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DOCTORAL SCHOOL**

**Doctoral field: INDUSTRIAL ENGINEERING**

**THESIS**

**-SUMMARY-**

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DOCTORAL SCHOOL**

**Doctoral field: INDUSTRIAL ENGINEERING**

**RESEARCH TO INCREASE THE SAFETY LEVEL  
OF SPECIFIC OPERATIONS WITH PYROTECHNIC  
FIREWORKS**

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Key words: Pyrotechnic articles of entertainment, fireworks, security of specific operations, integrated risk management system, fireworks lot sampling system, specialised computer application

## **1. Concepts, definitions, motivation of the thesis, objectives pursued**

The thesis "*Research to increase the safety level of specific operations with pyrotechnic articles for entertainment*" addresses a highly topical subject of study in the context of the globalisation of socio-economic and leisure activities, presenting a method of applied research harmonised with the current requirements specific to operations with pyrotechnic articles for entertainment, from the perspective of continuous improvement of the occupational safety and health climate in activities using these types of products in the organisation of fireworks displays, based on a unified approach at national level in line with European practice in the field.

The theoretical and practical foundation of the technical-scientific methods for analysing and assessing the safety of specific operations with pyrotechnic articles of entertainment involved the following research steps:

- Analysis of the legislation on the regime of pyrotechnic articles harmonised with the European one;
- Study of the classification/function parameters specific to pyrotechnic articles;
- Research on the testing of pyrotechnic articles in accordance with the requirements of the applicable regulations;
- Analysis and risk assessment of pyrotechnic articles for professional use (category F4);
- Development of the integrated risk management system specific to operations with pyrotechnic articles for entertainment (MR-PYRO);
- Development of a specialised IT application for the sampling system of pyrotechnic article batches;
- Development of a specialised IT application related to the risk management system in the field of pyrotechnic articles of entertainment MR-PYRO.

*The motivation* of the PhD thesis is related on the one hand to the need and possibility to develop/adapt the methodological mechanism for the analysis and risk assessment of the use of pyrotechnic articles for professional use (category F4), and on the other hand to the configuration of good practice tools in the field of ensuring both a system of traceability of the sampling activity in order to test the safety quality of these types of products and an integrated management system of occupational safety in the organization of fireworks.

*The main objectives* of the thesis were: analysis and safety assessment of specific pyrotechnic articles of entertainment operations; development of integrated risk management documentation specific to pyrotechnic articles of entertainment operations; research on the use of IT facilities in the field of integrated risk management and decision-making processes specific to pyrotechnic articles of entertainment. These main objectives are achieved by achieving the derived objectives, namely: study of the specific classification/operational parameters of pyrotechnic articles; testing of pyrotechnic articles for entertainment in accordance with the requirements of the applicable regulations; analysis and assessment of the risk in the use of pyrotechnic articles for professional use (category F4); development of the integrated risk management system specific to operations with pyrotechnic articles for entertainment (MR-PYRO); development of a specialised IT application relating to the pyrotechnic article batch sampling system; development of a specialised IT application relating to the risk management system in the field of pyrotechnic articles for entertainment MR-PYRO.

The derived objectives, in turn, are achieved by meeting the following primary objectives: the study of the literature by consulting the main bibliographical references in the field of interest of the thesis; the evaluation of the specific characteristics of pyrotechnic articles that

need to be verified before, during and after the performance of function tests; the establishment of the types of tests on pyrotechnic articles according to the applicable method standards; the analysis of the current conditions for testing and verifying the conformity of pyrotechnic articles for professional use (category F4) with the requirements specified in the applicable European regulations; carrying out tests on the concrete platform of the test range of pyrotechnic articles within INCD INSEMEX Petroşani; carrying out experimental tests (on verification of functioning and determination of pyrotechnic composition content) on pyrotechnic articles in accordance with the requirements of the test methods outlined in the applicable references; establishing theoretical and practical aspects on quantification of risks specific to the activity of use of pyrotechnic articles of category F4; analysis and reduction of the professional risk specific to the activity of use of pyrotechnic articles of category F4; assessment of the risks specific to the use of pyrotechnic articles of category F4; approaching risk management from the point of view of the organisational objectives for companies that carry out professional fireworks; layout of specific risk management system documents (MR-PYRO); establishment of the steps for implementing a risk management system (MR-PYRO) in order to avoid events such as injuries to persons or fires; formulation of theoretical and practical considerations on sampling systems applicable in the field of pyrotechnic articles; elaboration of the documentation of the sampling system specific to the field of pyrotechnic articles; realization of the specialized IT application of the sampling system of pyrotechnic article batches; elaboration of the system documents specific to risk management in the field of pyrotechnic articles of entertainment MR-PYRO; realization of the specialized IT application of the SSM system for the management of activities with pyrotechnic articles of entertainment MR-PYRO. EXE 01.

The paper begins with a summary of the main regulations applicable at international and national level in the field of analysis and safety assessment of specific operations with pyrotechnic articles of entertainment, which establish normative technical aspects of specific operations with these types of products.

The next step in the research focuses both on the development of the documentation of the integrated risk management system specific to operations with pyrotechnic articles of entertainment in order to organize and safely conduct fireworks games according to the applicable regulations, and on the provision of a traceability system of sampling activity for testing to assess the safety quality of these types of products.

With regard to the appropriate management of the security of specific operations with pyrotechnic articles, the technical-scientific steps taken have continued to develop the layouts of the traceability system documents and the integrated management system of the SSM in the field of pyrotechnic articles with a view to their transposition into executable format, as well as the configuration of the corresponding specialised IT applications.

The research strategy that was the basis for the realisation of the work focused on three main directions of action in the technical-scientific plan, namely:

- The thesis starts with the analysis and safety assessment of specific operations with fireworks in order to strengthen the theoretical basis on which the theoretical-applicative premises for ensuring an effective management of the organization of fireworks in safety are founded. Thus, following the interrogation of multiple databases with scientific articles, we have taken into account, for the realization of this work, a number of 32 bibliographical references;

- The second dimension of the research consisted in the design and implementation of conceptual mechanisms to support technical and scientific tools for assessing the risk of using pyrotechnic articles for professional use (category F4) in relation to the safety requirements specific to these types of products;

- The last dimension of the research consisted both in the establishment of technical solutions for the elaboration of the technical documentation in the field of integrated risk management and decision-making processes specific to pyrotechnic articles for entertainment, and in the use of IT facilities for the realisation of specialised IT applications related to the pyrotechnic articles batch sampling system (MR-PYRO.EXE 01) and the MR-PYRO risk management system (MR-PYRO.EXE 01).

## **2. Thesis structure and some contributions**

From a structural point of view, the thesis contains an introductory chapter with a specific theme and 7 chapters of content, plus a final chapter of Final Conclusions and personal contributions, totalling 179 pages, of which 177 pages represent the thesis itself and 2 pages represent the Bibliography which has a total of 45 bibliographical notes and specialised Annexes which contribute to a better understanding of the thesis and its objectives.

Among the author's main contributions, which are documented in the chapters of the thesis, are:

- Conducting an integrated analysis identifying the national and international legislative framework that allows for the safe and predictable conduct of specific operations with pyrotechnic articles for the safe organisation and conduct of fireworks displays;

- A synthesis study has been carried out to highlight the correspondence between national and international regulations applicable to the safety of specific operations with fireworks, in relation to the risk of use of these types of products, thus creating the basis for a particularly useful guide for economic operators working in this field, facilitating optimal decision-making when integrated safety is required for the organisation and holding of fireworks games;

- Analysis of the classification/operational parameters specific to fireworks;

- Development of a modern conceptual-applicative tool for analysing and assessing the risk of use of pyrotechnic articles for professional use (category F4);

- Development and procedure of test methodologies for pyrotechnic articles for the verification of operating parameters and determination of pyrotechnic composition content;

- Technical-scientific basis of possible situations encountered in practice relating to the measurement and determination of the height of ascent of pyrotechnic articles of category F4 according to the values of the angles of deviation in the horizontal plane  $\alpha_1$  and  $\alpha_2$  and of the location of surveillance cameras in relation to the level of the launch point;

- Synthesis of the results of pilot tests carried out on different types and categories of pyrotechnic articles to verify the functioning and determine the pyrotechnic composition content;

- Development of the documentation of the integrated risk management system specific to operations with fireworks;

- Implementation of the risk management system (MR-PYRO) in order to avoid events such as injuries to persons or fires;

- Development of the documentation of the sampling system specific to the field of pyrotechnic articles;

- Development of a specialised software application for the sampling system of pyrotechnic article batches;

- Development of a specialised IT application for the risk management system (MR-PYRO).

The exploitation of the results of the research undertaken was achieved through the support and publication of papers in the proceedings of conferences/symposia or journals indexed ISI or BDI.

## **3. Synthesis of papers**

The use of pyrotechnic fireworks has become increasingly common in recent years around the world for the celebration of significant cultural and religious events, the most well-known



and common being fireworks. Pyrotechnics can also be used for special effects at concerts, theatre performances, film productions and sporting events.

The PhD thesis, entitled *Research to increase the safety level of specific operations with pyrotechnic entertainment items*, is structured in 9 chapters.

The first chapter, entitled *Introduction*, presents the general considerations, the main and specific objectives, the motivation of the thesis and a brief summary of the work.

Chapter 2, *The current state of legislation on the pyrotechnic articles regime harmonised with the European one*, presents a summary of the main regulations applicable at international and national level in the field of pyrotechnic articles, highlighting the regulatory provisions on the working regime with these types of products.

The provisions of Law 126/1995 with subsequent amendments and additions apply to the preparation, production, testing, possession, transit through the country, transmission in any form, transport, storage, handling and use by legal or natural persons of explosive materials, including pyrotechnic articles.

Pyrotechnic articles fall under the Hazardous Products Hazard Class 1 - explosive. At European and national level there is Directive 2013/29/EU of the European Parliament and of the Council of 12 June 2013 on the harmonisation of the laws of the Member States relating to the making available on the market of pyrotechnic articles respectively Government Decision No 1102 of 10 December 2014 on the establishment of conditions for making available on the market of pyrotechnic articles.

Directive 2013/29/EU on pyrotechnic articles transposed at national level by GD 1102/2014 includes: rules aimed at achieving the free movement of pyrotechnic articles while ensuring a high level of protection of human health and public safety, as well as consumer protection and safety taking into account applicable environmental protection aspects; essential safety requirements that pyrotechnic articles must meet in order to be placed on the market.

Also under this Directive, pyrotechnic articles are classified by manufacturers according to their type of use or purpose and their level of risk, including their noise level.

Chapter 3 is called the *Study of the classification/functional parameters specific to pyrotechnic articles*. The regulatory documents set out the essential safety requirements that these products must meet and which must be taken into account both in the design and production phase of the products and in third party tests and assessments (carried out by a product certification body with an accredited laboratory). In the event of disputes and suspicions about the conformity of pyrotechnic articles for entertainment, the authorities designated for market surveillance may additionally require these tests to be repeated.

Depending on the type and category of pyrotechnic articles, their conformity is usually checked by applying the provisions of harmonised European standards specifying test methods with all the necessary technical and organisational requirements.

Chapter 4, *Contributions on the testing of pyrotechnic articles for fireworks in accordance with the requirements of the applicable regulations*, presents a number of application contributions on the testing of different types and categories of pyrotechnic articles for the purpose of verifying the performance parameters and determining the mass of pyrotechnic composition. Thus, technical and methodological aspects for the specificity testing of these pyrotechnic articles have been documented in this chapter, in accordance with the applicable references, namely: F1, F2 and F3 (SR EN 15947-2:2015); F4 (SR EN 16261-3:2013); T1 and T2 (SR EN 16256-5:2013); P1 and P2 ignition devices except those for pyrotechnic articles intended for vehicles (SR EN 16265:2016); pyrotechnic articles intended for vehicles (SR EN 14451-2:2013).

Aspects related to *Contributions to the analysis and risk assessment of the use of pyrotechnic articles for professional use (category F4)* are highlighted in Chapter 5 where we have presented a modern conceptual-applicational tool for the analysis and risk assessment of the use

of pyrotechnic articles for professional use (category F4). The scientific and technical importance of the issues related to the test technology of these types of pyrotechnic articles for professional use (category F4) lies in the following considerations: Compared to the category F1, F2 and F3 fireworks, these products present a significantly higher level of risk due to the mode of operation and the quantity of explosive material involved, requiring personnel authorised as pyrotechnicians; the equipment used for in situ determinations, which must reproduce real conditions of use, must be of a higher measuring accuracy and range than those provided for in the lower categories; the regulations in force at national level do not have explicit provisions for this type of products with a high level of hazard, and the implementation of the family of European standards harmonised with Directive 2013/29/EU offers the possibility of testing, evaluation or expertise at a technical level appropriate to the current level of scientific knowledge.

Chapter 6, *Contributions to the development of the Integrated Risk Management System for Fireworks and Recreational Craft Operations (MR-PYRO)*, presents a section dedicated to the summary of the Integrated Risk Management System for Fireworks and Recreational Craft Operations (MR-PYRO) system documents, namely: the SSM Management Manual (MC-PYRO-SSM) and 13 system procedures: Hazard identification, risk assessment and establishment of controls (PS-PYRO-SSM-01); Assessment of compliance with legal and other requirements (PS-PYRO-SSM-02); Competence, training and awareness (PS-PYRO-SSM-03); Communication (PS-PYRO-SSM-04); Participation and consultation (PS-PYRO-SSM-05); Document control (PS-PYRO-SSM-06); Emergency Preparedness and Response (PS-PYRO-SSM-07); OHSAS Monitoring and Performance Measurement (PS-PYRO-SSM-08); Incident Investigation (PS-PYRO-SSM-09); Non-conformities, Corrective and Preventive Actions (PS-PYRO-SSM-10); Control of Records (PS-PYRO-SSM-11); Internal Audit (PS-PYRO-SSM-12); Management Review (PS-PYRO-SSM-13).

Chapter 7, *Contributions on the development of a specialised software application for a lot sampling system for pyrotechnic articles*, summarises the documents of a harmonised traceable sampling system specific to the field of pyrotechnic articles which offers a number of advantages concerning: ease of systematic analysis of quantitative and qualitative factors characterising the degree of non-conformity expressed either as a percentage of non-conforming items or as non-conformities found per 100 items; greater awareness of the risks of non-fulfilment of the specified requirements, related to the pre-established quality level; improved transparency of the processes for carrying out sampling schemes configured in accordance with the applicable requirements; better measurement and evaluation of the performance of the sampling process.

In order to ensure the smooth implementation of the harmonised sampling system for lots of pyrotechnic articles, we considered it necessary to develop a specialised computer application based on methodological considerations set out in the sampling procedure and the working tools of the sampling mechanism, for the purpose of drawing up specific reporting documents in accordance with quality principles.

The specialised software application ESANTIONARE.EXE 01 ensures the operational and procedural elaboration of the working and reporting documents specific to the pyrotechnic article lot sampling system, at the level of the economic operators in the pyrotechnic article sector and the authorities in charge of this field. The program, in executable version ESANTIONARE.EXE 01, can be a viable solution to solve operationally and procedurally the problems in the field of sampling of lots of pyrotechnic articles, offering the possibility of: planned and documented approach to the sampling process; definition of areas of responsibility and acceptability; knowledge and awareness of the problems specific to the sampling and sampling system.

In order to ensure the security of the information and data contained in the ESANTIONARE.EXE 01 program, access to the application and to the layouts of the working and reporting documents is carried out in a controlled manner through authentication with a unique password identified and differentiated according to the document accessed, respectively when reading to consult the reference documents (applicable standards and specific procedure) and when reading and writing the reporting document (sample report).

In Chapter 8, *Contributions on the development of a specialised software application related to the MR-PYRO pyrotechnic article risk management system*, we have presented the MR-PYRO.EXE 01 software application that translates the integrated pyrotechnic article SSM system into a specialised software application in accordance with the principles and practice of the quality system. This program is a working tool used for operative and procedural elaboration of MR-PYRO system documents by entering data and information related to: applicable legal regulations in the field of SSM, objectives in the field of SSM, purpose, scope of use, responsibilities for elaboration and management of the SSM manual, implementation, maintenance and improvement of the SSM system, modes of action, information flows, modes of data recording in order to ensure compliance with the requirements of the model and efficient functioning of the management system in the field of SSM.

Chapter 9, entitled *Final Conclusions and Personal Contributions*, highlights the contributions made to increasing the safety level of specific operations with pyrotechnic articles of entertainment both in terms of setting up a modern conceptual-applicative tool for analysing and assessing the risk of their use, and by developing the methodological and IT infrastructure to ensure an appropriate system for sampling pyrotechnic articles for testing to ensure the safety quality of these types of products, as well as an integrated occupational safety and health management system, together with the way to implement and exploit the results of current and future research.

#### **4. Personal contributions**

##### **4.1 Theoretical contributions**

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

- The completion of an integrated analysis through which the national and international legislative framework has been identified that allows the predictable safe conduct of specific operations with pyrotechnic articles of entertainment in order to organize and conduct fireworks games safely;

- The completion of a synthesis study which highlighted the correspondence between national and international regulations applicable in the field of safety of specific operations with pyrotechnic articles of entertainment regarding the risk of use of these types of products, thus creating the premises for a particularly useful guide for economic operators working in this field, facilitating optimal decision making when integrated security is required in the organization and conduct of fireworks;

- analysis of the classification/operational parameters specific to fireworks;

- Developing a modern conceptual-applicative tool for analysing and assessing the risk of using pyrotechnic articles for professional use (category F4);

- Development and procedure of test methodologies for pyrotechnic articles for the verification of the operating parameters and determination of the pyrotechnic composition content;

- The technical-scientific basis of possible situations encountered in practice, relating to the measurement and determination of the height of ascent of pyrotechnic articles of category F4, depending on the values of the angles of deviation in the horizontal plane  $\beta_1$  and  $\beta_2$  and the location of the surveillance cameras in relation to the level of the launch point;

-Synthesis of the results of pilot tests carried out on different types and categories of pyrotechnic articles to verify the functioning and determine the pyrotechnic composition content;

-Development of the documentation of the integrated risk management system specific to operations with fireworks;

-Implementation of the risk management system (MR-PYRO) in order to avoid events such as injuries to persons or fires;

-Development of the documentation of the sampling system specific to the field of pyrotechnic articles;

-Design and development of a specialised software application for the sampling system of pyrotechnic article batches;

-Design and development of a specialised IT application for the risk management system (MR-PYRO).

#### **4.2. Contributions in the field of applied IT**

-ESANTIONARE.EXE 01 specialised software application related to the pyrotechnic article batch sampling system.

-Specialised IT application MR-PYRO.EXE 01 relating to the risk management system for pyrotechnic articles of entertainment MR-PYRO.

#### **4.3. Experimental and applied contributions**

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

-Tests on pyrotechnic articles carried out on the concrete platform of the Pyrotechnic Articles Test Range at INCD INSEMEX Petroşani, according to the applicable requirements of SR EN 15947-4:2016, SR EN 16261-3:2013, SR EN 16256:5:2013, SR EN 16263-4:2016, SR EN 16265:2016, SR EN 14451-2:2013;

-Pilot tests performed on a pyrotechnic product category F4 type fireworks battery imported from China - SC BEAUTIFUL SKY- SRL Bucharest, code 408, applying the test procedure describing the specific requirements contained in the series of standards, harmonized SR EN 16261; They have captured both the in-situ operation and the principle scheme related to the measurement and determination of the height of ascent of category F4 pyrotechnic articles (where the angles of deflection in the horizontal plane  $\beta_1$  and  $\beta_2$  are different from 0 and the cameras are located at the same level as the launch point);

-Experimental tests to determine the content of pyrotechnic articles were carried out on different categories of pyrotechnic articles (without preconditioning or after thermal or mechanical conditioning), respectively: jerry can, trade name PASTA MAYTABI BCSPM1 (category F1); jerry can, trade name SUPER VOLCANO BCSV and code 668 (category F2); battery, trade name FLOWER GARDEN BCS 25 (category F3); sound emitter, trade name CORSAR/K0203-3/YT-P1133 (category P1), with the following results: net mass of pyrotechnic mixture (grams) in the case of jerry cans and sound emitter; mass of propellant charge (grams)/mass of tail charge (grams)/mass of effect charge (grams)/total mass of pyrotechnic mixture per tube (grams)/total mass of pyrotechnic mixture per effect (grams)/total mass of pyrotechnic composition of article - NEC (grams) in the case of battery;

-Experimental tests to verify the performance of pyrotechnic articles were carried out on different categories of pyrotechnic articles (without preconditioning or after thermal or mechanical conditioning), respectively: jerry can, trade name PASTA MAYTABI BCSPM1 (category F1); Bengal fire, trade name MESALE BCS 017-K Red Flame (category F2); battery, trade name BRILLIANT STARS/BCS 16-1/BCS 16-2 (category F3); bomb, trade name MINORI BCS 6"-1 SILVER PALM (category F4), sound emitter, trade name CORSAR /

K0203-3/YT-P1133 (category P1); noise emitter, trade name IZT (category T2) with the following results: construction and stability/length of article/gauge determination/outside diameters/fixing of initiation fuse/design- verification/conformity with drawings and table of contents/measurement of sound pressure level (dB)/measurement of delay/measurement of label characters/extinguishing of flames (120s)/burning rate of composition/design fragments/glowing material/visual and acoustic examinations/function test (main effect/full operation/maintaining vertical position/explosion during operation).

#### **4.4. Future research directions**

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

- Design and configuration of procedures and methodologies for conducting tests of pyrotechnic articles within schemes for inter-laboratory testing and their implementation within the integrated quality system;
- Development of documentation for the accreditation of a testing laboratory and a conformity assessment body for pyrotechnic articles for entertainment and their implementation within the integrated quality system;
- Digitisation of the modern conceptual-applicative tool for risk analysis and assessment specific to operations with pyrotechnic articles of entertainment;
- Research on the creation and delimitation of a special intelligent space for the organisation of fireworks games, equipped with state-of-the-art IT devices and specialised computer applications designed for the remote monitoring of fireworks.