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Application of environmental risk according to IEC 62305-2 Edition 2

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***Abstract*— The 2nd edition of the lightning risk assessment standard (IEC 62305-2) considers structures which may endanger the environment. In these cases, the loss is not limited to the structure itself; which is the case for ”usual” structures. In Edition 1 of the standard this danger was simply taken into account by multiplying the calculated risk for the structure by a special hazard factor. In Edition 2, the calculated risk for the structure itself is added to another risk associated with the losses outside of the structure. The losses outside can be treated independently from what occurs inside. This is a major advantage in the analysis of the risk for sensitive structures such as chemical plants, nuclear plants, or structures containing explosives, etc. Edition 3 of the standard is currently under preparation. It is important to better define what the environmental risk really is and how it can be calculated efficiently. A methodology proposed in previous publications has been adapted to real cases already studied with Edition 1 of IEC 62305-2 for comparison.**

***Keywords*— lightning, risk, environment, chemical, explosion, nuclear**

I. Introduction

Risk management for lightning protection is an essential tool to estimate the vulnerability of people and contents inside a structure against lightning threats and to ensure that the necessary and most effective protection measures are selected.

Since the publication of the IEC 62305 series of standards in 2006, a great number of risk management investigations were performed for structures according to the initial edition of Part 2 of the standard. In 2010 the 2nd edition of international standard IEC 62305-2 [1] was published.

This 2nd edition of the lightning risk management standard allows a more detailed analysis of those structures which may endanger their surroundings due to explosion or contamination of the environment. In these cases, the loss is not limited to the structure itself, which is the case for “usual” structures. In Edition 1 [6] this danger was simply taken into account by multiplying the calculated risk for the structure by a special hazard factor. Now, in Edition 2, the calculated risk for the structure itself is added to the risk due to the losses outside the structure. The losses outside can be the treated independently from what occurs inside. This is a major advantage in analyzing the lightning risk for sensitive structures, like chemical plants, nuclear plants, military structures containing explosives, etc.

II. Risk Method

The risk due to lightning is the sum of different risk components, differing in their source of damage (S1, S2, S3, S4) and type of damage (D1, D2, D3).

- S1: flashes to the structure;
- S2: flashes near the structure;
- S3: flashes to the lines connected to the structure;
- S4: flashes near the lines connected to the structure.

and:

- D1: injury to living beings by electric shock;
- D2: physical damage (fire, explosion, mechanical destruction, chemical release) due to lightning current effects, including sparking;
- D3: failure of internal systems due to LEMP.

From this, we get the eight risk components R_A, R_B, R_C, R_M, R_U, R_V, R_W and R_Z. Each of the risk components is expressed by the following general equation:

$$R_X = N_X \cdot P_X \cdot L_X \quad (1)$$

where:

N_X is the number of dangerous events per annum;

P_X is the probability of damage to a structure;

L_X is the consequent loss

The number N_X of dangerous events is affected by the lightning ground flash density (N_g), by the physical characteristics of the structure to be protected, its surroundings, the connected lines, and adjacent and connected buildings.

The probability of damage P_X is affected by the characteristics of the structure to be protected, the connected lines and the protection measures provided.

The consequent loss L_X is affected by the use to which the structure is assigned, the attendance of persons, the type of service provided to public, the value of goods affected by the damage and the measures provided to limit the amount of loss. If the damage to a structure due to lightning also effects surrounding structures or the environment (e.g. chemical or radioactive emissions, blast overpressures, etc.), a more detailed evaluation of L_X that takes into account this additional loss should be performed.

If the structure is partitioned in individual zones, each risk component shall be evaluated for each zone. The total risk R of the structure is the sum of all risks components over all the zones which constitute the structure.

III. LOSS FACTOR FOR THE STRUCTURE

The values of acceptable amount of loss L_X should be evaluated and fixed by the lightning protection designer or the owner of the structure. Typical mean values of loss L_X in a structure given in [1] are values proposed by the IEC. In [2] specific values for the losses related to environmental risk have been additionally proposed based on IEC 62305-2 Edition 2. Different values of acceptable loss may be assigned by each National Committee (or other authority having jurisdiction) or after a detailed investigation.

For structures that may be dangerous to their surroundings, the main loss to be considered due to this special hazard is:

- L1: loss of human life

Economic losses L4 has been purposely neglected in the paper. For more information, see [2].

In addition to that, only the types of damage D2 and D3 are investigated. D1 is the injury to living beings due to electric shock and is a consequence of step and touch voltages inside the structure. With that, it is only relevant to the structure to be protected, not in the surroundings. Consequently, the risk components R_A and R_U can be neglected in the computation of this special hazard.

The loss value L_X for each zone can be determined according to (3), considering that:

- the loss of human life is affected by the characteristics of the zone. These are taken into account by increasing (h_z) and decreasing (r_t, r_p, r_f) factors;
- the maximum value of loss in the zone is reduced by the ratio between the number of persons in the zone (n_z) versus the total number of persons (n_t) in the whole structure;
- the time in hours per year for which the persons are present in the zone (t_z), if it is lower than the total 8760 hours in a year, also will reduce the loss.

$$L_B = L_V = r_p \cdot r_f \cdot h_z \cdot L_F \cdot n_z/n_t \cdot t_z/8760 \qquad (2)$$

$$L_C = L_M = L_W = L_Z = L_O \cdot n_z/n_t \cdot t_z/8760 \qquad (3)$$

where:

L_F is the typical percentage of persons injured by physical damage (D2) due to one dangerous event (see Table I);

L_O is the typical percentage of persons injured by failure of internal systems (D3) due to one dangerous event (see Table I);

r_p is a factor reducing the loss due to physical damage depending on the provisions taken to reduce the consequences of fire (see Table II);

r_f is a factor reducing the loss due to physical damage depending on the risk of fire or on the risk of explosion of the structure (see Table III);

h_z is a factor increasing the loss due to physical damage when a special hazard is present (see Table IV);

n_z is the number of persons in the zone;

n_t is the total number of persons in the structure;

t_z is the time in hours per year for which the persons are present in the zone.

When a structure is treated as a single zone, the ratio n_z/n_t should equate to a value of 1. Where the value of t_z is not known, the ratio t_z /8760 should equate to a value of 1.

Both types of damage D2 and D3 are relevant for this type of structure. An overvoltage and consequently the loss of a control system can result in a danger for human beings inside (and later also outside) the structure.

TABLE I. TYPE OF LOSS L1: TYPICAL MEAN VALUES OF L_F AND L_O

Type of damage	Typical loss value		Type of structure
D2 physical damage	L_F	10^{-1}	Risk of explosion
		10^{-1}	Hospital, hotel, school, civic building
		$5 \cdot 10^{-2}$	Public entertainment, church, museum
		$2 \cdot 10^{-2}$	Industrial, commercial
		10^{-2}	Others
D3 failure of internal systems	L_O	10^{-1}	Risk of explosion
		10^{-2}	Intensive care unit and operation block of hospital
		10^{-3}	Other parts of hospital

The values in Table I relate to a continuous attendance of people in the structure. In the case of a structure with risk of explosion, the values for L_F and L_O may need a more detailed evaluation considering the type of structure, the risk explosion, the zone concept of hazardous areas and the measures to meet the risk.

TABLE II. REDUCTION FACTOR r_p AS A FUNCTION OF PROVISIONS TAKEN TO REDUCE THE CONSEQUENCES OF FIRE (TABLE C.4 IN [1, 6])

Provisions	r_p
No provisions or structures with a risk of explosion	1
One of the following provisions: extinguishers; fixed manually operated extinguishing installations; manual alarm installations; hydrants; fire compartments; escape routes	0.5
One of the following provisions: fixed automatically operated extinguishing installations; automatic alarm installations [a]	0.2
[a.] only if protected against overvoltages, other damages and if firemen can arrive in less than 10 min.	

In Table II, if more than one provision is taken, the value of r_p should be taken as the lowest of the relevant values.

TABLE III. REDUCTION FACTOR r_f AS A FUNCTION OF RISK OF FIRE OR EXPLOSION OF STRUCTURE (TABLE C.5 IN [1, 6])

Risk	**Amount of risk**	r_f
Explosion	Zones 0, 20 and solid explosive	1
	Zones 1, 21	10^{-1}
	Zones 2, 22	10^{-3}
Fire	High	10^{-1}
	Ordinary	10^{-2}
	Low	10^{-3}
Explosion or fire	None	0

In Table III, the value for r_f may need a more detailed evaluation for the case of a structure with risk of explosion.

Structures with a high risk of fire are generally structures made of combustible materials, structures with roofs made of combustible materials or structures with a specific fire load larger than 800 MJ/m^2.

Structures with an ordinary risk of fire are considered to be structures with a specific fire load between 800 MJ/m^2 and 400 MJ/m^2.

Structures with a low risk of fire are considered to be structures with a specific fire load less than 400 MJ/m^2 or structures containing only a small amount of combustible material.

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

For the purposes of this part of IEC 62305, structures containing hazardous zones or containing solid explosive materials should not be assumed to be structures with a risk of explosion if any one of the following conditions is fulfilled:

a) the time of presence of explosive substances is lower than 0,1 hours/year;

b) the volume of explosive atmosphere is negligible according to IEC 60079-10-1 [3] and IEC 60079-10-2 [4];

c) the zone cannot be hit directly by a flash and dangerous sparking in the zone is avoided.

For hazardous zones enclosed within metallic shelters, condition c) is fulfilled when the shelter, as a natural air-termination system, acts safely without puncture or hot-spot problems, is not subject to arcing between metallic sections, and internal systems inside the shelter, if any, are protected against overvoltages to avoid dangerous sparking.

The values given in Table III for a risk of explosion consider in a simplified manner the existence of an explosive atmosphere. When the required information is available, the parameter r_f can also be evaluated as:

$$r_f = t_{ex}/8760 \tag{4}$$

where:

t_{ex} time in hours per year for which an explosive atmosphere is present in the relevant structure or zone.

TABLE IV. FACTOR h_z INCREASING THE RELATIVE AMOUNT OF LOSS IN PRESENCE OF A SPECIAL HAZARD (TABLE C.6 IN [1, 6])

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

IV. LOSS FACTOR FOR THE ENVIRONMENT

A. IEC 62305-2 standard

When the damage to a structure due to lightning involves surrounding structures or the environment (e.g. chemical or radioactive emissions), additional losses (L_{XE}) should be taken into account to evaluate the total loss (L_{XT}):

$$L_{XT} = L_X + L_{XE} \tag{7}$$

where:

L_X is the loss factor for the losses of human beings inside the structure;

$$L_{XE} = L_{VE} = L_{FE} \cdot t_e/8760 \tag{8}$$

where:

L_{FE} is the typical mean percentage of persons outside the structure injured by physical damage (D2) due to one dangerous event (see Table VII);

t_e is the time of presence of persons in the potentially dangerous place outside the structure.

If values of t_e are unknown, t_e/8760 = 1 should be assumed. Typical cases could include the case where the affected area surrounding the structure is a residential community with a permanent attendance of people (t_e/8760 = 1). In other cases, the structure may be located in an industrial park where the predominance of exposure occurs for only parts of a day (t_e/8760 < 1).

B. *Proposal from the authors*

IEC 62305-2 currently acknowledges the risk to the environment resulting from lightning damages to some structures but does not provide sufficient description to calculate the risk. Reference [2] proposes some improvements in the methodology as well as some new tables to facilitate the application of this method for the users.

$$L_{BE} = L_{VE} = r_p \cdot r_f \cdot L_{FE} \cdot t_e/8760 \quad (9)$$

$$L_{CE} = L_{ME} = L_{WE} = L_{ZE} = r_p \cdot r_f \cdot L_{OE} \cdot t_e/8760 \quad (10)$$

where:

L_{FE} is the typical mean percentage of persons outside the structure injured by physical damage (D2) due to one dangerous event (see Table VII);

L_{OE} is the typical mean percentage of persons outside the structure injured by failure of internal systems (D3) due to one dangerous event (see Table VII);

r_p is the factor reducing the loss due to physical damage depending on the provisions taken to reduce the consequences of fire (see Table II, in structures with a risk of explosion $r_p = 1$ for all cases);

r_f is the factor reducing the loss due to physical damage depending on the risk of fire or on the risk of explosion of the structure (see Table III and equation (4));

The values proposed in Table VI can be used to establish value t_e. These values are based on a French official document [5] giving the basic rules for counting the number of people around an industrial site and determining the potential number of victims in case of an event inside the site having an effect outside of the site.

TABLE VI. TYPE OF LOSS L1: PROPOSED TYPICAL VALUES FOR THE RELATED TIME OF PRESENCE FOR PEOPLE t_e/8760 IN DIFFERENT ENVIRONMENTS AS LIMITED BY TABLE VII

Type of surrounding	**t_e/8760(1)**
Working people inside the fence	0.25
Necessity of controlled area inside the fence Operation of plant with more than one shift	1.0
Public access areas	0.5
Zones of activities (industries and other activities not subject to public access)	0.75
Residences	1
Automobile lanes :	1
Railway tracks	0.25
Inland waterways	0.1
Motorways and pedestrian paths	0.75
Open grounds and very little attended (fields, meadows, forests, waste lands, marsh…)	0.25
Usable fields with limited use (horticultural gardens and zones, vines, fishing zones, marshalling yards …)	0.25
Usable fields potentially attended or very attended (carparks, parks and parks, zones of supervised bathes, sports grounds	0.5
Special cases (extremely temporary occupations)	0.1

1 : In case of "mixed" environments with different values, the highest value should be used.

For L_{FE} and L_{OE} the values given in Table VII are default values proposed by the authors. More detailed calculations may be performed. Where better information is available for the specific cases, this information may be used where allowed by the authorities having jurisdiction. When there is no risk for the surroundings, $L_{FE} = L_{OE} = 0$ should be assumed.

Table VII (as well as Table VIII) is based on the experience of a French working team established to analyze the environmental effect when using IEC standard or its European version EN62305-2 that only slightly differs from the IEC version. It has been developed and refined by the authors of [2] to be able to make calculations in some examples.

TABLE VII. TYPE OF LOSS L1: TYPICAL MEAN VALUES OF L_{FE} AND L_{OE} OUTSIDE THE STRUCTURE

Values of L_{FE} and L_{OE} **Scenario**	**Environmental risk – remaining inside the site fence** **L_{FE}(7)**	**L_{OE}(7)**	**Environmental risk – spreading outside of the site fence** **L_{FE}**	**L_{OE}**
Explosion and overpressure (1)	0.25	0.025	0.5	0.05
Thermal flux (2)	0.05	0.005	0.1	0.01
Toxic fumes (3)	0.1	0.01	1.0	0.1
Soil pollution (3)	0.1	0.01	0.5	0.05
Water pollution (3)	0.25(4)	0.025	2.5	0.25
Radioactive material (3), (5), (6)	0.5	0.05	5	

1 : The overpressure exceeds a value of 50 hPa

2 : The thermal power per area exceeds a value of 3 kW/m^2

3 : These maximum values could be reduced based on quantity of pollutant, danger of the pollutant and sensitivity of the environment

4 : only if pollution can reach the water bed or fresh water or sea/oceans

5 : this may not be applicable when a specific study including all scenario have been developed

6 : this is not applicable to sealed sources for example used in measuring devices or medical equipment

7 : Where a TWS is incorporated into the operating and safety plan, the values for L_{FE} and L_{OE} inside the site fence are multiplied by $(1 – P_{TWS})$.

Note: damage to windows (explosion with limited effect) are excluded from this investigation and should be dealt with, if any, by specific protection measures.

V. APPLICATION OF THE METHOD AND COMPARISON WITH EDITION 1 OF THE IEC 62305-2

In this clause, values given in Table VII and VIII are applied to illustrate the proposal.

A. *Fixed parameters*

The following parameters have been used to try cover as many cases as possible and allow easy comparison with cases calculated with Edition 1 of IEC 62305-2.

Ng = 1

	Small structure (S)	Large structure (B)
L (m)	30	100
W (m)	10	50
H (m)	6	12

The case studies discussed below consider combinations of either explosive areas Zone 0 (permanent) or Zone 2 (rare) and high risk of fire or ordinary risk of fire.

The 8 cases studied are numbered as follows:

S_0, S_2; S_HF and S_OF, respectively, for the small structure defined above with explosive area Z0, Z2 and high risk of fire or ordinary risk of fire, and the same for the large structure : B_0, B_2; B_HF and B_OF.

The structure is considered to contain a single zone.

Other parameters given in IEC 62305-2 are fixed as follows:

$C_d = 1$, $C_T = 1$, $C_e = 0.5$, $C_i = 0.5$; Length of line: 1000 m.

$P_{TA}=P_B=P_{SPD}=P_{MS}=P_{TU}=P_{EB}=P_{LD} = 1$

$C_{LD}=C_{Li}=1$

$P_{Li} = 0.3$

$L_t = 10^{-2}$, $L_f = 2\ 10^{-2}$ and $L_o = 10^{-1}$

$r_t = 10^{-5}$, $r_u = 10^{-4}$, $r_p = 0{,}5$, $h_z = 2$.

In addition, it was necessary to define the environment of the structures studied, as the purpose of the paper is to try to explain how to calculate environmental risk.

Cases S_HF and S_2 are associated with dwellings,

Case B_0, are associated with open grounds,

Case S_OF, are associated with areas with public access,

Cases B_HF and S_0 were associated with industrial areas,

and Cases B_OF and B_2 were associated with highways, pathways, or railways.

To set the conditions to be assumed in the following studies, the examples involving explosive area Zone 0 conditions will be assumed to lead to an explosion outside of the structure under consideration but the effective area of the environmental threat will remain inside the industrial site for the small structure and spread outside of the site border for the large structure.

For studies associated with explosive area Zone 2 and for high risk of fire, the effective area for a thermal flux effect will be considered to not propagate outside the industrial site.

For studies involving ordinary risk of fire, the scenarios considered assume toxic fumes are emitted and will propagate outside the industrial site border.

B. Results obtained

All cases have been simulated by JUPITER 2.2 software which is fully compliant with Edition 2 of IEC 62305-2.

TABLE VIII. RESULT OF RISK R1 FOR THE 8 DEFINED CASES WITHOUT PROTECTIVE MEANS

Risk R1 without protective measures							
Structure				IEC 62305-2 Edition 1 [6]	Method proposed in [2]	For information, method proposed in IEC 62305-2 Edition 2 for the structure itself (no environmental risk is considered) [1]
Coding	Environment	Effects				
		In the industrial site	Out of the industrial site			
S_0	Industrial areas	Explosion		**2,64E-01**	**1,96E-02**	**1,88E-02**
S_2	Dwellings	Thermal flux		**2,44E-01**	**1,78E-02**	**1,78E-02**
S_HF	Dwellings	Thermal flux		**9,88E-04**	**4,21E-05**	**1,02E-05**
S_OF	Public access areas		Toxic fumes	**2,47E-03**	**3,29E-05**	1,02E-06
G_0	Open grounds		Explosion	**3,22E-01**	**5,67E-02**	**5,29E-02**
G_0	Motorways and pedestrian paths	Thermal flux		**2,89E-01**	**5,06E-02**	**5,06E-02**
G_HF	Industrial area	Thermal flux		**1,66E-03**	**4,25E-05**	**2,39E-05**
G_OF	Motorways and pedestrian paths		Toxic fumes	**4,14E-03**	**7,71E-05**	2,39E-06

The bold values correspond to cases where risk R1 is greater than the tolerable risk. It can be seen that for each case studied, the tolerable risk is exceeded using both the method given in IEC 62305-2 Edition 2 and the method proposed in [2]. However, it is important to notice that according to the proposed method, the results are lower than those obtained using the method in Edition

1 of 62305-2. There was a clear indication from the field that Edition 1 led to results greater than necessary and not justified by experience, Edition 2 seems to be a more realistic method. When only the safety of people inside the structure is considered and no environmental risk is considered, the result is much more acceptable as there are 2 cases among the 8 studied where the structure appears as self-protected.

In the following table, proposed protective measures have been implemented. Level IV refers to a protection in 80% of cases and Level I refers to a protection in 98% of cases. Level I+ refers to a protection in 99% of cases and I++ in 99.9% of cases.

TABLE IX. RESULT OF RISK R1 FOR THE 8 DEFINED CASES WITH PROPOSED PROTECTIVE MEANS

	Risk R1 with protective measures					
Coding	IEC 62305-2 Edition 1			Method proposed in [2]		
	R1	Protective level of LPS	Protective level of SPD	R1	Protective level of LPS	Protective level of SPD
S_0	**2,64E-04**	I++	I++	**2,71E-05**	I++	I++
S_2	**2,45E-04**	-	I++	**1,81E-05**	-	I++
S_HF	8,25E-06	IV	IV	9,76E-06	-	II
S_OF	7,70E-06	I	I++	8,41E-06	-	IV
G_0	**3,22E-04**	I++	I++	**2,53E-05**	I++	I++
G_0	**2,92E-04**	IV	I++	**2,17E-05**	-	I++
G_HF	**4,06E-05**	I++	I++	3,46E-06	-	IV
G_OF	4,14E-06	I++	I++	6,42E-06	III	III

We can draw a few conclusions from Table IX.

There are cases where with both methods the risk cannot be reduced below the tolerable risk. This means that a more detailed study is needed with consideration of zoning of the structure or the implementation of thunderstorm warning systems to reduce the probability of a dangerous event.

In general, protective measures necessary for the proposed method are determined with a level of protection much lower than with Edition 1 of IEC 62305-2. In one case only, the level of protection for the SPD with the proposed method is greater than the one determined with Edition 1 but this is because the solution for Edition 1 incorporates an LPS with SPD while only the SPD is needed when using the proposed method in [2]. With the new method, the majority of studied cases do not require an LPS while an LPS is needed according to Edition1 in all studied cases except one.

VI. CONCLUSIONS

Edition 1 of IEC 62305-2 is considered to be too severe by many in the industry. It is clear that the field experience doesn't fully justify the level of protection required by the said risk method. This is especially the case when the risk to the environment is considered. Edition 2 of IEC 62305-2 has improved the risk calculation and has split the risk R1 in two parts: risk inside the structure (safety for the people) and risk to the environment. Personal safety is generally handled sufficiently by industry procedures so the risk method doesn't significantly improve on the existing method used by the industry, especially for protecting people inside the structure. For structures incorporating contents that may create a hazard to the environment, established operating and safety procedures, incorporating Thunderstorm Warning Systems where applicable, are in some cases more effective in reducing the overall risk than the installation of a lightning protection system. The method incorporated in Edition 2 is highly relevant for environmental risk but needs to be further developed in practice with additional guidance given in selecting values. The method proposed in [2] has suggested some ways to improve the method. Case studies applying the proposed method indicate that the results seem to be more realistic. Further improvements need to be introduced in revising 62305-2 and preparing the upcoming Edition 3 currently under development.

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REFERENCES

[1] IEC 62305-2 Ed.2:2010-12: Protection against lightning – Part 2: Risk management.

[2] Alain Rousseau, Alexander Kern, "How to deal with environmental risk in IEC 62305-2", ICLP 2014.

[3] IEC 60079-10-1: Explosive atmospheres – Part 10-1: Classification of areas – Explosive gas atmospheres.

[4] IEC 60079-10-2: : Explosive atmospheres – Part 10-2: Classification of areas – Combustible dust atmospheres.

[5] Circulaire DPPR/SEI2/CB-06-0388 du 28/12/06 relative à la mise à disposition du guide d'élaboration et de lecture des études de dangers pour les établissements soumis à autorisation avec servitudes et des fiches d'application des textes réglementaires récents.

[6] IEC 62305-2 Ed.1:2006-01: Protection against lightning – Part 2: Risk management.