MATEC Web of Conferences **373**, 00046 (2022) https://doi.org/10.1051/matecconf/202237300046
*UNIVERSITARIA SIMPRO 2022*

# Analysis of dangerous situations generated by explosive materials in non-compliant operations performed on industrial locations intended for their storage

*Cristian* Radeanu[1*], *Gabriel* Vasilescu[1], *Ciprian* Jitea[1], *Ladislau* Radermacher[2] , and *Gabriel* Ilcea[3]

[1]National Institute for Research and Development in Mine Safety and Protection to Explosion – INSEMEX Petrosani, G-ral V. Milea Street 32-34, Petrosani, Romania
[2]University of Petrosani, Department of Mining Engineering, Topography and Constructions, Universitatii Street 22, Petrosani, Romania
[3]University of Petrosani, Department of Automation, Computers, Electrical and Energy Engineering, Universitatii Street 22, Petrosani, Romania

**Abstract.** Design and efficient implementation of OSH management in the field of explosives for civilian use, having the effect of optimizing the activity of preventing unwanted events blast type specific to industrial locations intended for the preparation / storage of explosives for civil use, constitutes it explosion risk assessment which represents the integrated expression of the configuration components of this type of risk within the different accident scenarios. No matter what it's about a component within the location or his integral technical infrastructure such an analysis allows the identification and ranking of site specific accident hazards to be assessed, in order to properly allocate security resources for priority measures to prevent and combat / eliminate the causes of these types of dangerous events. To this end, the "Security Document" specific to the industrial site intended for specific operations with explosive materials must demonstrate that: an appropriate accident prevention policy and an effective safety management system have been implemented; the dangers of injury are identified and the necessary measures are taken to prevent them and to limit their consequences for man and the environment; in design any installations has been incorporated adequate safety and reliability for construction, operation and maintenance; emergency plans have been drawn up.

## 1 Introduction

Proper management of occupational safety and health with regard to full control of existing accident hazards at explosives storage sites must demonstrate that: an appropriate accident prevention policy and an effective safety management system have been implemented; the

* Cristian Radeanu: cristian.radeanu@insemex.ro

dangers of accidents are identified and the necessary measures are taken to prevent them and limit their consequences for man and the environment; in the design of any installation (technical unit within a site, located at or below ground level, in which hazardous substances are produced, used, handled or stored) the appropriate safety and reliability for construction, operation and maintenance has been incorporated; emergency plans have been drawn up [1, 2].

Starting from the definition of the notion of risk, which represents the danger / probability of destruction, general loss and / or the probability of a specific effect in a specified period or circumstance, in order to identify the hazards, the first step is to select an appropriate methodology, in order to systematically identify the hazards specific to the installation [3].

The analysis of hazardous situations generated by explosives in non-compliant operations performed on industrial sites intended for their storage has as general objective the assessment of the explosion risk specific to these storage activities in order to prevent and control the risks specific to such a site, by: description of the location and its environment (situation plan, areas in the immediate vicinity); description of existing facilities at the site level (main activities and technological processes); description of hazardous substances (physico-chemical and toxicological characteristics, storage, etc.); identification of sources of risk of explosion within the activities carried out at the site; analysis and assessment of the explosion risk generated by explosive materials (site zoning: risk curves, overpressure curves, contour maps regarding the design of fragments resulting from detonation, configuration of the main explosion risk scenarios and their production conditions); assessment of the exposure of on-site staff as well as the surrounding population; establishing technical and organizational prevention and protection measures to reduce and combat the risk of explosion [4, 5].

## 2 Methodological considerations for the probabilistic explosion risk assessment specific to industrial sites intended for the storage of explosives

In order to identify potential major accidents that may occur on industrial sites intended for the storage of explosives, a qualitative assessment of the risk associated with possible accident scenarios was performed.

The qualitative analysis aims to establish the list of possible accidents, making it possible to rank the events in the order of risks, identified based on the relationship:

$$Risk = Event\ probability\ x\ Severity \tag{1}$$

The measure of the probability of occurring can be achieved by falling into the following 5 levels: *unlikely* - can occur only in exceptional conditions; it is so unlikely that it can be assumed that it never happens; *isolated* - it could happen someday; it is unlikely to occur during the operation period of the objective; *occasionally* - it may happen sometime; it is possible to occur at some point during the operating period; *probably* - it can happen in certain situations; it can occur several times during the entire operation; *frequent* - happens in many situations; they are likely to occur frequently [6].

In order to take into account the risk specific to human health, a more complex version of the equation may be adopted, namely:

$$Risk = Event\ probability\ x\ Severity\ x\ Exposure \tag{2}$$

Equation (2) is a direct derivative of equation (1), where the probability of the event (in this case, the explosion) is expressed in terms of probability of the event and severity of consequences (the probability of fatality), also taking into consideration the presence of people, namely the exposure. To estimate the probability of fatality for a person (per year), $P_f$, the following equation is used:

$$P_f = P_e \times P_{\frac{f}{e}} \times E_p \tag{3}$$

where:

$P_e$ is the annual probability for an event (e.g. explosion) to occur on the site of the explosion (source type structure which implies the existence of explosive materials for specific operations).

$P_{f/e}$ is the fatality probability due to an event such as an explosion and the presence of at least one person.

$E_p$ is the exposure of one person in a source type location given the conditions of a well-defined time span (one year).

In addition to individual risk, consideration should be given to societal risk, which provides a mechanism to estimate the total number of people affected by the event. Thus, the term $E_f$, which may be applied to a group of people, represents the risk combined with the fatality of the people from the group (also called a group risk). $E_f$ can be defined as the sum of individual risks and offers a statistical perspective of the assessed scenario as a mathematical expectancy or an anticipated value (for instance the average number of deaths anticipated per year) as it is given by the following equation:

$$E_f = \sum \left( P_e \times P_{\frac{f}{e}} \times E_p \right) \tag{4}$$

The first term of the risk equation (4) is the probability of the event, Pe. This term is used to assess the probability of an event (e.g. explosion) to occur at a site of the explosives depot and can be defined as a function of three parameters:

- The specific activity (the type of activity);
- The store of the explosive products by groups of products considering their compatibility from a destructive energetic point of view (sensitivity);
- Environmental factors (external factors).

The second term of the risk equation (4) is the probability of fatality given by the type of explosion occurring in the presence of an exposed person, $P_{f|e}$. This term is determined by taking into consideration the possible lethal results at the level of the exposed site (exposed structure type) due to multiple hazardous mechanisms. The potential mechanisms of lethal accidents are analysed in parallel and may be grouped as follows:

- Overpressure/impact impulse (the explosion creates a shockwave described both through overpressure, and through the impact impulse);
- The structural response (overpressure and impact impulse specific to the exposed site-exposure type structure). Two consequences are therefore assessed: the fracture, separation, and projection of fragments from the structure (such as glass from windows) and the partial or total collapse of the building;
- The debris, i.e., the material composed of hazardous products, comes from three sources: main debris (explosive materials), secondary debris (at the level of a source type structure) and debris resulted after the impact (for instance from the crater which may be the result of the explosion);
- The radiation/the thermal flux, used only for the hazardous division (HD) 1.3 explosives – mass fire (Explosives regulations, 2014).

During the assessment process, the hazards corresponding to the exposed people are estimated based on different algorithms and models specific to each type of hazard [7, 8].

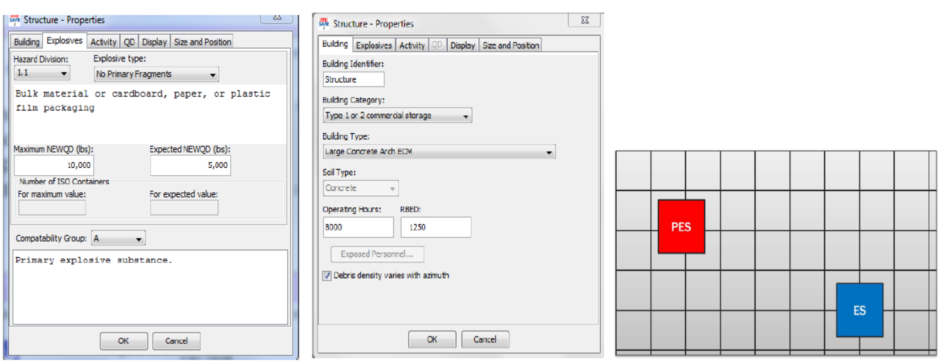
## 3 Computerized explosion risk assessment specific to industrial sites intended for activities in the field of explosives for civil use

IMESAFR v2 (IME Safety Analysis For Risk) is a specialized probabilistic assessment risk software for explosives storage unit personnel that calculates QD (Quantity Distances) - safety distances from explosive depots and can determine the level of safety based on the risk esteemed and appreciated.

This quantitative risk assessment tool is intended to calculate the risk to personnel performing operations on industrial sites intended for activities in the field of civil explosives. The analysis involves the following steps:

Definition of the scenario, events analysis, and exposure. This step also includes user inputs to describe the scenario (for the industrial location which comprises the source type and exposure structures) and the existing net explosive weights, and determines the probability of the event, exposure, and efficiency. To make this possible the specialized software needs user inputs to describe the scenario (for the industrial location that includes the source type and exposure structures) and details about the explosives analyzed (net masses), and determines the probability of the event, exposure and efficiency. . Information is gathered that defines the structure and operations of the PES. This information is used to define the characteristics of the PES and to calculate the probability of the event, $P_e$. Enter the ES structure and exposure data of the persons, then calculate the exposure parameter. Calculate the outdoor overpressure, $P_1$, and the impact impulse, $I_1$ [9].

As an example, Figure 1 shows the input data related to explosives (Figure 1a), data related to the source type structures (Figure 1b), and data related to the source type and exposure type structures (Figure 1c).




a b c

**Fig. 1.** Types of data required at the input: a) data related to explosives; b) data related to the source type structures (PES); c) data related to the source type and exposure type structures (ES).

- The overpressure / impact impulse, which determines the value of the pressure and the fatality mechanisms based on the impact impulse;

- The structural response on the exposed site (exposure structures), which determines the level of damage to the structural and non-structural elements of the building and the number of accidents that resulted in deaths or injuries;

- Debris, ie material resulting from an explosion and projection of fragments, which determines the extent of the mechanisms of hazardous debris and accidents resulting in death or injury;

https://doi.org/10.1051/matecconf/202237300046

- Radiation and heat flux, which determines the importance of the fatality mechanism caused by the heat factor);
- Quantification of final results through mechanisms of analytical composition, aggregation and summation.

At this stage, risk situations and general uncertainty are assessed [10].

# 4 Case study: Exploration of the explosion risk specific to the activity of preparation and storage of the simple mixture of AUSTINITE type at the level of the industrial site intended for the storage of explosive materials located in Bixad locality, Covasna county

## 4.1 Description of the industrial site and its environment

The site is located in the Bixad tectonic depression, on the administrative territory of Micfalău commune, Micfalău locality, out of town, on the border with the Bixad administrative administrative unit, at a distance of about 2.0 km from the center of Bixad, to the south, at a distance of about 2.0 km from Micfalău, to the north. The existing constructions in the urban area of Bixad commune (3 private houses and household annexes) are located at a distance of 325 m from the site boundary, the stone quarry of CARB SA is at 717m and the European road E578 (DN12) at 480 m (see Figure 2).


**Fig. 2.** The relationship of the location with the urban area of Bixad commune.

https://doi.org/10.1051/matecconf/202237300046

Within the site there are the following constructions: two buildings for storing explosives for civil use, office, warehouse, locker room, shed for storing porous ammonium nitrate, workshop for mixing production of ANFO type explosive (see Figure 3).

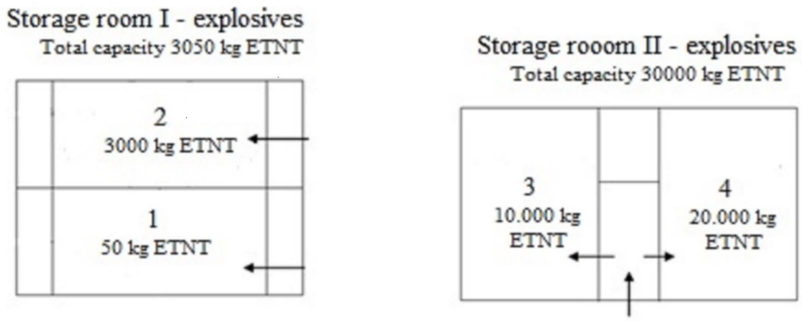



**Fig. 3.** Total storage capacities in trinitrotoluene net mass (ETNT).

The storage rooms where the explosive materials are stored are surrounded by earth waves on three sides with the dimensions indicated in the Technical Norm to Law 126/1995 with subsequent amendments and completions. The land is surrounded by two barbed wire fences. Explosives are storage on shelves or pallets. The boxes are placed on shelves in a single row. When placing the materials, the provisions of Law 126/1995 will be observed with the subsequent modifications and completions [11, 12].

## 4.2 Computer simulation of the level of damage generated based on the main accident scenarios that could occur at the industrial site for storage of explosives located in Bixad, as a result of the preparation and storage of simple explosive mixture type ANFO

The main scenarios imagined, the conditions under which they would occur, the events that may contribute to their onset, to assess the amplitude and severity of the consequences of the major accident are highlighted in Table 1 as reference scenarios.

**Table 1.** Detailed description of the reference scenarios.

| **Identif. reference scenario** | **A** | **B** | **C** | **D** |
|---|---|---|---|---|
| **Event** | **Explosion of a quantity of 50 kg ETNT (Room 1)** | **The mass explosion of a quantity of 3000 kg ETNT (Room 2)** | **The mass explosion of a quantity of 10000 kg ETNT (Room 3)** | **The mass explosion of a quantity of 20000 kg ETNT (Room 4)** |
| **Location possible** | Storage room I Detonating caps | Storage room I AUSTINITE (ANFO) | Storage room II AUSTINITE (ANFO) | Storage room II AUSTINITE (ANFO) |
| **Causes / Effects** | **Possible causes** - Mistake of handling or storage, slamming of staple boxes or falling off the shel; | **Possible causes** -The fall of the lightning rod system; -The effect of atmospheric electricity that causes the mass explosion of the explosive | **Possible causes** - Castrophic situations such as a large-scale earthquake that causes the collapse of the constructive elements; | **Possible causes** -Catastrophic situations such as a large-scale earthquake that causes the collapse of construction elements; |

| | | | | |
|---|---|---|---|---|
| **Causes / Effects** | - A large-scale earthquake that causes two boxes to fall off the shelf.<br>**Effects:**<br>The shock generated by the explosion can cause::<br>- Injury, death of surprised staff;<br>-Possibility to extend the explosions to the entire quantity stored in the room;<br>-The domino effect;<br>-Explosion of the entire amount of staples in the warehouse;<br>-Possibility of fires and their spread. | entire quantity of materials (from a storage room, respectively 3000 kg.<br>- Intrusion of unauthorized persons in order to steal explosives;<br>-Inappropriate handling of explosive boxes.<br>**Effects:**<br>The shock generated by the explosion can cause:<br>- Injury, death of surprised staff;<br>-Extension of the explosion to the other room of the warehouse;<br>-Possibility of fires and their spread;<br>-Noise and toxic gases that disperse immediately due to the speed of detonation or explosion. | - Catastrophic situations such as falling objects from the atmosphere (eg plane crash);<br>- The entry of unauthorized persons in order to steal explosives, improper handling of boxes with explosives;<br>**Effects:**<br>- Destruction of the warehouse building following the explosion;<br>-The death of the personnel caught in the explosion;<br>-Explosion of explosive materials in the other room of the warehouse;<br>-The effect of the shock wave of the explosion on the neighborhoods;<br>-Noise and toxic gases that disperse immediately due to the speed of detonation or explosion. | Catastrophic situations such as falling objects from the atmosphere (eg plane crash);<br>-The entry of unauthorized persons in order to steal explosives, improper handling of boxes with explosives;<br>**Effects:**<br>-Destruction of the warehouse building following the explosion;<br>-The death of the personnel caught in the explosion;<br>-Explosion of explosive materials in the other room of the warehouse;<br>-The effect of the shock wave of the explosion on the neighborhoods;<br>-Noise and toxic gases that disperse immediately due to the speed of detonation or explosion |
| **Way determination** | According to Annex No. 3a of the Technical Norms to Law 126/1995 with subsequent amendments and completions | | | |

The explosion is the sudden, intense emission of energy that is accompanied by loud noise, high temperature, flying fragments and pressure wave. It is considered as primary hazards that accompany the explosion: thermal radiation, overpressure and dangerous fragments.

Overpressure, the consequences of which are shown in Table 2, is the major hazard associated with an explosion, being caused by the energy emitted by the initial explosion. The pressure wave occurs almost instantly and can affect the population, buildings, trees, etc. The dangerous effect of overpressure can be maximum near and near the source decreasing as it moves away from it (Fig. 4 - 9). The evaluation of the effects is performed based on Law 126/1995 and the Technical Norm of application with subsequent amendments and completions [12].

**Table 2.** Possible consequences due to overpressure.

| **Area (color)** | **Overpressure value in front of the shock wave ΔPf (kg / cm2)** | **Effects on construction and human health** |
|---|---|---|
| **Zone of careful** (Red dashed line) | 0,05 /0,01 | -Loud noise, windows completely broken due to noise.<br>-Significant damage to reinforced concrete buildings, brick buildings with one or more floors, wooden houses, industrial constructions with metal frame / partially broken windows. |
| **Zone of affection light or reversible** (Yellow) | 0,15÷0,25 | Mild destruction to reinforced concrete buildings or brick and medium to wooden houses. |
| **Zone of serious or irreversible diseases** (Orange) | 0,25÷0,35 | -Medium damage to communal household, reinforced concrete and brick buildings, total destruction of wooden houses, medium destruction to metal constructions.<br>-Human injury: severe and moderate injuries, contusions, ringing in the ears. |
| **Lethal or mortality zone** (Red) | 0,35÷0,45 | -Total and major destruction of buildings.<br>-Human injury - lethal area, very serious injuries. |

The results obtained from the simulation, shown in Table 3, were compared with the safety distances provided in the applicable legislation, respectively Annex 3a of the Technical Norms to Law 126/1995 with subsequent amendments and completions.

**Table 3.** Evaluation the magnitude and severity of the consequences of the major accidents identified.

| **Overpressure value ($kg/cm^2$)** | 0,35÷0,45 | 0,25÷0,35 | 0,15÷0,25 | 0,01÷0,05 |
|---|---|---|---|---|
| **Effects on construction** | Total destruction | Damage strong and medium | Slight damage | Damage insignificant, broken windows In totality / windows partially broken |
| **Health effects humanity** | Lethal zone (m) | The area of serious (irreversible) affections and light (reversible) (m) | | The careful area (m) |
| **Reference scenario A:** ***Explosion of a quantities of 50 kg ETNT (Fig.4)*** | **18** | **22** | **31** | **307,0 ÷ 74,0** |
| **Reference scenario B:** ***Explosion of a quantity of 3000 kg ETNT (Fig.5)*** | **60** | **86** | **121** | **1202,0 ÷ 288** |
| **Overpressure value ($kg/cm^2$)** | 0,35÷0,45 | 0,25÷0,35 | 0,15÷0,25 | 0,01÷0,05 |
| **Effects on construction** | Total destruction | Damage strong and medium | Slight damage | Damage insignificant, broken windows In totality / windows partially broken |

https://doi.org/10.1051/matecconf/202237300046

| | | | | |
|---|---|---|---|---|
| **Reference scenario C:** ***Explosion of a quantities of 10000 kg ETNT (Fig.6)*** | **90** | **128** | **181** | **1795 ÷ 431** |
| **Reference scenario D:** ***Explosion of a quantities of 20000 kg ETNT (Fig.7)*** | **114** | **162** | **228** | **2262 ÷ 543** |
| **Affected population** | ~ 2 persons | ~ 4 persons | ~ 10 – 20 persons | ~ 1150 - 2500 persons |

The values obtained from the computer simulations do not take into account all the hazards that accompany the explosion phenomenon (scattering of fragments, seismic wave), as well as the forms of relief, there is the possibility that the effect of the explosion is actually diminished by the presence of different obstacles, earth waves, etc.), and the values presented should be higher than those produced in a real case (See the figures 4-7).

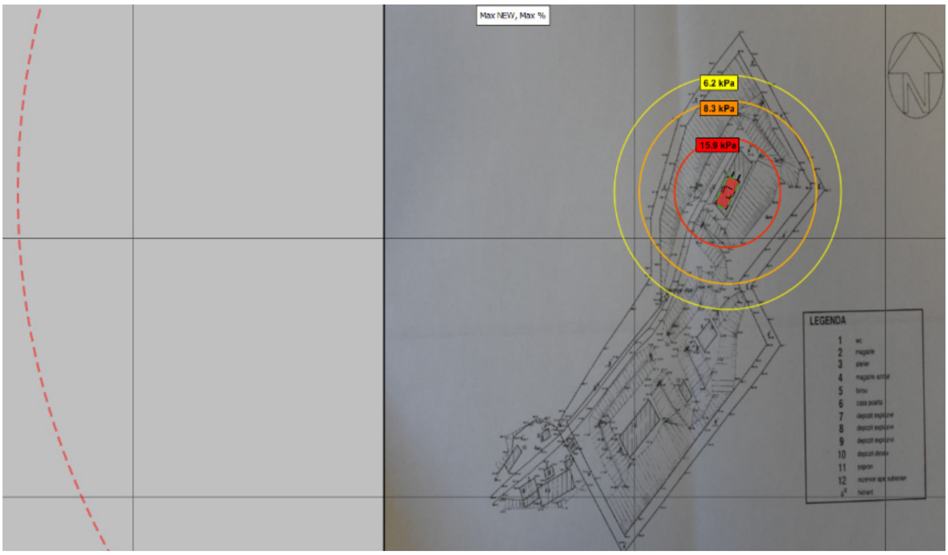



**Fig. 4.** Explosion of 50 kg ETNT (Reference Scenario A).

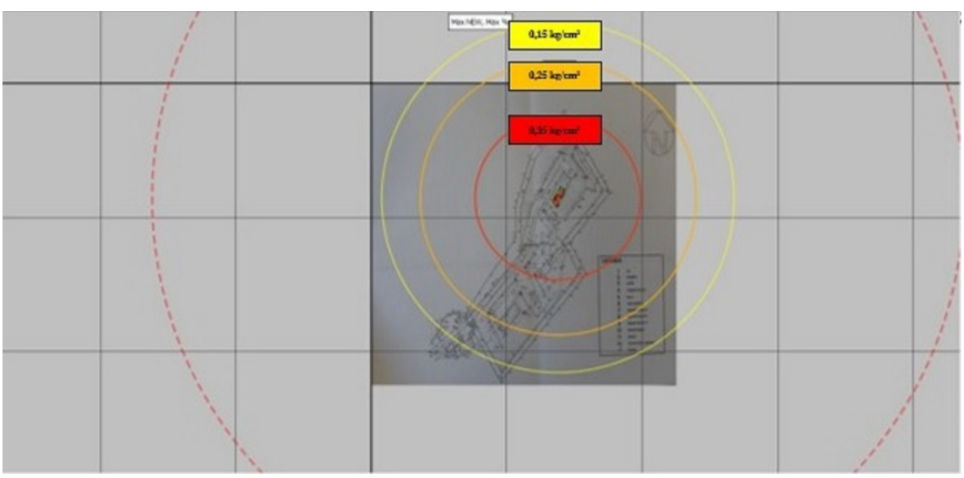



**Fig. 5.** Mass explosion of a quantity of 3000 kg ETNT (Scenario B).

https://doi.org/10.1051/matecconf/202237300046

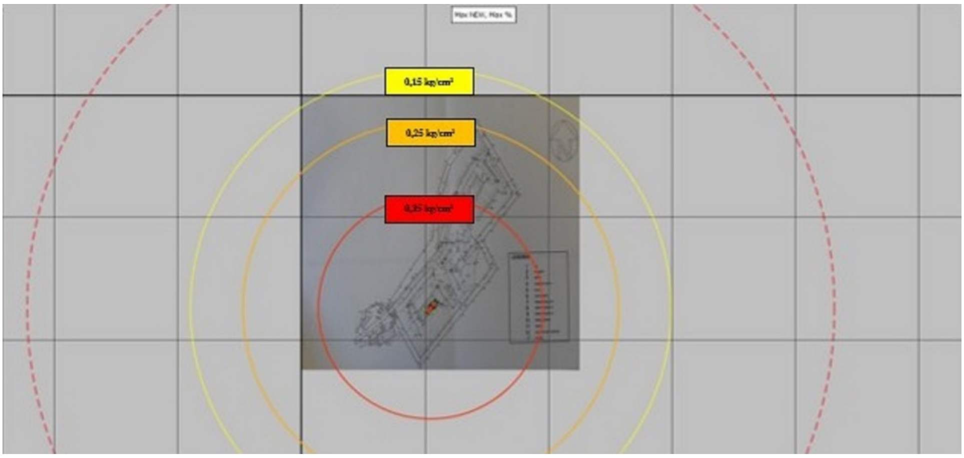



**Fig. 6.** Mass explosion of 10000 kg ETNT (Scenario C).

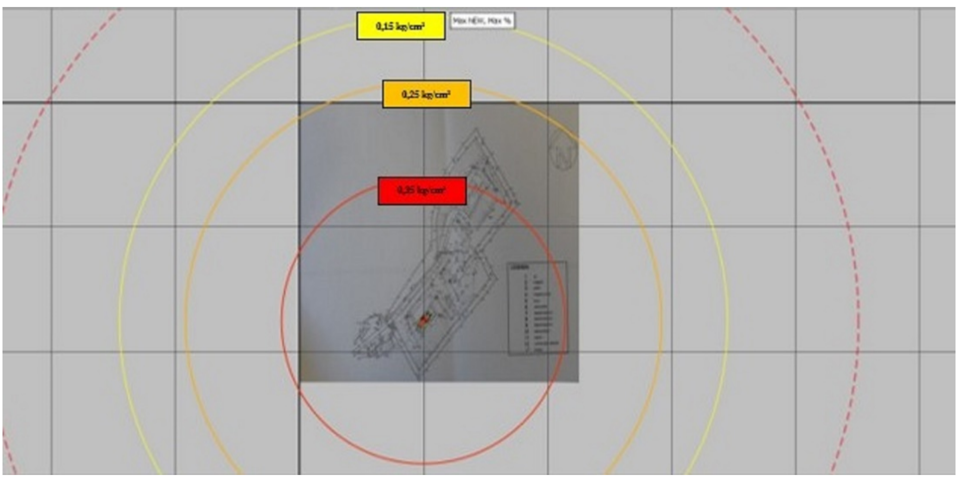



**Fig. 7.** Mass explosion of 20000 kg ETNT (Scenario C).

The overpressure of the shock wave front for which the safety distances given in Table 4 were calculated, represent the threshold values for specific effects on humans (zone I-mortality, zone II-major or irreversible lesions, zone III-medium or reversible lesions, zone IV-minor or insignificant injuries), according to the applicable legislation.

**Table 4.** Assessment of the consequences of major accidents identified on the human component.

| No. crt. | Identification code of the reference scenario | Location within the site | The amount of explosive (ETNT) | Area with effects | Determined radius (m) |
|---|---|---|---|---|---|
| 1. | A | Storage room I - Room 1: Detonating caps | 50 | Area I | 22 |
| | | | | Area II | 31 |
| | | | | Area III | 56 |
| | | | | Area IV | 115 |
| 2. | B | Storage room - Room 2 | 3000 | Area I | 86 |
| | | | | Area II | 86 |
| | | | | Area III | 121 |
| | | | | Area IV | 450 |

| No. crt. | Identification code of the reference scenario | Location within the site | The amount of explosive (ETNT) | Area with effects | Determined radius (m) |
|---|---|---|---|---|---|
| 3. | C | Storage room II – Room 3 | 10000 | Area I | 128 |
| | | | | Area II | 181 |
| | | | | Area III | 326 |
| | | | | Area IV | 673 |
| 4. | D | Storage room II – Room 4 | 20000 | Area I | 162 |
| | | | | Area II | 228 |
| | | | | Area III | 412 |
| | | | | Area IV | 848 |

## 5 Conclusions

From the analysis of the location of the areas in the immediate vicinity of the industrial site for the storage of explosives located in Bixad, there is no other location whose positioning to increase the risk or consequences of a major accident in case of emergency. The current access inside the warehouse can be made from DN12 located at 480 m from the location on a side access road. Also, considering that the distances in case of major accidents are 18 ÷ 114 m (mortality zone I) and 307 ÷ 2262 m (for the attention zone), it can be appreciated that the existing constructions in the area of Bixad commune, the stone quarry of CARB S.A. and the E578 road are located in the attention area of the site.

The explosion risk assessment specific to the studied industrial site was performed based on the identification and systematic analysis of potential hazards specific to the preparation and storage of simple ANFO type explosive mixture that may generate explosion events when hazardous substances such as civilian explosives are involved, in order to establish and substantiate the main possible accident scenarios, as well as the reference scenarios.

In order to identify the worst possible accident scenario at the level of the industrial site belonging to S.C. AUSTIN POWDER EXPLOSIVE S.R.L. reference scenarios (hypotheses) were defined and established, highlighting for each case the significant configuration aspects (scenario coding, type of event, possible location, causes / effects, production conditions, overpressure value, effects on constructions and on human health, the affected area, the result of computer modeling, etc.). From the analysis of the centralized situation of the results related to the explosion scenarios, it results that the recommended safety distance is 480 m from the limit of the studied industrial location.

Following the analysis of the dangerous situations generated by the explosive materials as a result of the development of the storage activities performed on the industrial sites destined for their storage, general prevention and protection measures of technical-organizational character can be provided, in order to prevent emergencies that may occur to the level of these categories of industrial sites, following the occurrence of type explosion events when hazardous substances such as explosives for civil use are involved.

This paper was developed within the “Nucleu Program (2018 – 2022)”, carried out with the support of Romanian Ministry of Research and Innovation, project no. PN-19-21-02-02 and title: “Development of the technical and methodological infrastructure for testing and evaluating security parameters specific to civil use explosives and pyrotechnic articles”.

## References

1. American Institute of Chemical Engineers AIChE. (2000). *Guidelines for Chemical Process Quantitative Risk Analysis*, **2nd Edition (Second Edition)**, New York
2. T. Aven, *Risk Analysis: Assessing Uncertainties Beyond Expected Values and Probabilities*. Wiley - UK, (2008)
3. C. Bejinariu, D.-C. Darabont, Baciu E.-R., I.-S. Georgescu, M.-A. Bernevig-Sava, C. Baciu, *Considerations on Applying the Method for Assessing the Level of Safety at Work. Sustainability*, **9** (7), 1263 (2017)https://doi.org/10.3390/su9071263
4. D.-C. Darabont, R.I. Moraru, A.E. Antonov, C. Bejinariu,. *Managing new and emerging risks in the context of ISO 45001 standard.* Quality-Access to Success, **18**, 11–14 (2017)
5. Explosives regulations. (2014). *Explosives regulations 2014: safety provisions: guidance on regulations*. Merseyside: Health and Safety Executive, HSE Books
6. A. Kovacs, G. Vasilescu, E.Gheorghiosu, D. Rus, I.-C. Jitea, S. Bordos,. *Appropriate management of preventing actions on health and safety for testing activities of high explosives in confined environment.* Quality-Access to Success, **18**, 93–96 (2017)
7. T. Ross, J. Tatom, IMESAFR Version 2.0, *Safety Assessment for Risk. Technical Manual*. A-P-T Research Inc, USA: Institute of Makers of Explosives (2015)
8. A. Ozunu, C. Anghel, *Evaluarea riscului tehnologic și securitatea mediului*, Ed. Accent, Cluj-Napoca, (2007)
9. S. Mannan, *Lees, Loss Prevention în the Process Industries. Hazard Identification, Assessment and Control*, Elsevier, Third Edition, Oxford, (2005)
10. Austrian Permanent Seveso Working Group, *Calculation of appropriate distances for the purposes of Land Use Planning, Emergency Planning and Domino Effects*.
11. F. Cavender, S. Phillips, M. Holland, *Development of emergency response planning guidelines (ERPGs)*, Journal of Medical Toxicology, **4** (2), 127-131 (2008)
12. ***Law no.126 of december 27,1995[*)] on the regime of explosives and Technical Standards with subsequent additions and amendments.