UNIVERSITATEA DIN PETROȘANI

UNIVERSITY OF PETROSANI

DOCTORAL SCHOOL

Doctoral field: INDUSTRIAL ENGINEERING

THESIS

-SUMMARY-

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DEVELOPMENT OF THE ANALYSIS INFRASTRUCTURE AND ASSESSMENT OF THE RISK OF MAJOR ACCIDENT GENERATED IN INDUSTRIAL PREMISES WITH THE DANGER OF EXPLOSION, TAKING INTO CONSIDERATION ACTS OF BAD-WILL

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CONTENT

1. Concepts, definitions, thesis motivation, pursued objectives

The thesis "***Development of the infrastructure for the analysis and assessment of the risk of a major accident generated in industrial spaces with a risk of explosion taking into account acts of malice***" addresses a highly topical subject of study in the industrial era in the context of the globalization of the activities carried out on the sites intended for operations specific with explosive materials presenting a way of applied research harmonized with the current requirements in the field of major accident risk, when dangerous substances of an explosive nature are involved from the perspective of permanent improvement of the security climate in work systems affected by the presence of these dangers considering the fact that their safe operation implies, at the level of currently used techniques, the necessity and obligation to carry out the assessment of professional risks, taking into account acts of malice.

The theoretical and practical substantiation of the development of the methodological infrastructure regarding the analysis and evaluation of the risk of major accidents generated in industrial spaces with explosion hazard, taking into account acts of ill-will, assumed the following research steps:

- Analysis of the main international and national regulations regarding the dangers that can generate significant unwanted events of a major nature due to dangerous substances of an explosive nature;
- The study of national and European legislation regarding the performance of activities in the environment with the risk of explosive atmospheres;
- Analysis and evaluation of the risks of major accidents specific to technical infrastructures in the field of civil explosives;
- Development of the major risk management system specific to technical infrastructures in the field of civil explosives;
- Research on the technology of rapid detection and identification of explosive substances;
- The development of a specialized and integrated IT application for the assessment of explosion risk specific to industrial sites in the field of civil explosives, taking into account malicious acts.

The motivation of the doctoral thesis is related, on the one hand, to the usefulness and ease of performing/improving the methodological mechanism regarding the assessment of the risk of a major accident, when explosive materials are involved, taking into account acts of ill-will, and on the other hand, to the configuration of the methodological tools of good practice in the field of securing the activities carried out in the presence of the specific dangers of industrial sites in the field of civil explosives, ensuring unitary orientation and guidance in the effective management of security quality based on an integrated system of occupational safety and health management.

The main objectives of the other thesis consist in the conceptualization of the mechanism for assessing the risk of a major accident, taking into account acts of ill-will that can make work systems vulnerable with activities in the field of specific operations with explosive materials, as well as the configuration of methodological tools of good practice in the field of major accident risk, when explosive materials are involved based on the results of the technical-scientific research undertaken. These basic objectives are achieved through derived objectives, respectively: the study of the main international and national regulations regarding the major dangers due to explosive substances (European SEVESO directives, explosives directive 2014/28/EU, Law 59/2016, etc.); the study of the aspects regarding the national and European legislation regarding the development of the activity of prevention of explosions and protection against explosions; the presentation of the national legislative framework related to carrying out activities in the environment with the risk of explosive

atmospheres (Law 319/2006); exposition of European ATEx directives; identification and analysis of the risks of major accidents specific to the technical infrastructures intended for the storage of explosive materials; computerized assessment of the global risk specific to explosives warehouses (explosion/occupational/terrorist attack); the description of the scenarios of major accidents produced at the warehouses of explosive materials; presentation of the main possible scenarios of major accidents for each identified risk area at the level of the explosive material warehouse; the study of the policy for the prevention of major accidents involving dangerous substances; systemic analysis of management from the point of view of safety and health at work; assessment of the security of technical infrastructures intended for specific operations with explosive materials; the elaboration of the □Security document□ specific to the technical infrastructures intended for the storage of civil explosives; establishing protection and intervention measures in order to prevent, limit or eliminate the consequences of major events resulting in accidents when storing explosive materials; establishing the principles of safe work with explosive substances; evaluation of the technical aspects of the technology of rapid detection and identification of explosive substances; thermochemical prediction of the detonating behaviour of explosive substances; the creation of a specialized and integrated computer application for the assessment of the explosion risk specific to industrial sites in the field of civil explosives, taking into account malicious acts.

The derived objectives are fulfilled based on the primary objectives, respectively: the study of specialized literature by consulting the main bibliographic references in the field of interest of the thesis; the identification of existing sources of major risk at the level of industrial infrastructures intended for the storage of explosive materials; the systematic analysis of the major risks identified at the warehouses of explosive materials; computerized probabilistic assessment IMSAFR v2 of the major risk estimated on the industrial site provided with technical facilities intended for the storage of explosive materials; DIRE Version 1.0 computerized analysis of deaths and injuries resulting from explosions generated by the major hazards specific to the technical infrastructures intended for the storage of civil explosives; mathematical modeling of explosion effects; estimation of the probability and severity of the consequences of major accidents produced at the warehouses of explosive materials; the synthetic presentation of the main possible major accident scenarios for each risk area identified at the explosives storage level (major accident scenario within the storage spaces/major accident scenario on the manoeuvring platform related to the storage space/major accident scenario at means of transport within the warehouse/forest fire scenario/disaster scenario – terrorist attack); formulation of general considerations regarding the security assessment of explosive materials used on dedicated industrial sites; the realization of some applications regarding the computerized evaluation of the risk of explosion generated by explosive materials; the design and layout of the "Security Document", as well as the provision with instructions for completing the generic sections specific to its structure; establishing general measures to reduce the possibility of occurrence of major events resulting in accidents; establishing the technical parameters and the equipment used for the security of the installations specific to the site intended for the storage of civil explosives; establishing measures with a protective and intervention role in the event of an accident to reduce its severity; the organization of the alert and the intervention and the plan for internal emergency; specialized and integrated computer application for the assessment of the explosion risk specific to industrial sites in the field of civil explosives, taking into account malicious acts.

The research strategy for fulfilling the objectives of the thesis aimed at four broad working horizons from a technical-scientific point of view, respectively:

- The paper begins with the synthetic exposition of the main regulations applicable at the international and national level in the field of the risk of a major accident generated, when dangerous substances of an explosive nature are involved, which establish normative technical aspects regarding the security of activities carried out in the presence of the specific dangers of explosive substances in industrial spaces with risk of explosion.

- The next step in research focuses both on the analysis and assessment of the risks of major accidents specific to technical infrastructures in the field of civil explosives, as well as on the development of the management system of major risks specific to technical infrastructures in the field of civil explosives.

- Another important step of the research resides in the expression of contributions on the technology of rapid detection and identification of explosive substances with the highlighting of the following results: establishing the principles of safe work with explosive substances; the substantiation of technical aspects on the technology of rapid detection and identification of explosive substances; making the thermochemical prediction of the detonating behavior of explosive substances.

- With regard to the need to use IT facilities in the field of computerized management of the integrated security state specific to operations with explosive materials carried out at the level of an industrial site in the field of civil explosives, further technical and scientific measures undertaken aimed at the development of a specialized IT application and integrated for the assessment of the explosion risk specific to industrial sites in the field of civil explosives taking into account malicious acts.

2. Structure of the thesis and some contributions

From a structural point of view, the work includes an introductory chapter with a characteristic theme and 5 content chapters to which is added a final chapter of Final Conclusions and personal contributions totalling 218 pages of which 205 pages represent the actual thesis and 13 pages represent the Bibliography which has a number of 213 bibliographic notes and specialized Appendices that facilitate a better understanding of the thesis and its objectives.

Among the main contributions of the author, which are documented in the chapters of the doctoral thesis, can be listed:

• Carrying out an integrated analysis through which the national and international legislative framework was identified that allows activities with a risk of major accidents to be carried out in predictable safety conditions, carried out on industrial sites intended for specific operations with explosive materials;

• Carrying out a synthesis study which highlighted the correspondence between national and international regulations applicable in the field of major accident risk, when dangerous substances of an explosive nature are involved, thus ensuring the premises of a particularly useful guide for industrial operators of materials explosives facilitating the making of optimal decisions, when the integrated security of the technical infrastructures within which operations with explosive materials are carried out is necessary;

• Analysis and assessment of the risks of major accidents specific to technical infrastructures in the field of civil explosives;

• Development of the major risk management system specific to technical infrastructures in the field of civil explosives;

• Development of the technology for rapid detection and identification of explosive substances;

• Carrying out applied computer simulations regarding the determination of the performance of explosive substances;

• The development of a specialized and integrated IT application for the evaluation of the explosion risk specific to industrial sites in the field of civil explosives, taking into account malicious acts.

The valorisation of the technical-scientific results of the conducted research was achieved by disseminating them within the framework of papers in the proceedings of conferences/symposiums or ISI or BDI indexed Journals.

3. Synthesis of papers

In the work of configuring scenarios for the occurrence of an undesirable event falling under the SEVESO directives, such as a major accident involving hazardous substances of an explosive nature, it is imperative to go through the main process steps in an iterative manner, namely: highlighting the risks that have been identified, assessed and prioritised on the basis of good knowledge, must take into account the maximum effect of their occurrence, the simultaneous and iterative nature of the unfolding process, essential aspects that determine that the planning must take into account both each risk individually and the combined or interlinked scenarios of occurrence of the undesirable event in order to ensure a rapid response of preparedness, protection and mitigation.

The PhD thesis entitled Development of the infrastructure for analysis and assessment of major accident risk generated in industrial premises with explosion hazard taking into account malicious acts comprises 8 chapters summarised below.

Chapter 1, *"Introduction"*, outlines the general considerations, the main and specific objectives, the motivation of the thesis and a brief summary of the work.

In **Chapter 2**, *"Analysis of the main international and national regulations on major-accident hazards involving dangerous substances"*, we have presented a summary of the main regulations applicable at international and national level in the field of major-accident hazards applicable to economic operators working in industrial premises with explosion hazards intended for specific operations with explosive substances.

Thus, the technical requirements on the major risk management system that have been regulated both at European and national level by a series of European directives and laws transposing them (Seveso directives, HG 804/2007, HG 79/2007, Law 59/2016) concerning the appropriate management of major accident hazards involving hazardous substances, as well as those specific to the field of explosives for civil use (Directive 2014/28/EU transposed at national level by HG 197/2016, Law 126/1995 with subsequent amendments and additions on the regime of explosive materials) have been analysed and documented.

Chapter 3 is called *"Study of national and European legislation on the conduct of activities in environments with the risk of explosive atmospheres"*. This chapter highlights regulatory data and information specific to the safe conduct of activities in an explosive atmosphere hazard environment, which provides: the zoning of premises with explosive atmospheres and their marking, in accordance with Directive 1999/92/EC; the use of equipment certified for operation in premises with hazardous atmospheres, in accordance with Directive 94/9/EC; ensuring the permanent and correct operation of protective systems and devices, measuring and control equipment, and installations for the capture, containment and neutralisation of harmful substances released in the course of technological processes, in accordance with the Law on Safety and Health at Work no. 319/2006; preparation of the Explosion Protection Document and compliance with its provisions, according to Directive 1999/92/EC. The predictable safety of workers working in a potentially explosive environment depends on: the correct zoning of hazardous atmosphere spaces associated with technical/technological installations; protective equipment and systems installed in technical/technological installations operating in hazardous atmospheres;

safety/control/regulating devices operating in non-hazardous environments but which are useful or contribute to the safe operation of protective equipment and systems installed in technical/technological installations operating in hazardous atmospheres; machinery operating outside hazardous atmospheres but necessary for or contributing to the safe operation of machinery installed in technical/technological installations operating in hazardous atmospheres; technically and constructively correct choice of machinery to be installed in machinery/technology installations operating in hazardous atmospheres; preventive and corrective maintenance of machinery associated with machinery/technology installations operating in hazardous atmospheres; metrological checks of measuring and control devices associated with machinery/technology installations operating in hazardous atmospheres; training and health of workers; unpredictable reactions/decisions of workers in extreme cases.

Chapter 4, *"Contributions on the quantification of major risks specific to technical infrastructures of explosive materials"*, presents a number of theoretical contributions on the integration of malicious acts in the process of analysis and assessment of the risk of major accidents.

The use of the complete software package specialised in the field of global risk assessment type IMESAFR v2 and DIRE Version 1.0 at civil explosives storage sites provides the necessary prerequisites for the preparation, under objective and highly accurate conditions, of the security document for these types of technical infrastructures and the quantification of the degree of impact on the work systems and the adjacent area that are located in their vicinity. Thus, the following planning zones have been defined for the scenarios of explosion accident events: planning zone I (high fatality) is defined as the area where approx. 50% of the exposed population; planning zone II (irreversible injury) is defined as the area in which the exposed population suffers severe somatic and lung injuries, severe illness, first and second degree burns. Light buildings suffer major damage rendering them unusable. Heavy structures may suffer minor damage; planning (attention) zone III is defined as the distance to which the effects of the accident can be felt and causes mild, short-lived illness or superficial, easily healed burns. In blast accidents, light structures in the attention zone may suffer minor damage.

The main accident scenarios that were analysed in the study are the following:

-I. Major accident scenario in storage premises and II. Major accident scenario on the manoeuvring platform adjacent to the storage area, involving a large quantity of explosive materials, leading to severe, wide-area effects. The likelihood of an accident is extremely low given the fact that the targets within the storage area have no internal electrical networks and access with fire sources to the premises is strictly prohibited. The only initiating events could be serious human error in handling the packaged explosives or an external cause such as an uncontrolled fire in the immediate vicinity of the warehouse or an armed attack on the warehouse;

-III. Scenario of a major accident to means of transport within the storage premises which could be caused by a technical failure, i.e. a vehicle breakdown, a handling error or a road accident. The transport of explosive substances is carried out with ADR-approved vehicles whose technical condition is regularly checked. A road accident or a handling error is practically impossible on the warehouse premises, given that the maximum permitted speed is 5 km/h. Such an accident could initiate a domino effect of an explosion accident at the depot if the vehicle is at the loading/unloading ramp.

-IV. Scenario of a forest fire, possibly caused by a thunderstorm with lightning strikes or due to human error. In order to prevent accidents caused by these disruptive atmospheric factors, there are paratoneres at the storage area, the tops of the tree crowns do not exceed the tops of these devices. Also, the facilitation of the occurrence of such a scenario can be

achieved through a possible human error involving the use of a fire source in the forest either deliberately through an act of malice or accidentally.

The aspects related to *"Contributions on the development of the major risk management system specific to technical infrastructures in the field of civil explosives"*, highlighted in Chapter 5, present at a synthetic level the integrated systemic approach to major risk management in relation to the systemic management of the organisation, including: organisational structure, responsibilities, documents (practices, procedures, processes) and resources for establishing and implementing the policy for the prevention of major accident events; it also includes: organisational arrangements and appropriate human resources, assessment and evaluation of identified major risks, operational control, management for upgrading, planning for emergency situations, appropriate performance monitoring, audit and review. From this perspective of systemic safety, the aim "Political of majore risk prevention" is highlighted regarding the implementation within the organisation of the legal requirements for the prevention of major events in order to minimise the impact and extent of human and material damage in the event of an accident when hazardous substances of an explosive nature are involved. Prevention covers the totality of principles, performance criteria, requirements and technical conditions imposed and regulated in order to ensure a predetermined level of safety (objectively determined on a technical-scientific basis) in the normal course of social and economic life, as well as preparedness for the elimination of negative effects on life, the environment and material assets. Technical and organisational aspects have been documented in the chapter, relating both to the need to develop, design and layout "Document of safety" and to the provision of instructions for completing the generic sections specific to its structure. This document must demonstrate that: a major accident prevention policy and safety management system is in place; major accident hazards are identified and the necessary measures are taken to prevent such accidents and limit their consequences for man and the environment; adequate safety and reliability for construction, operation and maintenance has been incorporated into the design of any facility; internal emergency plans have been prepared providing information to enable the preparation of the external emergency plan; information for land use planning decisions has been provided.

Chapter 6, *Contributions on technology for the rapid detection and identification of explosive substances*, presents a section devoted to summarising the general safety rules based on the four principles of safe work with explosive substances (hazard awareness, hazard separation, hazard mitigation and overlapping safety devices), as well as the specific features of general and particular explosion safety precautions, together with technical aspects relating to the possible causes of explosion, explosion effects and safety distances, protection against accidental initiation of explosion, and safety in the field of explosive powders and pyrotechnic systems, highlighting the limits related to the pyrotechnic safety principle (knowledge, prevention and limitation of pyrotechnic risk). Analysis of evidence to detect traces of explosive materials in residues and identification of the material in question for the purposes of technical expertise or criminal investigations (illegal possession/trading of explosive substances/materials, terrorist acts, etc.) are complex, laborious and difficult activities that require on the one hand rigorous and precise investigations based on ensuring the quality of the evidence collected with the mastery of forensic tactics and procedural actions and on the other hand the use of high performance equipment and analytical apparatus that offers the possibility of obtaining credible results in the shortest possible time. This chapter also summarises a number of results obtained by simulation and experiment respectively: Computer modelling with the specialised software EXPLO5 on the thermochemical prediction of the detonation behaviour of TNT type explosives (with highlighting of results for adiabatic Hugoniot shock, detonation, kinetic detonation, isobaric combustion, isochoric combustion); Computer simulation with the specialised software IMESAFR of an explosion

produced at an industrial site (with highlighting of damage areas as a result of detonation fragment design: lethality zone/major injuries/minor injuries; overpressure/risk curves); Computer simulation with DIRE specialized software of an explosion at an industrial site (highlighting the areas of damage due to a bomb explosion with shrapnel design or mass explosion; Determination of threat traces using specialised I-SCAN equipment from samples taken from explosive substances or following their detonation; Hybrid detection of explosives with modern LDS800 HDK type equipment using specialised state-of-the-art equipment and measurement principles on ion mobility spectrometry (I-SCAN) and Raman laser spectroscopy (G-SCAN).

Chapter 7 - *Contributions to the development of a specialised and integrated software application for site-specific explosion risk assessment in the field of civil explosives taking into account malicious acts*, highlights the TERRORISK programme. EXE 01, which is a working tool used for the operational and procedural management of documents for the assessment of the risk of explosion produced on industrial sites in the field of explosives for civil use when hazardous substances of an explosive nature are involved, using the working facilities of software dedicated to this field (IMESAFR, DIRE, EXPLO5), as well as the results of the determination of the traces of threat with the help of specialised I-SCAN equipment. In order to ensure the security of the information and data contained in the TERRORISK.EXE 01 program, both access to the application and to the system documents is carried out through authentication with a uniquely identified password. This specialised IT application ensures the operational and procedural management of documents for the assessment of the risk of explosion generated on industrial sites following the detonation of explosive materials, taking into account acts of malicious intent in order to maintain technical and organisational capacity, in accordance with the applicable requirements in the field, under predictable conditions of technological and occupational safety.

Chapter 8, entitled *Final Conclusions and Personal Contributions*, highlights the contributions made to the development of the infrastructure for the analysis and assessment of major accident risk generated in hazardous industrial premises taking into account acts of ill will, in terms of: conceptualisation and configuration of methodological mechanisms for the analysis and assessment of major accident risks specific to technical infrastructures in the field of civil explosives including systemic vulnerabilities generated by acts of malicious intent; development of the integrated system for the management of major site risks; development of technology for the rapid detection and identification of explosive substances; development of a specialised and integrated IT application for the assessment of explosion risks specific to industrial sites in the field of civil explosives taking into account acts of malicious intent.

4. Personal contributions

4.1.-Theoretical contributions

The main theoretical contributions with significant technical-scientific impact, drawn from the PhD thesis, are:

- Conducting an integrated analysis identifying the national and international legislative framework that enables the safe and predictable deployment of major accident hazards involving hazardous substances of an explosive nature;

- A synthesis study has been carried out to highlight the correspondence between national and international regulations applicable to the analysis and assessment of the risk of a major accident at industrial sites for specific operations with explosive substances, taking into account acts of malicious intent, thus creating the basis for a particularly useful guide for economic operators working in this field, facilitating optimal decision-making when integrated security of these technical facilities is required;

- Identification and analysis of major accident risks specific to technical infrastructures for the storage of explosive materials;

- Establishing the conceptual and application framework necessary for the computerised assessment of the overall risk specific to explosives storage facilities (blast/occupational/terrorist attack);

- Specialised description of likely scenarios of major accident events at explosive material storage sites;

- Summary presentation of the main possible major accident scenarios for each risk area identified at the level of the explosive material store;

- Study of the major accident prevention policy involving hazardous substances and analysis of the major risk management system;

- Security assessment of technical infrastructures for specific operations with explosive materials;

- Development "Document of safety" of specific technical infrastructures for the storage of explosives for civil use;

- Establishment of protection and intervention measures to prevent, limit or eliminate the consequences of major accidents specific to the storage of explosives for civil use;

- To substantiate the technical aspects of the technology for rapid detection and identification of explosive substances;

- Study of thermochemical prediction of the detonation behaviour of explosive substances.

4.2.-Contributions in the field of applied IT

- Specialised IT application TERRORISK.EXE 01 specific to the assessment of the risk of explosion from explosive substances taking into account malicious acts.

4.3.-Experimental and applied contributions

The main experimental and applied contributions with significant technical-scientific impact derived from the PhD thesis are:

- Computer modelling with the specialised software EXPLO5 on the thermochemical prediction of the detonation behaviour of TNT type explosives (with highlighting of results for adiabatic Hugoniot shock, detonation, kinetic detonation, isobaric combustion, isochoric combustion);

- Computer simulation with the specialised software IMESAFR of an explosion at an industrial site (highlighting areas of damage due to the design of detonation fragments: lethality zone/major injuries/minor injuries; overpressure/risk curves);

- Computer simulation with the specialised DIRE software of an explosion at an industrial site (highlighting the areas of damage due to a shrapnel bomb or mass explosion design;

- Determination of threat traces using specialised I-SCAN equipment from samples taken from explosive substances or following their detonation.

Future research directions

Taking into account the contributions expressed in the paper and the research issues identified, the following research directions can be highlighted as possible future research directions:

- Digitisation of security systems (biometric fingerprint recognition, etc.) related to existing facilities at industrial sites for specific operations with explosive materials;

- Development of technical infrastructure for integrated monitoring of civil explosives industrial sites with modern state-of-the-art devices (spectro-drones) dedicated to the exploration/search/zoning of spaces within industrial sites;

- Research on the realisation of an intelligent industrial space equipped with state-of-the-art IT devices and specialised software applications designed for integrated monitoring of industrial sites for specific explosives operations.