# Evaluation of the explosion risk specific to the preparation and storage activity of the simple explosive mixture type ANFO

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**Abstract.** The paper presents the results of the theoretical and practical research regarding the evaluation of the explosion risk specific to the activity of preparation/storage activity of the ANFO type explosive mixture, based on the identification and systematic analysis of the potential dangers that can generate explosion events, in order to establish and substantiate the possible accidents main scenarios, as well as reference scenarios. From a structural point of view, each accident scenario, defined at the level of the industrial site analyzed, is configured procedurally in synthetic form, comprising typical sections of methodological approach, respectively: location, description of the consequences (unimportant, important), evaluation of the risk of explosion (identification, estimation and appreciation) and measures to prevent damage/measures to reduce the risk of explosion.

## 1 Introduction

The paper provides the results of research in the field of the methodologies and algorithms that are used for calculating the risk of explosion specific to the operations with the explosives for civil used. The three elements of the methodology that are take into account, are the probability of explosion event, the probability of fatality given an explosion event, and the exposure of personnel. The models and algorithms presented in this paper are based on physics, but are anchored wherever possible by test and/or accident data. As additional test data become available, this information can be incorporated into the models as improvements or used to validate current predictions. In general, there are three types of quantitative risk assessment models: (1) physics-based, (2) empirical, and (3) semi-empirical.

Physics-based models can be developed to model explosives safety scenarios, however they are, by necessity, quite complex and therefore expensive to developed. Physics-based models may also assume behavior that does not exist in the real world. Empirical models, which report only data points available from tests and accidents, are by their nature limited in scope. Semi-empirical models, which use anchor points from available data but „*fill in the gaps*„ with physics-based algorithms, often offer the best compromise between development

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cost, capabilities, and acceptance of results. The methodologies presented in this paper are semi-empirical. The amount of conservatism is inversely related to the amount of available data. If there are very few (or no) data points available to anchor an algorithm, the model is designed to err on the side of caution. However, when an algorithm has been corroborated by test and/or accident data, the model does not include the same level of conservatism. This is important because the inclusion of conservatism would prevent model results from comparing, well with the empirical data anchor points (i.e., reality) [1,2].

# 2 General considerations regarding on the probability rules used

## 2.1. Theoretical rules used

*For cases of four events the addition rule can be extended as shown below (Fig.1):*
$P(X \cup Y \cup Z \cup W) = P(X) + P(X^C \cap Y) + P(X^C \cap Y^C \cap Z) + P(X^C \cap Y^C \cap Z^C \cap W) = P(X) + P(X^C)P(Y) + P(X^C)P(Y^C)P(Z) + P(X^C)P(Y^C)P(Z^C)P(W) = P(X) + [1-P(X)]P(Y) + [1-P(X)][1-P(Y)]P(Z) + [1-P(X)][1-P(Y)][1-P(Z)]P(W)$

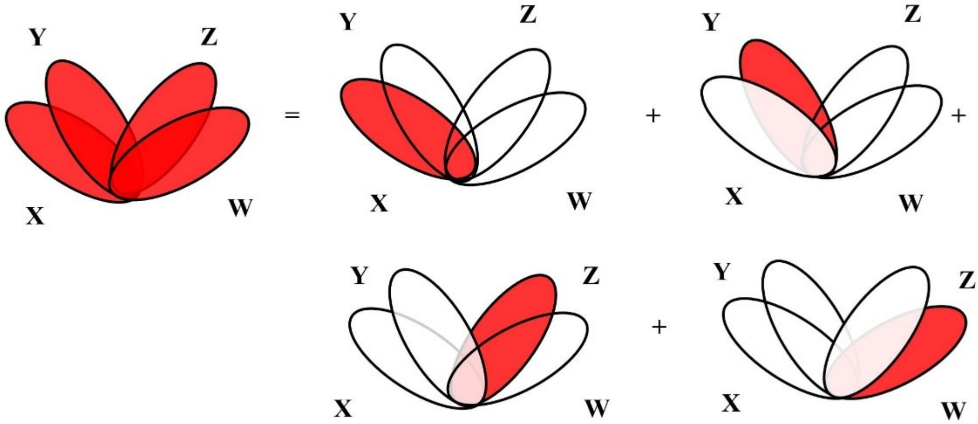


**Fig.1.** Probability rule for cases of four events

## 2.2. The risk equation based on the theoretical rules

The Quantitative Risk Assessment methodology presented in this paper is based on the concept of risk developed in 1662 by the French mathematician Blaise Pascal: *″Our fear of harm ought to be proportional not only to the magnitude of the harm, but also the probability of the event″* [3,4].

$$\text{Risk} = \text{Probability x (Consequence Level x Human Exposure)} \quad (1)$$

Equation (1) is a direct derivative of Pascal′s equation where the likelihood of an explosives event is expressed in terms of a probability, and undesired consequences are expressed in terms of the probability of fatality given the presence of people.

The Risk to Person(s) from explosives events (Annual Risk) is:

$$P_f = P_e \text{ x } P_{f/e} \text{ x } E_p \quad (2)$$

The $P_f$ is defined as the probability that an explosives event will occur per Potential Explosion Site (PES) per year and the $P_e$ is defined as the probability of event per year. The $P_{f/e}$ is defined as the probability of fatality given an explosives event and the presence of a person. $E_p$ is defined as the exposure of one person to a particular PES on an annual basis.

The expansion of $P_{f/e}$ term is the following:

$$\mathbf{P_{f/e} = P_{f/e\ (Overpressure/impulse)} + P_{f/e\ (Glass\ and\ Building\ Failure)} + P_{f/e\ (Debris)} + P_{f/e\ (Temperature)}} \quad (3)$$

Where:

- $\boldsymbol{P_{f/e\ (Overpressure/impulse)}} = P_{f(Overpressure)/e} = P_{f(Impulse)/e} + (1-P_{f(Impulse)/e}) P_{f(Building\ Failure,\ Debris)/e} + (1-P_{f(Impulse)/e})(1-P_{f(Building\ Failure,\ Debris)/e}) P_{f(Secondary\ fragments)/e}$
- $\boldsymbol{P_{f/e\ (Glass\ and\ Building\ Failure)}} = (1-P_{f(Impulse)/e})(1-P_{f(Building\ Failure,\ Debris)/e})(1-P_{f(Secundary\ fragments)/e}) P_{f(Glass\ Failure)/e} + (1-P_{f(Impulse)/e})(1-P_{f(Building\ Failure,\ Debris)/e})(1-P_{f(Secundary\ fragments)/e})(1-P_{f(Glass\ Failure)/e}) P_{f(Building\ Colapse)/e}$
- $\boldsymbol{P_{f/e\ (Debris)}} = (1-P_{f(Impulse)/e})(1-P_{f(Building\ Failure,\ Debris)/e})(1-P_{f(Secundary\ fragments)/e})(1-P_{f(Glass\ Failure)/e})(1-P_{f(Building\ Colapse)/e}) P_{f(Vertical\ debris)/e} + (1-P_{f(Impulse)/e})(1-P_{f(Building\ Failure,\ Debris)/e})(1-P_{f(Secundary\ fragments)/e})(1-P_{f(Glass\ Failure)/e})(1-P_{f(Building\ Colapse)/e})(1-P_{f(Vertical\ debris)/e}) P_{f(Horizontal\ debris)/e}$
- $\boldsymbol{P_{f/e\ (Temperature)}} = (1-P_{f(Overpressure)/e})(1-P_{f(Building\ Failure)/e})(1-P_{f(Debris)/e})(1-P_{f(Temperature)/e})$

# 3 Evaluation of the explosion risk specific to the preparation activity of the simple explosive mixture type ANFO

The starting point in the effective design and realization of SSM management in the field of civilian explosives, having as an effect the optimization of the activity of preventing unwanted explosion-type events, specific to the industrial sites intended for the preparation and storage of civilian explosives, is the explosion risk analysis and evaluation which represents the integrated expression of the configuration components of this type of risk in the different accident scenarios. Regardless of whether it is a component within the site (installation or part of the installation) or its integrated technical infrastructure, such analysis allows the identification and ranking of accident hazards specific to the evaluated site, in order to properly allocate the security resources for priorities measures for preventing and combating / eliminating the causes of these types of dangerous events. The proper management of the state of health and safety at work in order to achieve a full control over the accident hazards existing at the site level must demonstrate that: an appropriate accident prevention policy and an effective safety management system have been implemented; accidents hazards are identified and the necessary measures are taken to prevent them and to limit their consequences for humans and the environment; in the design of any installation the safety and reliability adequate for construction, operation and maintenance were incorporated; emergency plans were drawn up [5,6].

The activity carried out within Installation 1 - Surface storage for explosives for civil use, consists of keeping explosive materials in a specially arranged and designated place for this purpose, respectively in the permanent basic surface storage, which has an authorized capacity of 40.1 t ETNT or 43.811 t.

The activity carried out within Installation 2 - Production of ANFO type explosive (AUSTINITE) within the industrial sites intended for the preparation and storage of civilian explosives, consists of a technological process of mechanical mixing of porous ammonium nitrate and diesel within the WR-ANFO MIXER 1,000 type plant with a capacity of 40 kg / min., 8 t / day, having a periodic operation of approx. 1,100 t / yr. Also, the maximum amount of ammonium nitrate that can be stored in the warehouse is 60 t, and that of Diesel fuel is 0.845 t. This activity is carried out on the basis of the related authorization, for the preparation, production, holding, transport, placing on the market, storage, loading of explosive materials according to articles 8 and 9 of Law 126/1995, as subsequently amended and supplemented.

**The explosion** is the sudden, intense emission of energy that is accompanied by loud noise, high temperature, flying fragments and pressure wave. They are considered as primary hazards accompanying the explosion: thermal radiation, overpressure and dangerous fragments. All these hazards are not present in each explosion and the severity of the hazard varies from case to case. These hazards occur in the period immediately following the explosion. **Overpressure** 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 with the distance from it. The evaluation of the effects is carried out on the basis of Law 126/1995 and of the Technical Norm of application with the subsequent modifications and completions.

The results obtained from the simulation were compared with the safety distances provided by the applicable legislation, respectively Appendix 3a of the Technical Norms to Law 126/1995 with the subsequent modifications and completions. The values obtained from the computerized simulations do not take into account all the hazards that accompany the phenomenon of explosion (fragment scattering, seismic wave), as well as the relief forms, the possibility of the explosion effect being reduced in reality by the presence of different obstacles (trees, relief forms, ground waves, etc.), and the values presented are to be greater than those produced in a real case.

**Table 1.** Assessment of the magnitude and severity of the consequences of major accidents identified

| **The Overpressure values ($kg/cm^2$)** | **0.35÷0.45** | **0.25÷0.35** | **0.15÷0.25** | **0.01÷0.05** |
|---|---|---|---|---|
| **Effects on construction** | **Total destruction** | **Medium and strong destructions** | **Small destructions** | **Insignificant destruction, broken windows totality / partially broken windows** |
| **Human health effects** | **Lethal zone (m)** | **Serious disease area (irreversible) and mild disease area (reversible), (m)** | | **Attention area (m)** |
| **Reference scenario A: Explosion of a quantities of *50 kg ETNT (Fig.2)*** | **18** | **22** | **31** | **307.0 / 74.0** |
| **Objectives in the area on and off site** | Storage area and the one inside the earth wave | Storage area and the one inside the earth wave | | <u>On site</u>: SV - area deposit <u>Outside site</u>: NE, NV, V – stream valley E - agricultural land |
| **Affected population** | ~ 2 persons | ~ 2 persons | | ~ 20 persons |
| **Reference scenario B: Explosion of a quantity of *300 kg ETNT*** | **32** | **40** | **56** | **558.0 / 134.0** |
| **Objectives in the area on and off site** | Storage area and the one inside the earth wave | <u>On site</u>: warehouse area <u>Outside site</u>: NE, NV, V - stream valley | | <u>Outside site</u>: NE, NV, V - stream valley SV- access road to warehouse E, SE - agricultural land |
| **Affected population** | ~ 2 persons | ~ 2 persons | | ~ 20 persons |
| **Reference scenario C: Explosion of a quantity of *1,300 kg ETNT (Fig.3)*** | **52.6** | **63.8** | **90.6** | **898.1 / 215.6** |

| | | | | |
|---|---|---|---|---|
| **Objectives in the area on and off site** | Storage area and the one inside the earth wave | On site:<br>warehouse area<br>Outside site:<br>NE, NV, V - stream valley<br>E, SE - agricultural land | | Outside site:<br>N, E, V, S- agricultural land<br>SV- warehouse access road<br>V - dwelling house |
| **Affected population** | ~ 2 persons | ~ 4 persons | | ~ 20 persons |
| **Reference scenario D: Explosion of a quantity of *3,000 kg ETNT (Fig.4)*** | **60** | **86** | **121** | **1,202 ÷ 288** |
| **Objectives in the area on and off site** | Storage area and the one inside the earth wave | On site:<br>warehouse area<br>Outside site:<br>NE, NV, V – stream valley<br>E, SE - agricultural land | | Outside site:<br>N-stream valley stream, agricultural land<br>NE, E, SE, S - agricultural land<br>SV- warehouse access road, river, railway<br>V- river, railroad<br>NV-V- river, railroad. |
| **Reference scenario E: Explosion of a quantity of *20,000 kg ETNT (Fig.5)*** | **114** | **162** | **228** | **2,262 ÷ 543** |
| **Objectives in the area on and off site** | Storage area and the one inside the earth wave | On site:<br>warehouse area<br>Outside site:<br>NE, NV, V - stream valley<br>E, SE - agricultural land | Outside site:<br>NE, NV, V - stream valley, a dwelling house<br>SV- warehouse access road<br>E, SE - agricultural land | Outside site:<br>N - the stream valley, agricultural land<br>NE, E, SE - agricultural land<br>S - agricultural land<br>SV- road access depot, river, railway<br>V- river, railway<br>NV V- river, railway |
| **Affected population** | ~ 2 persons | ~ 4 persons | ~ 20 persons | ~ 2500 persons |
| **Reference scenario F: Explosion of a quantity of *10,000 kg ETNT*** | **90** | **128** | **181** | **1,795 ÷ 431** |
| **Objectives in the area on and off site** | Storage area and the one inside the earth wave | On site:<br>warehouse area<br>Outside site:<br>NE, NV, V - stream valley<br>E, SE - agricultural land | Outside site:<br>NE, NV, V - stream valley, a dwelling house<br>SV- warehouse access road<br>E, SE - agricultural land | Outside site:<br>N - the stream valley, agricultural land,<br>NE, E, SE, - agricultural land<br>S - agricultural land<br>SV- road access depot, river, railway<br>V- river, railway<br>NV V- river, railway |
| **Affected population** | ~ 2 persons | ~ 4 persons | ~ 10 persons | ~ 2500 persons |
| **Reference scenario G: Explosion of a quantity of *20,000 kg ETNT of ammonium nitrate stored due to a fire spread*** | **114** | **162** | **228** | **2,262 ÷ 543** |
| **Objectives in the area on and off site** | On site:<br>- The plant for the production of the explosive for civil use ANFO type - 40.1 t ETNT explosive storage facility for civilian use | On site:<br>-The two installations mentioned. Outside the site:<br>NE, NV, V - stream valley<br>E, SE - agricultural land | Outside site:<br>NE, NV, V - stream valley<br>V- dwelling house<br>SV- access road to warehouse<br>E, SE - agricultural land | Outside site:<br>S - agricultural land<br>NE, E, SE, - agricultural land<br>SV- warehouse access road, river, railway<br>V-river, railway<br>W-V- river, railway |
| **Affected population** | ~ 2 persons | ~ 4 persons | ~ 20 persons | ~ 2500 persons |

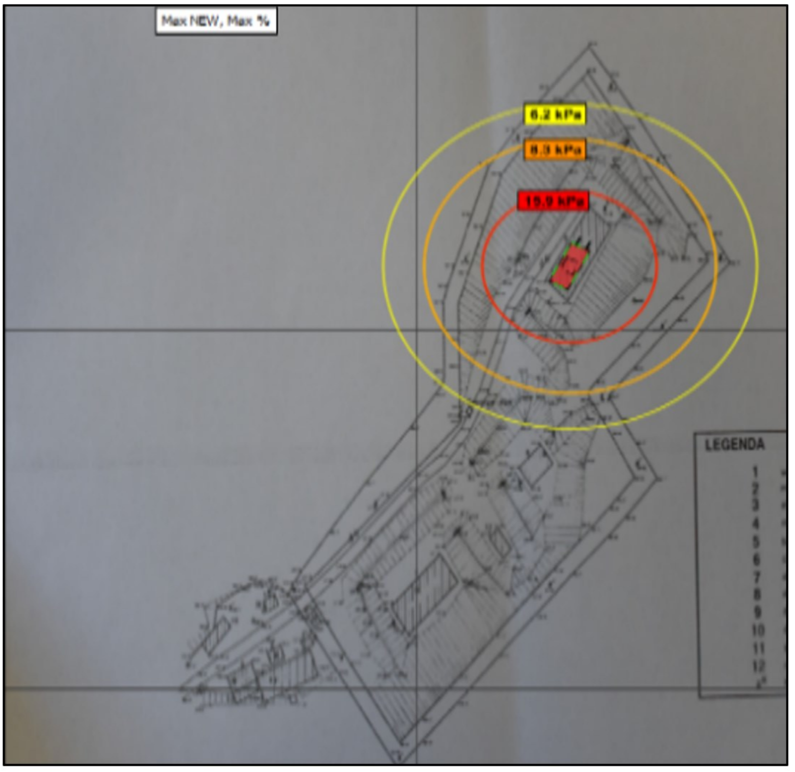


**Fig.2.** Graphical exemplification regarding the computerized assessment of the explosion risk of the baseline scenario A 50 kg ETNT, through the overpressure curves

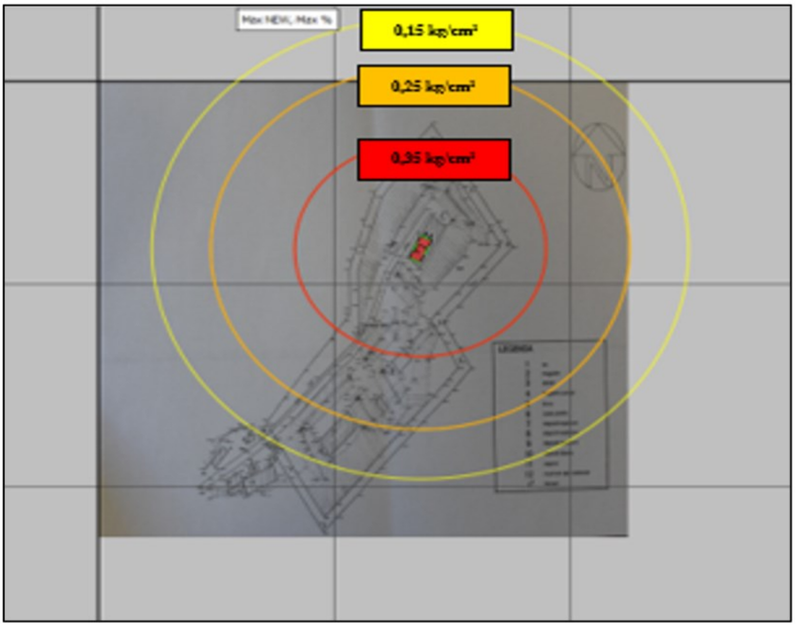


**Fig.3.** Graphical exemplification regarding the computerized assessment of the explosion risk of the baseline scenario C 1,300 kg ETNT, through the overpressure curves

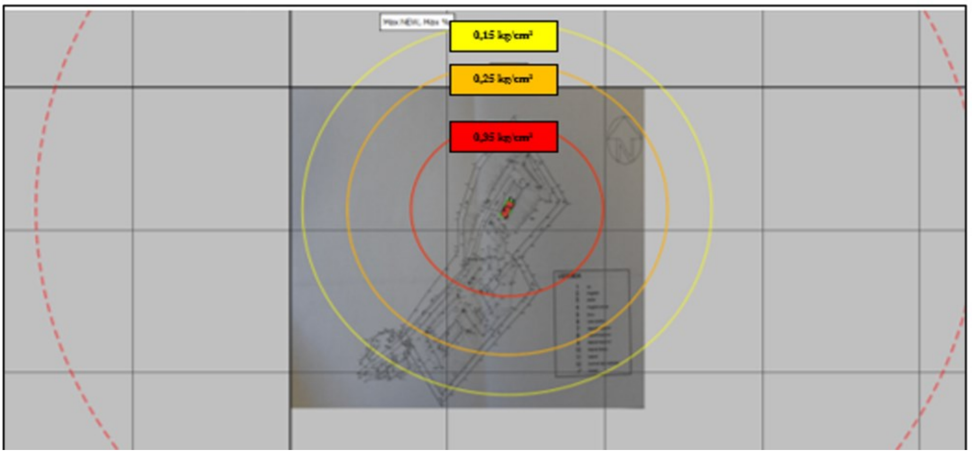


**Fig.4.** Graphical exemplification regarding the computerized assessment of the explosion risk of the baseline scenario D 3,000 kg ETNT, through the overpressure curves

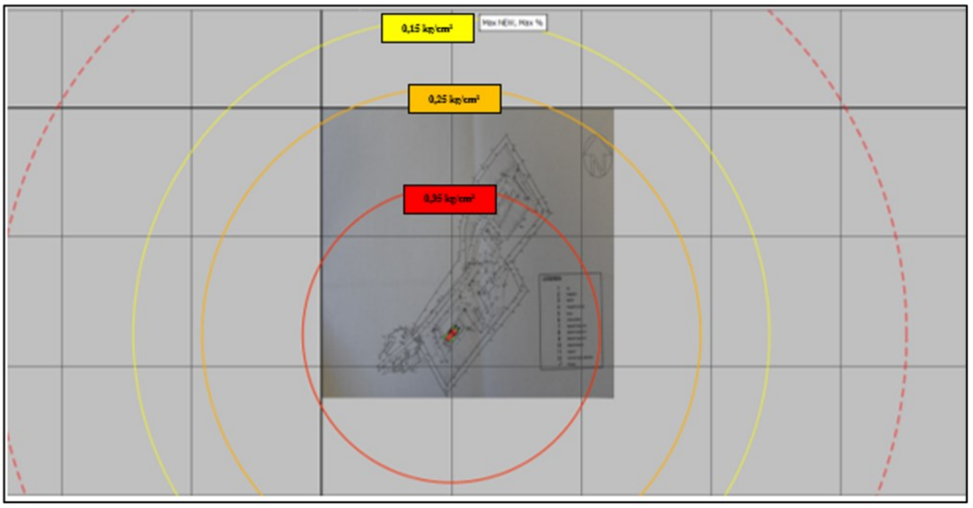


**Fig.5.** Graphical exemplification regarding the computerized assessment of the explosion risk of the baseline scenario E 20,000 kg ETNT, through the overpressure curves

## 4 Interpretation of the results obtained

In order to establish the safe distance, the analyzed scenarios can be divided into the following categories: **Accidents which for reasonable reasons should not be excluded (A, B and G).** These unwanted events characterized by the instantaneous explosion of smaller quantities of explosive materials are more likely to occur and consequently the limit of the attention area will be considered for the safety zone; **Accidents which, for reasonable reasons, should not be excluded in order to limit their effects, taking special defense measures against hazards (accidents that "can nevertheless occur" (C, D, E and F).** These unwanted events may be due to catastrophic situations (earthquake, fall of bodies in the atmosphere that cause the collapse of buildings), and therefore the explosion is unlikely to occur simultaneously, the real case being the production of several successive explosions with smaller effects than simultaneous explosion. In this situation, one can consider the limit of the area of reduced damage, respectively of less important damage to buildings; **Accidents which for reasonable reasons are excluded such as the explosion of the amount of ammonium nitrate deposited.** This unwanted event will not be taken into consideration when establishing the safe distance because the fire must be extinguished as soon as possible and must not be reached by explosion [6].

## 5 Conclusions

Explosion risk assessment specific to the industrial site intended for the preparation and storage of civilian explosives was realized based on the identification and systematic analysis of the potential dangers specific to the activity of preparation and storage of the simple explosive mixture type ANFO (AUSTINITE), which can generate explosion-type events when dangerous substances such as explosives of civil use are involved, in order to establish and to substantiate the main possible accident scenarios, as well as the reference scenarios.

To identify the worst possible accident scenario at the level of the industrial site intended for the preparation and storage of civilian explosives reference scenarios (hypotheses) were defined and established, highlighting for each case the significant configuration aspects (coding of the scenario, type of event, possible location, causes / effects, production conditions, value of overpressure, effects on constructions and on human health, the affected area, the result of computer modeling, etc.), respectively: (A) The accident scenario regarding the explosion of a quantity of 50 kg ETNT at the Warehouse III - staples; (B) The accident scenario regarding the explosion of a quantity of 300 kg ETNT at Store III - staples; (C) The accident scenario regarding the mass explosion of a quantity of 1,300 kg ETNT at Store III - staples; (D) The accident scenario regarding the mass explosion of a quantity of 3,000 kg ETNT at the Warehouse III - AUSTINITE; (E) The accident scenario regarding the mass explosion of a quantity of 20,000 kg ETNT at the Store I - LAMBREX, EMILEX, NITRAMON, AUSTINITE; (F) The accident scenario regarding the mass explosion of a quantity of 12,500 kg ETNT at the Store I - AUSTROGEL; (G) The accident scenario regarding the explosion of 20,000 kg ETNT of ammonium nitrate deposited due to a fire spread at the ammonium nitrate depot.

This work was supported by the grant of the Romanian National Authority for Scientific Research and Innovation, CNCS/CCCDI – UEFISCDI: project PN 19 21 02 02 – CORE Programme *"Development of technical and methodological infrastructure for testing and evaluation of safety parameters specific to explosives for civil use and pyrotechnic articles"*.

## References

1. D. Rus, G.D. Vasilescu, A. Kovacs, E. Gheorghiosu, C. Jitea, Quality-Acces to Success J., **18**, 41-46 (2017)
2. A. Kovacs, G. Vasilescu, D. Rus, E. Gheorghiosu, I.C. Jitea, S. Bordoş, Quality-Acces to Success J., **18**, 93-96 (2017)
3. G.D. Vasilescu, R. Laszlo, A. Kovacs, C. Radeanu, O. Miclea, Quality-Acces to Success J., **20**, 43-48 (2019)
4. D.C. Rus, E. Ghicioi, R. Laszlo, C. Rădeanu, A. Attila, G. Vasilescu, Quality-Acces to Success J., **20**, 89-92 (2019)
5. G. Vasilescu, R. Laszlo, A. Kovacs, I.C. Jitea, D. Rus, C. Rădeanu, C. Miron, MSE 2019, *Determination of threats traceability in the use of explosive materials in different environments,* (Sibiu, Romania, 2019)
6. Directive 2014/28/EU, on the harmonization of the laws of the Member States relating to the making available on the market and supervision of explosives for civil uses (2014)