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# METHODOLOGY FOR ANALYSIS, ASSESSMENT AND CLASSIFICATION OF MAJOR-ACCIDENT HAZARDS (EXPLOSION) IN THE CASE OF EXPLOSIVES DEPOTS

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***Abstract:*** *This paper presents a methodology for the analysis, assessment and classification of explosive hazards in the case of landfills, including the quantification of possible effects on neighborhoods and on human health and the environment.*

**Keywords: major-accident hazard, explosion scenarios, security measures, probability, consequences**

## 1. Introduction

Major accidents involving hazardous substances pose a serious threat to both humans and the environment. However, the use of hazardous substances in this case, represented by explosives for civil use, might be inevitable in many industrial sectors with an high level of importance for a developed, industrialized society. To minimize the associated risks, major-accident prevention measures are needed to ensure an adequate level of preparedness and response in the event of such accidents. From a historical perspective, the industrial areas have been located outside the localities, in areas with low population density. This way of developing the industrial activity can be considered at the moment as outdated, due to the acceleration of the urbanization process, due to the interest of the population to approach the areas of economic interest.

## 2. Methodology for analysis, assessment and classification of major accident hazards (explosion) in case of explosive deposits, possible effects and delimitation of emergency planning areas

**2.1**. **The purpose** of developing a working methodology for the analysis and assessment of the risk of explosion and the delimitation of areas likely to be affected by the effects of a possible explosion at sites where specific activities for the production and storage of explosives for civil use are carried out is as follows:

- major accidents on an industrial site of explosives storage are represented by explosions, fires and emissions of toxic substances, the consequences can be serious, even catastrophic;
- risk quantification involves identifying the potential for failure of the various components of the system, which can be achieved by constructing accident

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sequences in the systems in which explosives are used or stored.

- explosive depots must be examined on the basis of the identification of the initiating events, and it will be established which of these possible initiating events are also physically possible.
- the accidental sequences are delimited, starting from an initiating event, errors or specific successes of the functionality of the protection measures, including here the human factor.
- a system of trees specific to accident sequences is obtained by prioritizing safety measures for each accident sequence;
- the methodology of analysis, assessment and classification of major accident hazards (explosion), in the case of explosives depots, allows the quantification of possible effects on neighborhoods and human health, including the delimitation of emergency planning areas;

**2.2. The logical model of accidental sequences. elaboration of explosion scenarios**

**2.2.1. Systematic identification of events initiating explosions**

The direct causes that may underlie the explosion-type events, specific to explosive operations, identified following the study on the literature as well as the events produced in Romania, have been structured in six general ways for ignition / explosion of explosive materials, as it follows: shock wave, mechanical energy, thermal energy, electricity, chemical instability / reactivity, electromagnetic radiation.

These 6 direct causes have been further detailed, being identified a number of 15 initiating events (triggering factors), which, being located at the base of the event tree, represent direct causes of the explosion / ignition type event and are described below in Table 1.

*Table 1 Triggers identified*

| Symbol | Description | Symbol | Description |
|---|---|---|---|
| **D1** | Incompatible explosives | **D9** | Sparks from malfunction of electrical equipment |
| **D2** | Car accident inside the warehouse | **D10** | Sparks due to static electricity |
| **D3** | Plane crash | **D11** | Chemically unstable explosives |
| **D4** | Earthquake | **D12** | Impurities in the composition of explosives |
| **D5** | Explosions in the neighborhood | **D13** | Electro-explosive devices |
| **D6** | Impact sensitive explosives | **D14** | Outdoor fires |
| **D7** | Friction sensitive explosives | **D15** | Indoor fires |
| **D8** | Atmospheric surges, lightning | | |

**2.2.2. Identify specific security measures**

In accordance with the triggers identified in the previous paragraph, a number of specific safety measures, technical or organizational, have been identified to ensure that both explosion prevention and limitation of possible effects should occur if the explosion occurs. All identified - technical and organizational measures are listed in Table 2 and Table 3.

**2.2.3. Development and graphical presentation of event trees and accident scenarios / sequences**

At this stage, the accident sequences and event trees were developed for each of the 15 triggers presented in Table 1, for each of

these scenarios being identified and presented the security barriers that can be applied (technical and / or organizational measures) are being identified and presented. These are presented below for the trigger factor D1- Incompatible explosives stored together.

The graphical presentation of the event tree for the trigger factor type D1 - Incompatible explosives stored together is made in Figure 1 and the accident sequences are shown in Table 4.

*Table 2 Technical safety measures for explosives depots*

| Symbol | Name of the measure |
|---|---|
| T1 | Constructive protection of the warehouse (building) - type of warehouse |
| T2 | Arrangement of separate rooms for storage of incompatible explosives |
| T3 | Protective barriers between storage rooms |
| T4 | Shock-resistant equipment |
| T5 | Racks and shelves arranged so that the impact energy is less than the ignition energy |
| T6 | Storage of explosives on shelves racks in packing boxes so as to avoid friction and / or frictional energy less than the ignition energy |
| T7 | Lightning protection |
| T8 | Earthing of electrical equipment and protection of personnel |
| T9 | Explosive distribution flow adapted to reduce storage time |
| T10 | Prevention of contact with impurities - Maintenance and cleaning of storage spaces |
| T11 | Explosion-proof encapsulation of electrical equipment |
| T12 | Disposal of sources |
| T13 | Dispersion currents with energy lower than ignition energy |
| T14 | Elimination of laser radiation sources |
| T15 | Elimination of radio sources |
| T16 | Elimination of mobile telephone radiation sources |
| T17 | Outdoor and indoor fire detectors |
| T18 | Trained operators for fire detection and operational intervention |
| T19 | Water tanks, wells water or connection of the storage to the water network, fire hydrants |
| T20 | Equipped with high pressure pumps, diesel or electric pumps |
| T21 | Equipped with sprinklers, sprinklers |
| T22 | ADR authorized vehicles, fire protected |
| T23 | Fire extinguishers |
| T24 | Barricades, fences, earth waves for protection of the deposit |

As can be seen from the figures presented for each of the possible triggers of an explosion in the explosives depot, in the first phase the technical and organizational measures were identified that lead to the reduction of the risk of explosion, thus constituting prevention measures, after which measures have been identified which, in the event of an explosion, lead to the limitation of its effects as well as the area in which these effects may occur.

**2.3. Assess the probability of explosion and quantify the consequences**

After identifying the accidental sequences and elaborating the event trees, the next step is to evaluate the probability of the explosion and quantify its possible consequences.

For a correct classification of major-accident hazards, the probability of occurrence and the effects of the accident must be taken into account. Thus, the level of risk is defined as the product between the probability of an event occurring and the severity of its effects and consequences, according to equation 1:

**Risk (R) = Probability (F) x Consequences (G) (1)**

*Table 3 Organizational safety measures for explosives depots*

| Symbol | Name of the measure |
|---|---|
| O1 | Procedures for avoiding the joint storage of incompatible explosives |
| O2 | Procedures for labeling explosives by compatibility groups |
| O3 | Procedures for licensing and licensing of vehicles and drivers for the transport of dangerous goods (ADR) |
| O4 | Procedures for limiting the speed of vehicles transporting explosives inside the site |
| O5 | Procedures for clearing of vegetation inside the warehouse |
| O6 | Procedures for operating / maintenance procedures to avoid shocks caused by impact |
| O7 | Procedures for handling, loading / unloading and transport to avoid shocks caused by impact |
| O8 | Procedures for selecting equipment to reduce impact, shock absorption |
| O9 | Procedures for handling, transport and storage for prevention and reduction of contact and friction between stored explosives |
| O10 | Verification of equipment according to ATEX procedures |
| O11 | Procedures for performing explosives stability tests |
| O12 | Procedures for adapting explosives storage flow to shorten storage times |
| O13 | Quality control |
| O14 | Production control |
| O15 | Procedures for space maintenance and cleaning |
| O16 | Procedures and checks for measuring electromagnetic fields |
| O17 | Procedures for preventing laser radiation |

Based on the criteria for evaluation / assessement of the severity of the consequences of the explosion - materialized in the adoption of conventional scales for quantifying the severity of G - and establishing their limits of acceptability, the P - G coordinate plan delimits three areas characteristic of technical risk / technological.

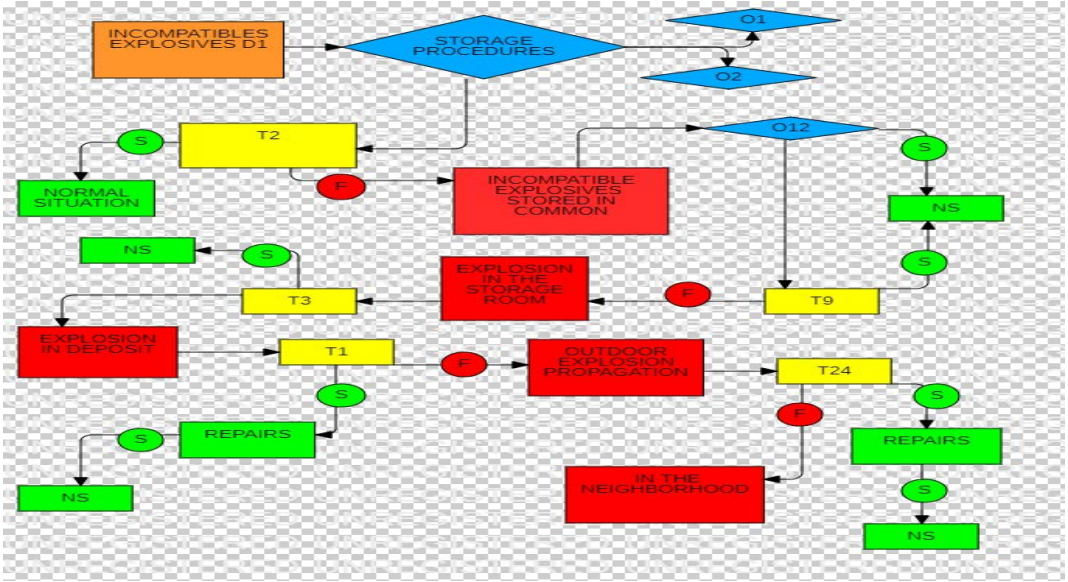



*Figure 1: Event tree for trigger factor D1 - Incompatible explosive*
*where Technical (T) and Organizational (O) safety measures are described in the Tables 2 and 3*

*Table 4 Accident sequence table for trigger factor D1 - Incompatible explosives*

| | |
|---|---|
| D1*O2e*O1e*O12e*T2e*T9e*T3e*T1e*T24e | D1*O2e*O1e* O12e *T2e*T9e*T3r |
| D1*O2e*O1e* O12e *T2e*T9e*T3e*T1e*T24 r | D1*O2e*O1e* O12e *T2e*T9r |
| D1*O2e*O1e* O12e *T2e*T9e*T3e*T1r*T24r | D1*O2e*O1e* O12e *T2r*T9r |
| D1*O2e*O1e* O12e *T2e*T9e*T3e*T1r | D1*O2e*O1e*T2r |
| D1*O2e*O1e* O12e **T2e*T9e*T3r*T1r*T24r | D1*O2r*O1r*T2r |
| D1*O2e*O1e *O12e **T2e*T9e*T3r*T1r | |

The risk matrix, developed based on the Layer of Protection Analysis (LOPA) analysis method for the explosion hazard classification, is presented in Table 5, where the values of the risk level corresponding to the three areas presented above are:

- **1-6 - the field of negligible risk** - risk associated, as a rule, with the assignments / defects or minor, rare and very rare damages;
- **6-16 - acceptable risk range** - risk associated with frequent minor damage (or major damage;
- **> 16 - unacceptable risk area** - risk associated with major or frequent damage.

*Table 5 Risk matrix for identifying major accident hazards*

| Consequences / Frequency | Insignificant G1 | Lower G2 | Media G3 | Big G4 | Very big G5 | Catastrophe G6 |
|---|---|---|---|---|---|---|
| F6 | 6 | 12 | 18 | 24 | 30 | 36 |
| F5 | 5 | 10 | 15 | 20 | 25 | 30 |
| F4 | 4 | 8 | 12 | 16 | 20 | 24 |
| F3 | 3 | 6 | 9 | 12 | 15 | 18 |
| F2 | 2 | 4 | 6 | 8 | 10 | 12 |
| F1 | 1 | 2 | 3 | 4 | 5 | 6 |

The interpretation of the level of consequences of a major accident on human health and the effects produced in the vicinity, on the environment, constructions is presented in Table 6.

*Table 6 The level of consequences of a major accident on human health and the effects produced in the neighborhood*

| Conseq-uences | Insignifi-cant G1 | Lower G2 | Media G3 | Big G4 | Very big G5 | Catastro-phe G6 |
|---|---|---|---|---|---|---|
| Man | No effects | Minor injuries | Hospitaliza-tion | Hospitaliza-tion, disabilities | Disabilities, death | Death |
| Environ-ment | No effects | Slight damage, quick fix | Significant damage, possible repair | Major damage, difficult repair | Severe damage, difficult or impossible repair | Serious damage, disasters |

The probability classes to be considered are shown in Table 7. The quantification of the frequency of all accident sequences begins with the determination of the general frequency of accidents for the best possible location, in which all possible safety measures are implemented, hereinafter referred to as “full” location.

*Table 7 Probability classes of the event*

| CLASS | PROBABILITY | The value of probability |
|---|---|---|
| **F1** | NEAR IMPOSSIBLE | $P<10^{-6}$/ year |
| **F2** | RARE | $P-10^{-5} – 10^{-6}$/ year |
| **F3** | IMPROBABLE | $P\ 10^{-5} – 10^{-4}$/ year |
| **F4** | POSSIBLE | $P\ 10^{-4} – 10^{-3}$/ year |
| **F5** | PROBABLE | $P\ 10^{-3} – 10^{-2}$/ year |
| **F6** | VERY PROBABLE | $P10^{-2} – 10^{-1}$/ year |

The tree specific to a certain type of installation is based on the "complete" sequence of accidents. If a specific safety measure has not been provided in an installation, then it is removed from the "complete" sequence. As a result, sequences involving the success of a system are eliminated, leaving only sequences involving failure (failure), which equates to the redevelopment of event trees without the missing measures.

## 3. Conclusions

This paper describes tools and solutions to support those involved in site-specific explosion risk assessment for the storage of explosive materials, as follows:

- Identify and analyze all possible occurrences of initiating events that could lead to a potential explosion at an explosives storage site;
- Identification, inventory, analysis and prioritization of security measures that could be adopted such as technical barriers or organizational measures;
- Carrying out the analysis of explosive deposits by the event tree method (AAE) and their elaboration;
- Delimitation of accidental sequences, starting from an initiating event, errors or specific successes of the functionality of protection measures, grouping them into classes;
- Elaboration of the methodology for analysis, assessment and classification of major accident hazards (explosion) in the case of explosives depots, quantification of possible effects on neighborhoods and human health, necessary tool for delimiting emergency planning areas.

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