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PHD THESIS

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DEZVOLTAREA INFRASTRUCTURII TEHNICE ȘI METODOLOGICE DE PREVENIRE ȘI CONTROL A RISCURILOR SPECIFICE OPERAȚIUNILOR CU MATERII EXPLOZIVE

DEVELOPMENT OF THE TECHNICAL AND METHODOLOGICAL INFRASTRUCTURE FOR THE PREVENTION AND CONTROL OF RISKS SPECIFIC TO THE OPERATIONS WITH EXPLOSIVE MATERIALS

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CONTENTS

Keywords:

For a good understanding of the following presentation, it is necessary to list some notions specific to the field covered: *explosive materials, conformity assessment, test procedures, explosive safety and protection, electronic detonators, explosives initiation, certification, ANFO, quality management system, occupational safety, technological risk, hybrid detection, methodological infrastructure, safety standards, impact of explosives, test methods, international regulations, risk analysis and assessment, controlled demolition.*

The motivation for my PhD thesis is based on the need to increase the level of safety in industries using explosive materials, a central concern of my work in the Explosives and Pyrotechnics Safety Department. During my 14 years in the business, I have gained experience by participating in explosives testing, using civil explosives in various industrial applications and working with pyrotechnics of all existing categories, as well as through responsibilities in the certification of new products or keeping them on the market. My involvement in over 30 technical expertises has brought me face to face with tragic consequences: loss of life, permanent trauma, and significant property and environmental destruction. These incidents, many of them preventable, highlight the increase in associated risks and the imperative need to develop and implement advanced prevention and control methods to protect both workers and the environment.

The objectives aimed were the development of an advanced technical infrastructure, the creation and implementation of new technologies and equipment to provide improved control over the handling and use of explosive materials, the implementation of real-time monitoring and response systems to detect and rapidly warn of any deviations from safety procedures, the development of a robust risk assessment methodology, the development of predictive models to assess the risks associated with various operational scenarios, integrating risk analysis into the planning and execution of industrial operations, promoting a safety culture among employees, training and certification programs for industrial workers, emphasizing the importance of safety protocols, contributing to national and international legislation and regulations by proposing amendments or additions to existing legislation based on the findings and recommendations of the thesis. Collaboration with international authorities and organizations to standardize security practices.

By addressing these objectives, the thesis aims to make a substantial contribution to improving safety in industries using explosive materials, thereby reducing the risk of accidents and environmental impact.

The PhD thesis provides an in-depth analysis of strategies and methodologies to ensure safety in industries using explosive materials. The study emphasizes the importance of creating and implementing a robust legislative framework, at both national and European level, to regulate the management of these hazardous materials. It details the implementation of quality systems according to international standards in the evaluation and testing of explosive materials, as well as conformity assessment procedures to ensure compliance with safety standards. The thesis also addresses the need for detailed technical expertise in the case of incidents, where cause and effect analysis is essential to prevent recurrence.

In addition, methodological approaches in occupational and technological risk analysis in the context of controlled demolitions are highlighted, emphasizing the importance of rigorous planning and continuous monitoring. Particular emphasis is placed on the use of computer simulation technology to anticipate and manage possible risks, thereby improving safety and emergency response protocols.

Through the integration of these components, the thesis proposes a replicable model for risk management and safety enhancement in the exploitation of explosive materials in various industrial applications, contributing significantly to the development of safety practices in this field. This multidimensional approach aims not only to protect human lives and infrastructure, but also to minimize the impact on the environment and local communities.

Doctoral thesis entitled: *Development of technical and methodological infrastructure for prevention and control of risks specific to operations with explosive materials*, is structured in 8 chapters.

In the first chapter the general considerations of the PhD thesis are presented: motivation, objectives, conclusions, main contributions and some future research directions.

In Chapter II, the legislative framework and standardization at EU and national level in the field of explosives and pyrotechnics safety management and occupational health and safety were studied. The results of the analysis highlight several aspects of an integrated and multidimensional approach to this issue: By harmonizing European directives, such as the European Explosives Directive and the European Pyrotechnic Articles Directive, and implementing them through national legislation, a coherent framework has been created that facilitates safety, trade and mobility of products across the Union. This not only supports industry, but also ensures uniform protection of consumers and the environment in all Member States. The detailed legislation imposes clear responsibilities on all economic operators in the supply chain, from manufacturers to distributors, emphasizing the importance of proper documentation, testing procedures and conformity assessment to ensure that safety and security standards are met. In the context of public safety and the prevention of illegal use, the current regulations strengthen the ability to trace products throughout their life cycle, making a key contribution to the ability to intervene quickly and effectively in the event of irregularities. By integrating specific occupational health and safety requirements into the legislation and rules applicable to the explosives sector, the need for preventive measures such as risk assessment, appropriate training of workers and the use of protective equipment is emphasized, thus improving the quality of the working environment. Through this research, I contribute to strengthening the theoretical and practical basis for the effective management of the risks associated with civil explosives and pyrotechnic articles, while emphasizing the importance of a proactive approach to environmental protection. This work encourages further interdisciplinary and trans-national dialog on legislative and technological developments, ensuring optimal alignment with global safety dynamics.

In Chapter III, the modernization of the methodological infrastructure required for the assessment and verification of explosive material safety parameters using state-of-the-art technology was presented. The study highlighted the effective integration of advanced testing equipment such as BAM Fall Hammer (BFH 12A) for impact sensitivity determination and BAM Friction Apparatus (FSKM-10) for friction sensitivity assessment. Furthermore, within the Explosives and Pyrotechnics Security Department, advanced methodological procedures have been implemented and specialized equipment has been purchased for the hybrid detection of explosives and other hazardous materials. These include the blast chamber for controlled explosives testing and hybrid detection equipment, such as the LDS800 HDK, which have enabled accurate and efficient testing, increasing the ability to respond to risk situations. The experimental results obtained, presented in detail in Chapter 3, confirm the effectiveness of the updated test procedures (PI-83 and PI-84), developed in

accordance with the relevant European standards. They have demonstrated that the use of modern equipment not only meets the technical requirements imposed, but also offers superior economic efficiency.

The proposed implementations have the potential to positively influence industrial practices and ensure a safer environment through the effective detection and management of explosive materials.

The conclusions drawn in this chapter demonstrate the need for further research in the field and the development of new techniques and technologies that dynamically respond to changes in global security requirements, thus providing future directions for research and development in explosive domain.

Chapter IV of the thesis emphasized the importance of the adoption and rigorous implementation of international and national standards in the conformity assessment of explosive materials. It was emphasized that strict adherence to these standards ensures not only the efficiency and reliability of assessments, but also essential protection of users and the environment. It is presented in detail the organizational culture geared towards continuous improvement and perpetual staff training, emphasizing that these aspects are important for maintaining standards of excellence in adapting to emerging technologies and innovative testing methodologies. This is instrumental in maintaining compliance to the highest possible standards.

The diversity and complexity of conformity assessment procedures was also presented, illustrating the commitment to accurate assessment in full compliance with legal requirements. These procedures are used to ensure the safety of explosive materials and their responsible placing on the market.

The role of notified bodies, including INSEMEX, in ensuring compliance with European regulations for explosive products and pyrotechnic articles has been recognized as fundamental to consumer protection and public safety. The participation in international forums has been reflected as a valuable experience, which has not only provided new perspectives in my career, but has also strengthened my commitment to the professional community in this field.

In conclusion, Chapter IV contributes to the literature in explosives conformity assessment, providing a methodological basis and highlighting the need for a structured quality system to ensure continued safety and compliance in this complex and critical sector.

In Chapter V, the technical expertise methods and procedures used in incidents related to the misuse of explosive materials were presented in detail, emphasizing the need for a multidisciplinary and systematic approach to carry out thorough and objective analyses. The importance of close collaboration between different categories of specialists, ranging from engineers to technicians and researchers, was demonstrated by their ability to comprehensively assess the causes and effects of incidents, thus contributing to the formulation of effective preventive measures.

The case study presented in this chapter highlights the adaptability and innovation in survey techniques that are necessary to meet the unique challenges imposed by each incident. This adaptability is essential for continuous improvement of safety methodologies and accident prevention.

Based on detailed technical expertise, recommendations have been made to improve safety standards and prevent future incidents. These proposals are designed to have a positive impact on national and international policies and practices.

By analyzing a real case, Chapter V contributes to the literature and provides a replicable model for the management and technical expertise of similar incidents. It thus

emphasizes the vital role of technical expertise in the field of security and explosion protection. The approach adopted not only improves the understanding of the associated phenomena but also increases the effectiveness of preventive measures implemented in similar contexts.

These conclusions underline the need for a proactive and rigorous strategy to manage the risks from explosive materials.

In Chapter VI, the technical-economic advantages of controlled demolition of buildings by controlled explosions compared to traditional methods were analyzed, showing that they represent optimal solutions even in urban environments with significant constraints. It emphasized the importance of rigorous planning in the determination and placement of explosive charges, respecting the calculation guidelines in the literature to ensure not only the efficient collapse of structures, but also the protection of the environment.

Two main methods of controlled demolition used both nationally and internationally have been documented: vertical collapse demolition and lateral tilt-slide demolition, both adapted to the specific urban environment. The concept of implosion demolition has also been introduced, which minimizes the risks of throwing materials outside, focusing on loosening and breaking up the internal structures of buildings.

In the context of the negative effects of demolitions, we highlighted measures to mitigate the impact on the environment and adjacent buildings, such as the choice of the type of explosive, the appropriate sizing of the charges and the optimization of their distribution. The need to check the condition of structures prior to the execution of the works was emphasized and we discussed the main undesirable effects such as material displacement, shock waves and dust and gas pollution.

National legislation requires obtaining a technical opinion from the National Institute for Research and Development in Mine Safety and Protection to Explosion – INSEMEX PETROSANI, covering everything from load calculations to health and safety measures.

By adopting an innovative methodological tool for risk diagnosis and forecasting, we have provided an analytical basis for the assessment and management of demolition risks. This approach allows us not only to identify risks, but also to implement effective mitigation strategies, thus contributing to the prevention of accidents at work and minimizing environmental impacts.

Finally, a case study on the controlled demolition of an industrial chimney illustrated the practical applicability of the methodologies discussed and emphasized their relevance in improving safety and protection practices in demolition with explosives. This research contributes to the literature and provides insight into the safe and effective management of controlled demolitions in complex contexts.

In Chapter VII , the added value of theoretical models, corroborated by advanced simulations and experimental validations, for the analysis of ballistic and safety parameters of civil explosives was demonstrated. The use of state-of-the-art software packages such as ANSYS Multiphysics and AUTODYN has facilitated detailed simulations of detonation processes and thermochemical dynamics of explosives, allowing me to comprehensively address the mechanical effects of explosions under controlled conditions.

Thermochemical modeling performed with EXPLO5 software allowed a detailed assessment of the detonation behavior of TNT, focusing on the detonation and combustion processes under different environmental conditions. The simulations provided accurate predictions of the adiabatic Hugoniot-type shock curve and explored the kinematic detonation, contributing to a deep understanding of the explosive material's response to various energy application rates.

Using the IMESAFR software, we performed thorough analyses of the effects of detonation of a standardized ISO 1C container, assessing the impact of fragments and defining the zones of lethality and injury. These simulations were essential for accurately estimating overpressure curves and determining the risk profile associated with different amounts of explosive.

The numerical and experimental validation confirmed the accuracy of the theoretical models by the agreement of simulation results with data obtained from experimental tests carried out under controlled conditions. This interdisciplinary approach has validated the robustness and accuracy of the analyses performed, highlighting the consistency between model predictions and actual observed behaviour.

The findings of this research reinforce the usefulness of advanced simulations in the assessment and design of explosives safety, providing a solid basis for the continued development of safety protocols in industry. These findings emphasize the role of integrating advanced simulation technologies into research and development processes, contributing significantly to optimizing the safe handling and use of explosive materials.

This thesis therefore highlights the importance of technological advances in improving security standards for explosive materials in diverse and complex contexts.

Chapter VIII entitled *Final Conclusions and Personal Contributions* explores the theoretical, experimental and applied contributions, providing a detailed overview of advanced research in the field of civil explosives.

THEORETICAL CONTRIBUTIONS

In terms of dissemination of results:

During the course of the doctoral activities and initial documentation efforts undertaken, as author/co-author, I published a number of 30 scientific articles and research papers divided into the following categories:

- 5 articles published in Clarivate Analytics Web of Science - WoS indexed journals
- (ISI);
- 25 articles published in peer-reviewed journals;
- 1 book;
- 1 patent application.

As part of my doctoral training, participation in international academic events was an important point in developing and enriching the theoretical perspectives of my thesis. In October 2022, I had the opportunity to participate at the University of Leon, Spain, as part of the Erasmus+ program for a short-term mobility, which took place from October 12 to 21. This experience allowed me to explore and integrate new dimensions and approaches in my study, important for the development of the theoretical frameworks of the research.

Moreover, on October 19-21, 2022, the participation in the second **EURECA-PRO Conference** on Responsible Consumption and Production, also at the University of Leon, strengthened the theoretical foundation of the thesis by integrating new perspectives on sustainability and responsibility in production and consumption. This conference was instrumental in contextualizing my research in a global sphere, giving me access to the latest research and debates in the field

In the course of my doctoral research, participation in international conferences and collaboration with colleagues from various universities have played a special role in the development of my research skills and contributions to scientific knowledge. Consequently, I have co-authored several significant papers together with doctoral students from various academic institutions, thus demonstrating the interdisciplinary nature of our research:

- "The Applicability of the European Green Deal in the Transport Sector: A Qualitative Analysis" – This paper was presented at CYSENI 2023, the International Conference of Young Scientists on Energy and Natural Sciences Issues, held from May 23-26, 2023, in Kaunas, Lithuania. In collaboration with Artur Budzyński, a Ph.D. student in Civil Engineering and Transport at the Silesian University of Technology, Katowice, Poland; Johannes Fabian Bauer, a Ph.D. student in Reservoir Engineering at TU Bergakademie Freiberg, Germany; Svetlana Kunskaja, a Ph.D. student in Economics at the Lithuanian Energy Institute, Kaunas, and Ilie-Ciprian Jitea, a Ph.D. student in Industrial Engineering at the University of Petroșani, Romania, this paper explores the integration of sustainable policies in the transport sector.
- "Thermal Hydrogen Production from Depleted Oil Reservoirs and SDG 12: A Critical Perspective" – Published at the "Contemporary Problems of Power Engineering and Environmental Protection" conference in 2022, this paper offers a critical analysis of thermal hydrogen production and its alignment with SDG 12. The interdisciplinary collaboration included the same co-authors, whose diverse expertise enabled a detailed approach to the technical complexities and environmental implications.
- "A Research Analysis: The Implementation of Innovative Energy Technologies and Their Alignment with SDG 12" – This paper, published in the Eastern-European Journal of Enterprise Technologies in 2023, addresses the implementation of innovative energy technologies and their contribution to achieving sustainable development goals.

Collaboration with colleagues from different fields of specialization underscores the important role of technological innovation in promoting sustainable practices. These collaborations have enriched not only my knowledge but also that of the scientific community, demonstrating the importance of academic and interdisciplinary exchange in solving complex global problems and strengthening the theoretical foundation of doctoral research.

The main theoretical contributions with significant technical-scientific impact derived from the doctoral thesis are:

- Emphasizing the role of personal expertise in evaluating the compliance of explosive materials. The author details their extensive experience and active involvement in coordinating and supervising certification procedures, highlighting the importance of technical leadership in promoting safety and quality standards in the specialized field of explosive materials.
- Presenting a case study that illustrates adaptability and innovation in expertise methods, essential for efficiently managing the specific challenges of each incident. This demonstrates the continuous ability to improve security techniques and prevent accidents.
- Contributing to the specialized literature by meticulously documenting and analyzing a real case of technical expertise. A replicable model for the technical expertise of similar incidents is presented, highlighting the importance of technical expertise in the field of anti-explosive security and protection, thereby increasing the understanding of associated phenomena and the efficiency of preventive measures.
- Addressing the demolition of constructions through controlled explosions as the optimal technical and economic solution, even under restrictive urban conditions. This includes determining explosive charges according to calculation manuals from the specialized literature, aiming to minimize the impact on the surrounding environment.

- Developing an innovative methodological tool for estimating and assessing risk in the demolition of industrial/civil objectives with civil-use explosives. This graph-analytical tool, based on a theoretical and practical approach, facilitates the explanation of risk parameters through simplified or conjugated alphanumeric and numeric variables.
- Applying the innovative methodological tool for analyzing and reducing risks assessed as unacceptable, to prevent and combat undesirable events such as work accidents and occupational illnesses, as well as minimizing the effects of explosions on nearby constructions. This chapter concludes with a case study on the evaluation of professional/technological risk in the controlled demolition of an industrial chimney in Zlatna.

EXPERIMENTAL AND APPLICATIVE CONTRIBUTIONS

- In the doctoral thesis, I demonstrated the effectiveness of theoretical models, validated through simulations and experiments, in evaluating the ballistic and safety parameters of civil-use explosives. I used ANSYS Multiphysics and AUTODYN software packages to conduct detailed simulations of detonation processes and thermochemical behavior, as well as to analyze the mechanical effects of explosions in controlled scenarios.
- I utilized thermochemical modeling with the EXPLO5 software to evaluate the detonative behavior of TNT, focusing on detonation and combustion processes under various conditions.
- The simulations included detailed predictions of the Hugoniot adiabatic shock curve, which characterizes the material's behavior under extreme pressure and temperature conditions. Additionally, I analyzed kinetic detonation to explore the explosive's response to different rates of energy application and its behavior in isobaric and isochoric combustion scenarios to measure the influence of constant pressure and constant volume on chemical reactions.
- Using IMESAFR, I thoroughly analyzed the detonation effects in a standardized ISO 1C container. This included evaluating the spatial distribution of fragment impact, defining lethality and injury zones, and providing a precise estimation of overpressure curves that measure the impact of generated shock waves. These simulations allowed me to determine the risk profile associated with different quantities of explosives, thus contributing to formulating recommendations for safety and handling practices.
- Experimental and numerical validation was achieved by comparing simulation results with experimental data obtained under controlled conditions. This interdisciplinary approach confirmed the accuracy of theoretical models, showing the concordance between computerized predictions and actual behavior observed in tests.
- The obtained results reinforce confidence in using advanced simulations for the analysis and design of explosive safety and provide a solid foundation for the continuous development of safety protocols in the industry. These findings underline the importance of integrating advanced simulation technology into research and development processes, contributing to the optimization of explosive material usage under maximum safety conditions.

FUTURE RESEARCH DIRECTIONS:

Given the results obtained in the doctoral thesis through the use of advanced simulations and experimentation in evaluating the safety of civil-use explosives, here are some future research directions that could expand and deepen these findings:

- Development of more complex predictive models: Integrating advanced predictive models to simulate detonation scenarios and the behavior of explosives under even more diverse and extreme conditions. These models could include factors such as variations in the

ambient environment and interactions with other materials to better understand the risks associated with the use of explosives in various industrial applications.

- Optimization of explosive materials: Using the knowledge gained about the thermochemical and mechanical behavior of explosives, new compositions or mixtures of explosives can be developed to offer improved performance in terms of efficiency and safety. This would include research on substitutes for TNT or other traditional materials that could reduce environmental impact or handling risks.
- Simulations for accident and disaster scenarios: Expanding the use of simulations to model and analyze the responses of explosives in real accident scenarios, including accidental explosions in urban or industrial environments. This would help design more effective protective measures and develop emergency response protocols.
- Extensive validation of models through multiple case studies: Implementing an extensive validation program for models through a larger number of experimental tests and by collecting data from real accidents. This would improve understanding of potential discrepancies between simulations and reality, allowing for adjustments to the models to more accurately reflect real behavior.
- Integration of artificial intelligence in simulations: Applying artificial intelligence technologies to optimize simulations and quickly identify the most effective risk management strategies. AI could rapidly analyze large amounts of simulation data to identify trends and propose changes in composition or handling procedures that minimize risks.

These directions would not only consolidate existing knowledge in the field but could also significantly contribute to the development of safer and more efficient practices in the use of explosive materials.

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