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Risk management according to IEC 62305-2 edition 2: 2010-12

Assessment of structures with a risk of explosion

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***Abstract* — Risk management for structures with a risk of explosion should be considered very carefully when performing a risk analysis according to IEC 62305-2. In contrast to the 2006 edition of the standard, the 2010 edition describes the topic “Structures with a risk of explosion“ in more detail. Moreover, in Germany separate procedures and parameters are defined for the risk analysis of structures with a risk of explosion (Supplement 3 of the German DIN EN 62305-2 standard). This paper describes the contents and the relevant calculations of this Supplement 3, together with a numerical example.**

Keywords; Risk management, structures with a risk of explosion, duration of the presence of a dangerous explosive atmosphere, example of a gas station

I. INTRODUCTION

Since the 1990ies, the risk analysis for lightning threats has been investigated. Risk management for lightning and surge protection is an essential tool to estimate the vulnerability of a structure and the people and content inside against lightning and surge threat and to ensure that the necessary and most effective protection measures are selected in the required quality.

The first technical report in the frame of standardization dealing with risk analysis was published in 1995 as IEC 1662 [1]. Further development on this subject and the use of this publication led to the 1st edition of the lightning protection standard IEC 62305-2 in 2006 [2]. Risk management investigations were then performed for a great number of structures. The worldwide experiences lead to further improvement. In 2010 the 2nd edition of the international IEC 62305-2 [3] standard was published.

Structures with a risk of explosion should be considered very carefully when performing a risk analysis according to IEC 62305-2. In contrast to the 2006 edition of the standard, the 2010 edition describes the topic “Structures with a risk of explosion“ in more detail. However, many experts state that the duration of the presence of an explosive atmosphere in structures with a risk of explosion should be considered in a more detailed way in a risk analysis. Annex ND of the Supplement 3 of the German implementation of the standard IEC 62305-2 [3] deals with this topic.

In this paper, the concept of this Supplement 3 to DIN EN 62305-2, “Additional information for the application of DIN EN 62305-2” [4] is described, together with a numerical example.

II. BASIC ASSUMPTIONS FOR THE RISK MANAGEMENT

As defined by IEC 62305-2 [3], four different types of loss, and with that, four different risks, which can be considered and assessed for an object, can be used for a risk analysis:

- Type of loss L1 / Risk R_1: Risk of loss of human life
- Type of loss L2 / Risk R_2: Risk of loss of service to the public
- Type of loss L3 / Risk R_3: Risk of loss of cultural heritage
- Type of loss L4 / Risk R_4: Risk of loss of economic value

The risks R_1, R_2, R_3 and R_4 are the sum of risk components R_X which may be grouped according to the source of damage (Fig. 1).

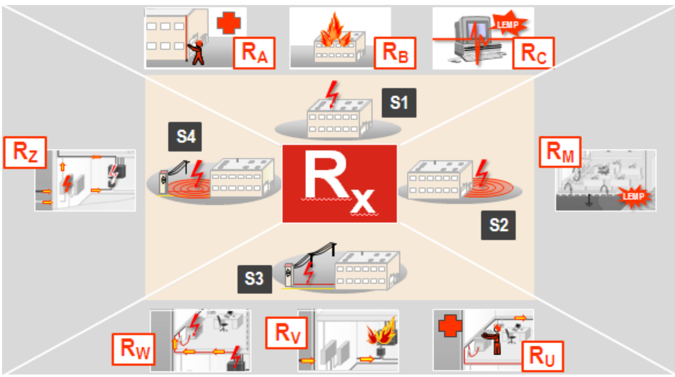

Figure 1. Risk components R_x depending on the source of damage S_x

Consequently, the risk components are possible main risks. The components are sub-divided according to the sources of damage as follows:

S1: Direct lightning strikes:

- Risk component R_A: Injury to living beings caused by touch and step voltage inside and outside the structure
- Risk component R_B: Physical damage, particularly fire
- Risk component R_C: Surges caused by LEMP

S2: Lightning strikes near the structure:

- Risk component R_M: Surges caused by LEMP

S3: Direct lightning strikes to a line:

- Risk component R_U: Injury to living beings caused by touch voltage inside the structure
- Risk component R_V: Physical damage, particularly fire
- Risk component R_W: Surges caused by LEMP

S4: Lightning strikes near a line:

- Risk component R_Z: Surges caused by LEMP

Each of these eight risk components R_X can be expressed by the following equation:

$$R_X = N_X \cdot P_X \cdot L_X \tag{1}$$

where:

N_X is the number of dangerous events (number of lightning strikes);

P_X is the probability of damage depending on the properties, contents and internal systems of the structure;

L_X is the possible loss.

The value L_X defines the possible, consequent loss depending on different factors, particularly the factor r_f. This factor reduces or increases loss due to physical damage depending on the risk of fire or explosion of the structure. The reduction factor r_f is defined in IEC 62305-2:2010 [3] (Table I).

TABLE I. REDUCTION FACTOR R_F ACCORDING TO IEC 62305-2, TABLE C.5

Risk	Amount of risk	r_f
Explosion	Zones 0, 20 and solid explosives	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

However, the requirements for explosive atmospheres given in Table I have shown that the factor r_f should be considered preferably in more detail.

III. Risk Management for Structures with a Risk of Explosion

Risk management for structures with a risk of explosion requires special consideration when performing a risk analysis as per IEC 62305-2 [3]. This risk analysis is based on the presence of an explosive atmosphere which can be subdivided into so-called Ex zones depending on the frequency and duration of the presence of an explosive atmosphere. This topic is regulated in the 1999/92/EC directive on minimum requirements for improving the safety and health protection of workers potentially at risk from explosive atmospheres [5].

The operator of the structure is responsible for dividing the structure into Ex zones. Thus, the division into Ex zones forms the basis for a risk analysis. Ex zones are defined in [5]. The definitions are adopted in Supplement 3 to DIN EN 62305-2 [4] (see Table II).

TABLE II. DEFINITIONS OF HAZARDOUS AREAS [5]

Zone	Definition
Zone 0	Place in which an explosive atmosphere consisting of a mixture of air and flammable substances in the form of gas, vapour or mist is present continuously or for long periods or frequently.
Zone 1	Place in which an explosive atmosphere consisting of a mixture of air and flammable substances in the form of gas, vapour or mist is likely to occur in normal operation occasionally.
Zone 2	Place in which an explosive atmosphere consisting of a mixture of air and flammable substances in the form of gas, vapour or mist is not likely to occur in normal operation but, if it does occur, will persist for a short period only.
Zone 20	Place in which an explosive atmosphere, in the form of a cloud of combustible dust in air, is present continuously, or for long periods, or frequently.
Zone 21	Place in which an explosive atmosphere in the form of a cloud of combustible dust in air, is likely to occur in normal operation occasionally.
Zone 22	Place in which an explosive atmosphere in the form of a cloud of combustible dust in air is not likely to occur in normal operation but, if it does occur, will persist for a short period only.

The frequency and duration of the presence of a dangerous explosive atmosphere are decisive for dividing a room or a local area into Ex zones. It is the responsibility of the plant operator and/or the authority having jurisdiction to define the different Ex zones.

To be able to assess the frequency and duration of the presence of an explosive atmosphere in the form of hours/year (h/year) and to use them for calculations, the basic values according to a well-established guideline [6] are defined (see Table III).

The duration of the presence of a dangerous explosive atmosphere is used for calculating the loss value by means of the factor r_f, for example loss of human life L1. The values given in Table I (Table C.5 of [3]) can be used for the factor r_f. These values include the time during which an explosive atmosphere occurs in a greatly simplified way.

TABLE III. BASIC VALUES FOR THE PRESENCE OF A DANGEROUS EXPLOSIVE ATMOSPHERE (SUPPLEMENT 3 TO DIN 62305-2 [4], TABLE ND.2)

Mixture of air and flammable substances	**Duration of the presence of a dangerous explosive atmosphere**		
	Continuously, for long periods or frequently (> 50% of the operating time)	**Occasionally (< 50% of the operating time)**	**Not likely to occur or only for a short period (< 30 min/year)**
Gas, vapour, mist	Zone 0	Zone 1	Zone 2
Dust	Zone 20	Zone 21	Zone 22

However, if detailed information is available, the parameter r_f can also be determined preferably in a more detailed way. If r_f includes the duration of the presence of a dangerous explosive atmosphere, and if we assume that in case of an occurring spark due to a lightning event within this duration an explosion follows immediately, it can be defined:

$$r_f = t_{ex}/8760 \qquad (2)$$

where:

t_{ex} is the time in hours per year during which the explosive gas / air mixture is present in the structure / building / zone.

Based on (2), the individual risk components can be calculated for the types of loss, where Ex zones are of interest, usually L1, L2, and L4. According to the definition and concept given in [3], the factor r_f influences the loss factors only. With that, only the loss factors will be further investigated in the following. The number of dangerous events N_X and the damage probabilities P_X are calculated directly as defined in IEC 62305-2, Annexes A and B. Furthermore, the type of damage D1: Electric shock as a consequence of touch and step voltages is disregarded in the following because it is not linked to an Ex zone.

A. *Loss of human life L1*

Loss of human life L1 in case of a structure with a risk of explosion can result from physical damage D2 and failure of internal systems D3. The duration of an explosive atmosphere t_{ex} (factor r_f) is used to calculate the possible loss:

D2: Physical damage

$$L_B = L_V = r_f \cdot L_F \cdot (n_z/n_t) \cdot (t_z/8760) \qquad (3)$$

D3 Failure of internal systems

$$L_C = L_M = L_W = L_Z = r_f \cdot L_O \cdot (n_z/n_t) \cdot (t_z/8760) \qquad (4)$$

where:

r_f is the reduction factor (due to physical damage) depending on the risk of fire or explosion of the structure, given by Table I or (2);

L_F is the typical mean relative number of victims by physical damage due to one dangerous event;

L_O is the typical mean relative number of victims by failure of internal systems due to one dangerous event;

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.

In an extension to IEC 62305-2, Annex C, the factor r_f is also considered for the surge-related losses here. This is due to the idea that if a failure of an electrical or electronic system occurs during the presence of an explosive atmosphere, this failure leads to a malfunction and with that to an explosion within the Ex zone. This approach is much more severe than the usual consequence of surges. It extinguishes that the consequences of a malfunction are comparable to the consequences of a “common” physical damage.

One may also expect the factor r_p in (3) and (4) representing provisions taken to reduce the consequences of fire. However, those provisions are assumed to work only against fire, they do not protect against explosion. Therefore, it must always be assumed $r_p = 1$, and with that this factor can be disregarded in (3) and (4).

This approach is valid under the assumption that r_f (and with that the time t_{ex}) and the time t_z are independent from each other. If there is a dependency, the approach may need an even more detailed investigation (e.g. an appearance of an explosive atmosphere (t_{ex}) is only possible if people are present in the zone (t_z), or exactly the opposite).

The division of the total structure into several zones follows the basic concept of IEC 62305-2. If only one zone makes up the structure, $(n_z/n_t) = 1$.

B. *Unacceptable loss of service to the public L2*

As is the case for L1, the loss of service to the public L2 can also result from physical damage and failure of internal systems due to an explosion. In this case, the duration t_{ex} (factor r_f) is also used to calculate the possible loss (the conditions and explanations given for L1 are valid also here):

D2: Physical damage

$$L_B = L_V = r_f \cdot L_F \cdot (n_z/n_t) \qquad (5)$$

D3 Failure of internal systems

$$L_C = L_M = L_W = L_Z = r_f \cdot L_O \cdot (n_z/n_t) \qquad (6)$$

where:

r_f is the reduction factor (due to physical damage) depending on the risk of fire or explosion of the structure, given by Table I or (2);

L_F is the typical mean relative number of users not served, resulting from physical damage due to one dangerous event;

L_O is the typical mean relative number of users not served, resulting from failure of internal systems due to one dangerous event;

n_z is the number of users served by the zone;

n_t is the total number of users served by the structure.

C. Loss of economic value L4

Finally, the loss of economic value L4 in such a case can also result from physical damage and failure of internal systems due to an explosion. The duration t_{ex} (factor r_f) is used again to calculate the possible loss (the conditions and explanations given for L1 are valid again):

D2: Physical damage

$$L_B = L_V = r_f \cdot L_F \cdot [(c_a + c_b + c_c + c_s)/c_t] \quad (7)$$

D3 Failure of internal systems

$$L_C = L_M = L_W = L_Z = L_O \cdot c_S/c_t \quad (8)$$

where:

r_f is the reduction factor (due to physical damage) depending on the risk of fire or explosion of the structure, given by Table I or (2);

L_F is the typical mean relative value of all goods damaged by physical damage due to one dangerous event;

L_O is the typical mean relative number of all goods damaged by failure of internal systems due to one dangerous event;

c_a is the value of animals in the zone (can be disregarded usually);

c_b is the value of building relevant to the zone;

c_c is the value of content in the zone;

c_s is the value of internal systems including their activities in the zone;

c_t is the total value of the structure (sum over all zones for animals, building, content, internal systems).

The approach of non-considering r_f in case of the loss factors regarding the type of damage D3 (see (8)) assumes that economic losses caused by failures of internal systems are more common (i.e. not reduced by the reduction factor r_f) and usually limited to the systems itself. With that, this is the usual approach defined in the basic standard IEC 62305-2 [3].

An alternative approach could be to consider r_f also in case of failures of internal systems, and then to assume that in such a failure the consequences may be comparable to the consequences of a "common" physical damage (as for the loss of human life L1, and the unacceptable loss of service for the public L2). This would lead to the loss factors given in (9):

D3 Failure of internal systems

$$L_C = L_M = L_W = L_Z = r_f \cdot L_O \cdot [(c_A + c_B + c_C + c_S)/c_t] \quad (9)$$

Consequently, one would have to investigate, whether the loss factors given in (8) or those given in (9) are the higher ones for the type of damage D3. Then this worst case approach would lead to results being on the safe side. However, Supplement 3 to DIN EN 62305-2 [4] currently does not go so far. Here, the approach described at first and based on (8) is used.

IV. Case Study for a Gas Station with a Risk of Explosion

The content of this paper is the correlation between Ex zones and the duration of an explosive atmosphere and the description of calculation methods. A case study calculation shows the use of the described concept, the calculation results, and the resulting protection measures.

Particularly gas stations are often divided into Ex zones which must be considered for the lightning protection zone concept and risk analysis.

Depending on their design and application, gas stations are divided into Ex zone 2 or Ex zone 1 and 2. Odorisation rooms are classified into Ex zone 1.

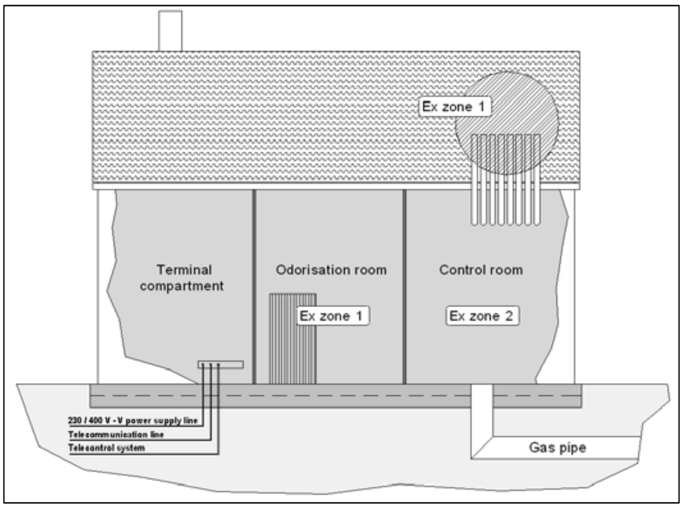

Figure 2. Schematic description of the gas station

The following goals should be considered in the case study for the gas station:

- Calculation method for determining the risk and protection measures;
- Influence of the different risk components on the overall risk;
- Influence of the protection measures for limiting such risks;
- Integration of the Ex zones of the structure into the calculation.

A. *Selection of the types of loss to be considered*

Due to the type and use of the structure, the following types of damage are assessed:

- Loss of human life (L1);
- Loss of service to the public (L2);
- Loss of economic value (L4).

The calculated values for L1 and L2 are compared with the relevant acceptable values R_T after the assessment of the actual state.

B. *Characteristics of the surroundings and the structure*

This gas station is an isolated structures with dimensions of 20 m x 20 m x 8 m. Due to its location, a ground flash density N_g = 3.0/km²/year can be assumed.

The following supply lines must be considered for the risk analysis:

- 230 / 400 V power supply line;
- Telecommunication line;
- Telecontrol system.

C. *Definition of zones in the gas station*

According to IEC 62305-2 Ed.2 [3], the building is divided into the following zones:

- Z_1 : Outdoor area (outside the structure);
- Z_2 : Terminal compartment (inside the structure);
- Z_3 : Odorisation room (inside the structure);
- Z_4 : Control room (inside the structure).

This definition considers that:

- the type of soil near and inside the structure is different;
- the structure is divided into two different Ex areas; odorisation room (Ex zone 1), control room (Ex zone 2);
- the internal systems which are connected to the power supply and telecommunication line and telecontrol system are distributed to all zones Z_2, Z_3 and Z_4 inside the building;
- there is no spatial shielding.

TABLE IV. DISTRIBUTION AND TIME OF PRESENCE OF PEOPLE FOR THE DIFFERENT ZONES

Zone	Number of persons	Time of presence in h / year
Z_1 - outside the structure	5	6,000
Z_2 - Terminal compartment	3	700
Z_3 - Odorisation room	3	700
Z_4 - Control room	3	700
Total	n_t = 14	-

In the different zones inside the building, a total number of 9 persons is assumed, whereas outside the building a total number of 5 persons is assumed for zone Z_1. The time of presence of the persons differs for the individual zones. Table IV gives the details.

The following Ex zones (Table V) are defined for zones Z_3 (odorisation room) and Z_4 (control room).

TABLE V. DEFINITION OF EX ZONES

Zone	Ex zone	Duration of the presence of an explosive atmosphere t_{ex}
Z_3 - Odorisation room	1	< 800 h/year (occasionally)
Z_4 - Control room	2	6 h/year (for a short period)

The reduction factor r_f is determined by means of the duration of the presence of an explosive atmosphere t_{ex} as given in (2). Consequently, the reduction factor r_f has the values given in Table VI.

TABLE VI. VALUES OF THE REDUCTION FACTOR R_F

Zone	r_f
Z_3 - Odorisation room	0.09
Z_4 - Control room	0.0007

D. *Evaluation of risk R_1, risk of loss of human life*

The risk analysis reveals that protection measures must be taken (Table VII). In addition, the risk components R_B (fire, direct lightning strike to the building, S1) and R_V (fire, direct lightning strike to the incoming/outgoing supply lines, S3) are higher than R_T. However, the dominating risk component, R_Z, is due to indirect strikes next to the incoming/outgoing supply lines, S4. Consequently, lightning and surge protection measures must be taken (see Chapter IV.F).

TABLE VII. RISK R_1 FOR THE UNPROTECTED STRUCTURE (VALUES X 10^{-5})

	Risk comp.	Z_1	Z_2	Z_3	Z_4	Total structure
D2 Physical damage	R_B	-	0	0.42	0	0.42
	R_V	-	0	6.16	0.06	6.22
D3 Failure internal systems	R_C	-	-	0.21	0	0.21
	R_M	-	-	3.57	0.04	3.61
	R_W	-	-	3.08	0.03	3.11
	R_Z	-	-	236.30	2.36	238.66
Total				249.74	2.49	252.23
Tolerable		$R_1 > R_T$ Protection necessary				$R_T = 1$

E. *Evaluation of risk R_2, risk of loss of service to the public*

TABLE VIII. RISK R_2 FOR THE UNPROTECTED STRUCTURE (VALUES X 10^{-5})

	Risk comp.	Z_1	Z_2	Z_3	Z_4	Total structure
D2 Physical damage	R_B	-	0	41.3	0.4	41.7
	R_V	-	0.6	600.0	6.0	606.6
D3 Failure internal systems	R_C	-	4.1	4.1	0	8.2
	R_M	-	69.6	69.6	0.7	139.9
	R_W	-	60.0	60.0	0.6	120.6
	R_Z	-	4 600	4 600	46.0	9 246
Total		-	4 734	5 375	53.7	10 163
Tolerable		$R_1 > R_T$ Protection necessary				$R_T = 100$

When evaluating the risk R_2 (Table VIII), it can be seen again that the risk components related to the incoming/outgoing supply lines, R_V and R_W (direct lightning strike, S3) and R_Z (indirect lightning strike, S4) are dominating, together with the component R_M (lightning strike next to the building S2, LEMP).

F. Definition of protection measures

The dominating risk components for R_1 and R_2 can be reduced to an acceptable level by selecting the following protection measures (Table IX):

- Protection of the entire gas station by means of an LPS II in conformity with IEC 62305-3 [7] to reduce the risk component R_B ($P_B = 0.05$). The component R_V is also reduced due to the necessary lightning equipotential bonding, here selected according to LPL I ($P_{EB} = 0.01$) [8].
- Protection of zones Z_2, Z_3, and Z_4 by means of a coordinated SPD system according to IEC 62305-4 [9] better than for LPL I ($P_{SPD} = 0.002$) for the internal power supply and telecommunication system. As a result, the risk components R_C, R_M, R_W, and R_Z are reduced.

TABLE IX. RISKS R_1 AND R_2 FOR THE GAS STATION WITHOUT AND WITH PROTECTION (VALUES X 10^{-5})

Risk	Unprotected	Protected
R_1	252.23	0.60
R_2	10163	27.20

G. Evaluation of risk R_4, risk of loss of economic value

To be able to determine the possible loss of economic value, the values of the relevant zones must be defined. These are subdivided as follows (Table X):

- c_b : Value of the building, for the zone;
- c_c : Value of the content in the zone;
- c_s : Value of internal systems in the zone;
- c_t : Total value of the structure.

TABLE X. ECONOMIC VALUES FOR THE GAS STATION

Value	Zone 2 (Z_2)	Zone 3 (Z_3)	Zone 4 (Z_4)
c_b	375,000 €	375,000 €	375,000 €
c_c	50,000 €	50,000 €	50,000 €
c_s	75,000 €	75,000 €	75,000 €
c_t	500,000 €	500,000 €	500,000 €

When considering the risk R_4, it can be seen that particularly the risk resulting from component R_Z (indirect lightning strike next to incoming/outgoing supply lines, S4) frequently occurs. To reduce the loss of economic value to an acceptable level, at least surge protection measures must be provided.

Finally, if the protection measures defined in Chapter IV.F, necessary to reduce the risks R_1 and R_2 to a tolerable value, are considered for the loss of economic value the results in Table XI are obtained for the damage costs.

TABLE XI. DAMAGE COSTS FOR THE UNPROTECTED AND PROTECTED STRUCTURE

Protection	Damage costs
Unprotected	C_L = 222,849 €
Protected	C_{RL} = 549 €

The costs for the protection measures defined are assumed to be C_P = 26,800 € in total. The annual costs then are estimated to be C_{PM} = 3,484 €. The annual saving S in money is given by:

$$S = C_L - (C_{RL} + C_{PM}) \tag{10}$$

In case of the investigated gas station the annual saving is S = 218,815 €. Consequently, the protection measures, necessary to prevent loss of human life and service to the public, also reduce the loss of economic value to an acceptable level.

V. CONCLUSIONS

If a risk analysis according to IEC 62305-2 [3] is performed for structures with a risk of explosion purely on the basis of this standard, usually very high risk values are obtained. To facilitate the application and to obtain more realistic results for such cases, the Supplement 3 to DIN EN 62305-2, "Additional information for the application of DIN EN 62 305-2" [4] is established in Germany.

Basis for the detailed consideration of the presence of an explosive atmosphere is the definition of Ex zones. This is required by 1999/92/EG [5].

The Supplement 3 to DIN EN 62305-2 [4] enables the users to evaluate in detail structures with the risk of explosion and to define tailored protection measures. This Supplement prepared together with and accepted by the German authorities having jurisdiction is used successfully since 2013.

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