Structure's attributes
- Environmental influences
- Effect of services entering facility
- Existing protection measures

The simplified software is IEC 62305-2 compliant, but is conservative in nature. That is, worst case or conservative values are assumed. In situations where multiple identical structures are to be constructed, it may be appropriate to conduct a full risk analysis in case a small economic saving can be obtained and applied across the many structures.

Loss	Risk to Structure	Risk to Services
L1 – loss of human life	R_1 – Risk of loss of human life	
L2 – loss of essential services	R_2– Risk of loss of essential services	R'_2– Risk of loss of essential services
L3 – loss of cultural heritage	R_3– Risk of loss of cultural heritage	
L4 – economic loss	R_4– Risk of economic loss	R'_4– Risk of economic loss

Table 6. *Risk assessment losses.*

4.1.1. Sources of damage, type of damage, type of loss and risk of loss

For those interested in a better understanding of the risk management process, or a desire to manually calculate a structure's risk, the remaining sections of this chapter provide an introduction to the topic. It should be helpful in understanding the effect of selection of parameters in risk assessment tools based on IEC 62305-1/2, and if a manual assessment is to be undertaken, help introduce the concepts of the standards which should be followed.

It is important to understand the sources of damage, types of damage and types of losses as the procedure to assess the risk evaluates various combinations considering structure, contents, services and environment with the source and type of damage.

IEC 62305-1 introduces the concepts of sources of damage (***Figure 11***) where:

- S1 – Lightning flash to the structure
- S2 – Lightning flash near the structure
- S3 – Lightning flash to the services
- S4 – Lightning flash near to the services

With the possible sources of damage due to lightning flash defined, three possible types of damage are identified:

- D1 – Injury of living beings (humans and animals) due to touch and step potential
- D2 – Physical damage (fire, explosion, mechanical destruction, chemical release)
- D3 – Failure of internal electrical/electronic systems due to lightning electromagnetic impulse

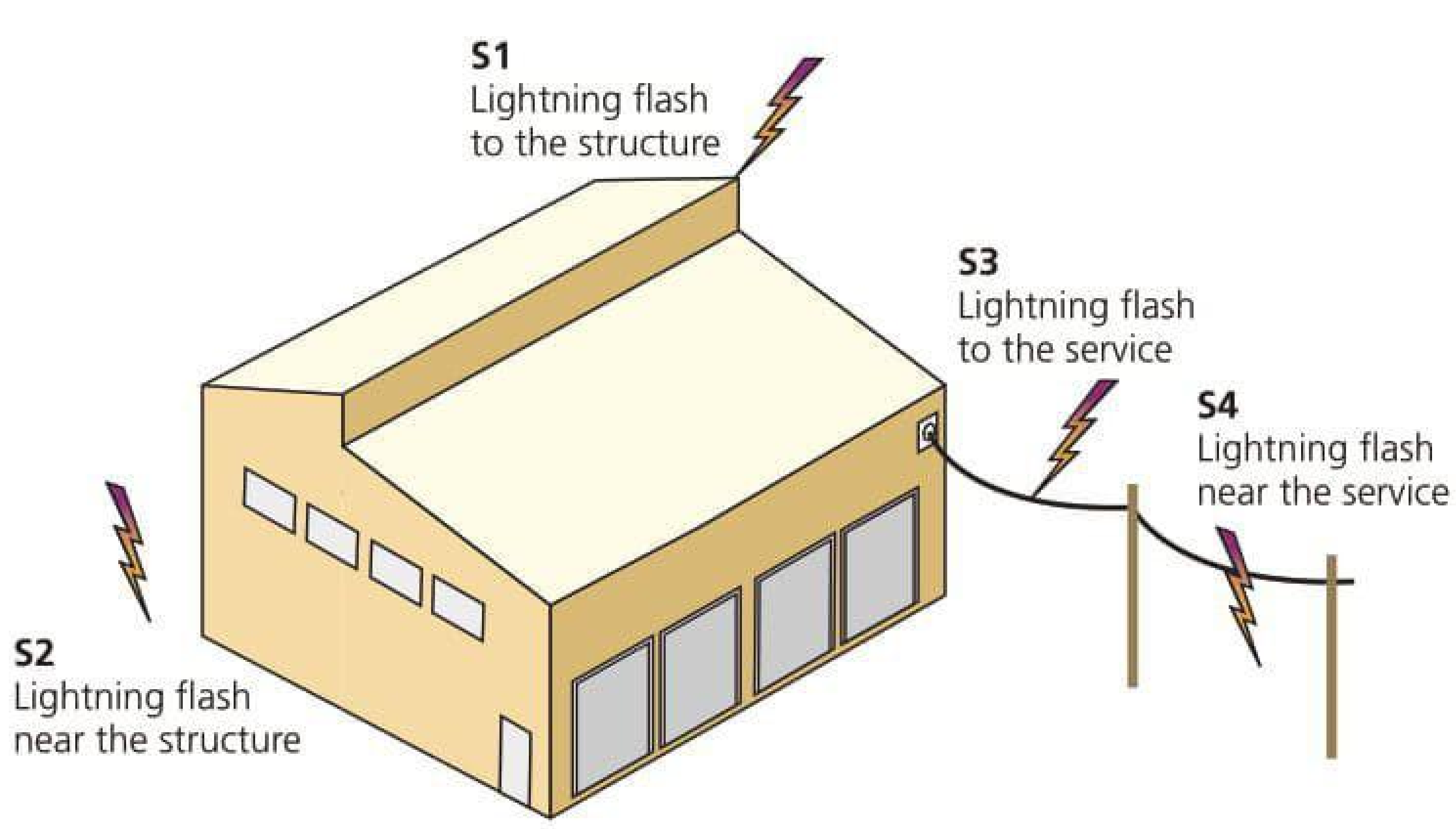

Figure 11. *Sources of damage*

With each type of damage, four types of losses are identified:

- L1 – Loss of human life
- L2 – Loss of essential service to the public
- L3 – Loss of cultural heritage
- L4 – Economic loss (structure and its contents, service and loss of activity)

Care is required with the term "services", as it is dependant upon its context within the standard. This may refer to the physical services connected to the building (water, power, gas, fuel or data/telecommunications), or services provided to the public (e.g. information services). The scope of services to the public includes any type of supplier who, due to lightning damage, can not provide their goods or "service" to the public. For example a supermarket closed due to damage to cash register/check-out systems, or an insurance company unable to transact business due to phone or website failure.

Table 7 summarizes the types of damage and types of loss for each of the four sources of damage [from IEC 62305-1 Table 3]. For each of the first three types of losses (L1, L2 & L3), the procedure of IEC 62305-2 evaluates the risk of these respective losses (R_1, R_2 & R_3) and compares them to tolerable levels. For Loss L4, the economic cost of the loss, with and without lightning protection, is compared to the cost of the protection measures.

Table 8 details the types of damages and losses associated with a service. As the loss and calculation of the risk of loss is different to that of the structure, the convention L'2 & L'4 are used to differentiate these losses.

4. Risk Management *(continued)*

Source of damage (Point of strike)	Type of damage	Type of loss
S1 Lightning flash to the structure	D1 - Injury	L1 – Loss of human life L4 – Economic loss (1)
	D2 – Physical damage	L1 – Loss of human life (2) L2 – Loss of service L3 – Loss of heritage L4 – Economic loss
	D3 – Failure of systems	L1 – Loss of human life (2) L2 – Loss of service L4 – Economic loss
S2 Lightning flash near the structure	D3 – Failure of systems	L1 – Loss of human life L2 – Loss of service L4 – Economic loss
S3 Lightning flash to the services	D1 - Injury	L1 – Loss of human life L4 – Economic loss (1)
	D2 – Physical damage	L1 – Loss of human life L2 – Loss of service L3 – Loss of heritage L4 – Economic loss
	D3 – Failure of systems	L1 – Loss of human life (2) L2 – Loss of service L4 – Economic loss
S4 Lightning flash near to the services	D3 – Failure of systems	L1 – Loss of human life (2) L2 – Loss of service L4 – Economic loss

Notes:
(1) Only for properties where animals may be lost
(2) Only for structures with risk of explosion and for hospitals or other structures where failure of services or internal systems endangers human life

Table 7. *Damages and losses in a structure for different sources.*

Source of damage (Point of strike)	Type of damage	Type of loss
S1 Lightning flash to the structure	D2 – Physical damage	L'2 – Loss of service L'4 – Economic loss
	D3 – Failure of systems	
S3 Lightning flash to the services	D2 – Physical damage	
	D3 – Failure of systems	
S4 Lightning flash near to the services	D3 – Failure of systems	

Table 8. *Damages and losses in a structure for different sources.*

4.1.2. Risk management procedure & tolerable risk

For each of the losses L1 to L3, the risk of each loss is determined ($R_{1\ to\ 3}$). The risk of each loss is then compared to a tolerable risk:

- If the calculated risk is equal or less than the respective tolerable risk (R_T), then lightning protection is not required
- If the calculated risk is higher than the tolerable risk then protection is required. Protective measures should be evaluated to reduce the calculated risk to be equal or less than the tolerable risk

The flow chart in ***Figure 12*** shows the general procedure, while ***Table 9*** provides the tolerable risks as provided by IEC and BS standards. The tolerable risk is expressed in the form of number of events per year and is given in engineering units (e.g. 10^{-x}). ***Table 9*** also expresses these in the format of x in y events (per year).

Types of loss	$R_T(y^{-1})$	
	IEC 62305-2	BS EN 62305-2
Loss of human life	10^{-5} (risk of 1 in 100,000)	10^{-5} (risk of 1 in 100,000)
Loss of service to the public	10^{-3} (risk of 1 in 1,000)	10^{-4} (risk of 1 in 10,000)
Loss of cultural heritage	10^{-3} (risk of 1 in 1,000)	10^{-4} (risk of 1 in 10,000)

Table 9. *Tolerable risk R_T.*

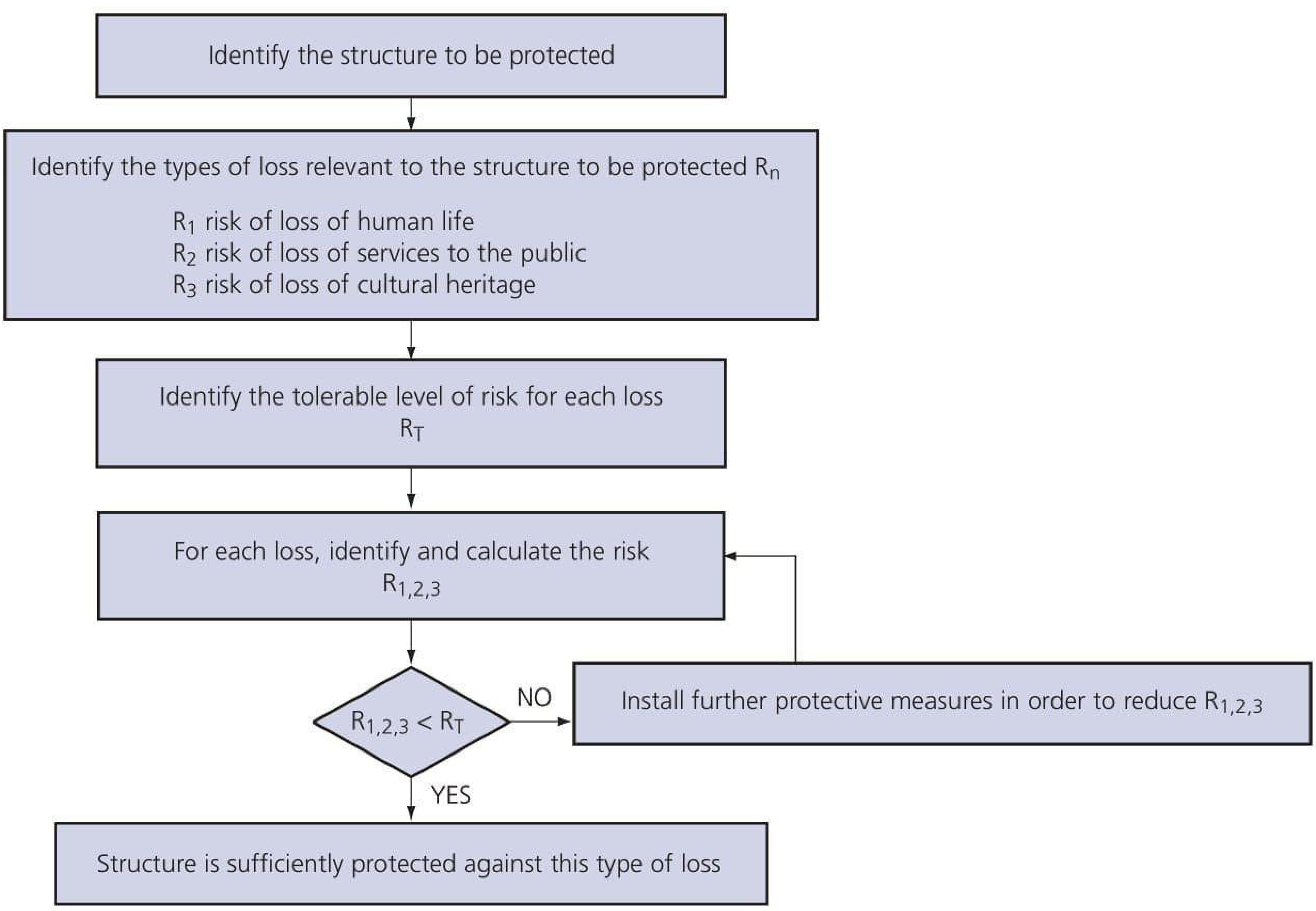

Figure 12. *Damages and loses in a structure for different sources.*

Risk Component	Source of damage	Type of damage	Formula
R_A	S1	D1	$R_A = N_D \times P_A \times L_A$
R_B	S1	D2	$R_B = N_D \times P_B \times L_B$
R_C	S1	D3	$R_C = N_D \times P_C \times L_C$
R_M	S2	D3	$R_M = N_M \times P_M \times L_M$
R_U	S3	D1	$R_U = (N_L + N_{DA}) \times P_U \times L_U$
R_V	S3	D2	$R_V = (N_L + N_{DA}) \times P_V \times L_V$
R_W	S3	D3	$R_W = (N_L + N_{DA}) \times P_W \times L_W$
R_Z	S4	D3	$R_Z = (N_1 + N_L) \times P_Z \times L_Z$

Table 10. *Risk assessment losses.*

4.1.3. Risk components

The risks $R_{1\text{ to }4}$ are calculated from the sum of the appropriate risk components:

Risk of loss of human life:

$$R_1 = R_A + R_B + R_C^{(1)} + R_M^{(1)} + R_U + R_V + R_W^{(1)} + R_Z^{(1)}$$

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

Risk of loss of services to the public:

$$R_2 = R_B + R_C + R_M + R_V + R_W + R_Z$$

Risk of loss of cultural heritage:

$$R_3 = R_B + R_V$$

Risk of loss of economic value:

$$R_4 = R_A^{(2)} + R_B + R_C + R_M + R_U^{(2)} + R_V + R_W + R_Z$$

(2) Only for structures where animals may be lost.

Each of the components is obtained using further calculations, sub-calculations and reference tables based on the general equation:

$$R_X = N_X \times P_X \times L_X$$

Where

$\mathbf{N_X}$ = number of dangerous events per year

$\mathbf{P_X}$ = probability of damage to structure

$\mathbf{L_X}$ = amount of loss

The number of dangerous events per year is primarily based upon the structure dimensions, length and type of service and the ground flash density. The physical dimensions of the structure and service are used to calculate the effective lightning capture area, and the ground flash density is used to determine the probable number of events per year. Several graphical and calculation methods are provided by the standard.

The probability of damage is obtained from the given tables in the standard, with some simple calculations being required.

The amount of loss is also obtained from the given tables in the standard with calculations being required.