Assessment of the Risk of the Accidental Initiation of Semi-Fabricated Products Containing Pyrotechnic Articles with a Technical Destination in the Automotive Field

Ilie-Ciprian Jitea[1*)], Bogdan Garaliu-Bușoi[2)], Cristian Rădeanu[3)], Robert Laszlo[4)], Gabriel Vasilescu[5)]

[1*)] National Institute for Research and Development in Mine Safety and Protection to Explosion –INSEMEX. Department of Safety of Explosion and Pyrotechnic Articles, G-ral V. Milea Street 32-34, Petrosani, Romania; email: ciprian.jitea@insemex.ro; https://orcid.org/0009-0009-5214-7032

[2)] National Institute for Research and Development in Mine Safety and Protection to Explosion –INSEMEX. Department of Safety of Explosion and Pyrotechnic Articles, G-ral V. Milea Street 32-34, Petrosani, Romania

[3)] National Institute for Research and Development in Mine Safety and Protection to Explosion –INSEMEX. Department of Safety of Explosion and Pyrotechnic Articles, G-ral V. Milea Street 32-34, Petrosani, Romania

[4)] National Institute for Research and Development in Mine Safety and Protection to Explosion –INSEMEX. Department of Safety of Explosion and Pyrotechnic Articles, G-ral V. Milea Street 32-34, Petrosani, Romania

[5)] National Institute for Research and Development in Mine Safety and Protection to Explosion –INSEMEX. Department of Safety of Explosion and Pyrotechnic Articles, G-ral V. Milea Street 32-34, Petrosani, Romania; https://orcid.org/0000-0003-3591-9458

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Abstract

The identification of the danger of accidental initiation, respectively the establishment of the causes and the possibilities that can generate the triggering of pyrotechnic devices with a technical destination in the automotive field containing pyrotechnic articles of the P1 category, is carried out for each piece of equipment depending on the phases of the technological process of their manufacture. The protection against the accidental initiation of pyrotechnic devices intended for equipping auto vehicles is of particular interest for occupational safety in the manufacturing process of these types of products, because their triggering can endanger the life and health of workers as a result of the uncontrollable effects of functioning, with the generation of thermal and dynamic effects, as well as the emission of toxic reaction products that can affect the human component and/or destroy the work space. The paper highlights the way to analyse the risk of accidental initiation of pyrotechnic devices actuator type from the P1 category, using the latest generation technical-scientific tools in order to computerize the effects following their untimely triggering and establish the safety distances in relation to the amplitude of the degree of damage to the human component, respectively the destruction caused to the work space. In the case of pyrotechnic articles from category P1 type pyrotechnic actuator, the main risks of their accidental initiation are determined by the following technical factors: the production of an electrical discharge greater than 25 KV, the generation of a current with an intensity greater than 0.4 A at the terminals pyrotechnic device, their exposure to a temperature higher than 165°C. The main effects generated after the untimely initiations of these products are determined by: flame, thermal radiation, dynamic pressure waves, projected fragments and hazardous releases of chemical combustion products. Depending on the results obtained following the estimation and assessment of the assessed risks, preventive and countermeasures of a technical and organizational nature are established, in order to secure the predicTab. operations of specific operations with these types of products.

Keywords: assessment of the risk, semi-fabricated products, pyrotechnic articles, automotive field

Introduction

The object of the evaluation of the risk factors that can lead to the accidental initiation of semi-finished products containing pyrotechnic articles in the process of handling / use / storage / transport within the technological flow of production is represented by the estimation and appreciation of the risk of initiation / detonation of pyrotechnic devices having the name " PYROFUSES" - pyrotechnic actuator for vehicle type 8057-01, classified in category P1", based on the quantification of the specific hazards of operations with these types of products, carried out in various phases of the technological flow, used in the manufacture of subassemblies for breaking the electrical circuit (pyrofuse type) in motor vehicles.

The role of the actuator is to interrupt the electrical circuit in which it is connected, in the situation where a vehicle is involved in an accident, an electrical signal is generated in the circuit that initiates the pyrotechnic device.

According to the specifications in the technical documentation on the Pyrofuse process, the employer is responsible for the security of the employed personnel. All persons involved must be informed of clearly defined procedures for operation and emergencies, and adequate training must be provided for employees. The responsibility for the security of the operations rests with the employees during their involvement in the activities specific to the Pyrofuse line. It is also necessary that the instructions issued by the equipment suppliers regarding the installation, maintenance, security and/or modifications of the equipment, are included in the training courses and distributed to the personnel who are trained to perform the work [1-6].

Technical Aspects Regarding the Actuator-Type Pyrotechnic Device

The pyrotechnic actuators type 8057-01, classified in the P1 category, are certified according to the requirements of Directive 2013/29/EU, having the registration number 2463-P1-000069 and the CE examination certificate no.PIP14-P1-069, being intended for equipping autovehicles, in order to interrupt the electrical circuit in which it is connected, following its initiation by an electrical signal generated upon the impact of the motor vehicle (Fig. 1).

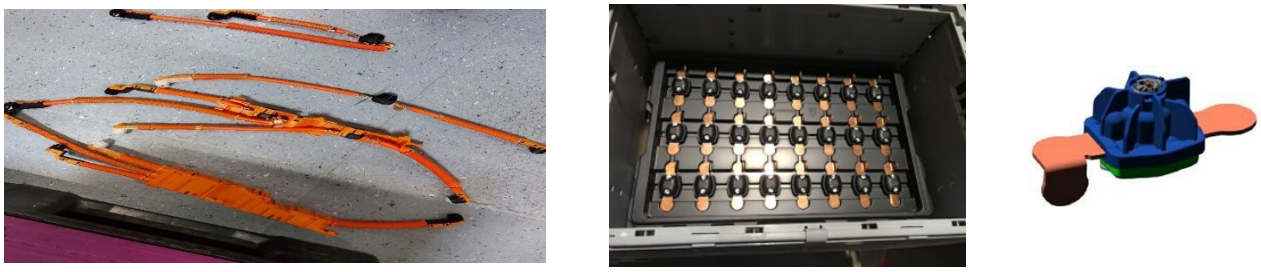

Fig. 1. Pyrotechnic actuators type 8057-01, included in category P1 intended for equipping vehicles

From a constructive point of view, the pyrotechnic actuator consists of: a plastic casing in which a pyrotechnic article with a net mass of pyrotechnic composition of 45 mg is hermetically sealed and a copper conductor through which the electrical circuit of the vehicle is connected.

Accidental initiation/detonation in the event of a potential hazard of the pyrotechnic actuator can be generated by the following factors: electrical discharge > 25 kV; when a current with intensity > 0.4 A passes through the two actuator initiation pins; if the product is heated to a temperature > 165°C.

Presentation of the Methodological Infrastructure for Quantitative Risk Assessment Specific to Operations with Dangerous Explosive Substances

The quantitative risk assessment methodology, addressed in this chapter, is based on the concept of risk developed since 1662 by the French mathematician Blaise Pascal, who argued that: *"Fear of harm ought to be proportional not merely to the gravity of the harm, but also to the probability of the event".* In this sense, Risk can be expressed mathematically through the following basic relationship:

$$R = P \times G, \quad (1)$$

where: R-professional risk (of occupational injury and/or illness); P-probability of occurrence of the unwanted event; G-severity of the maximum foreseeable consequence.

If the occurrence of an "explosion" event (generated during specific operations with explosive materials carried out in a year) is expressed in terms of probability, and the undesired consequences in terms of the probability of death or injury by causing major/minor injuries ($P_{dl}^{M,m}$) (considering the presence of the human operator), then relation (1), in the case of individual risk, becomes:

$$R_{personal} = P_{d,l}{}^{M,m} = P_{explozion} \; x \; P_{d,l}{}^{M,m}{}_{/explozion} \; x \; E_{personal}, \quad (2)$$

where: $P_{dl}^{M,m}$- annual probability of death or injury from major/minor injuries; $P_{explozion}$- the annual probability of an explosion-type event occurring on a site intended for specific operations with explosive materials; $P_{dl}^{M,m}{}_{/explosion}$ - probability of death or major/minor injury following an explosion-type event, given the human operator's exposure to the event; $E_{personal}$ - personal human exposure to the occurrence of an explosion-type event on a site intended for specific operations with explosive materials [hours/year].

Considering the previously mentioned technical aspects, in Tab. 1, highlight the risk assessment matrix that is based on the concept of compliance with the principle of logical proportionality, respectively:

Tab. 1. Risk assessment matrix

Classes of probability	**Gravity classes**				
	Catastrophic	**Critical**	**Medium**	**Negligible**	**p**
Frequent	M	M	S	Me	10^{0} 10^{-1}
Probable	M	M	S	Me	10^{-2}
Occasional	M	S	Me	Mi	10^{-3}
Rare	S	Me	Me	Mi	10^{-4} 10^{-5} 10^{-6}
Unlikely	Me	Me	Me	Mi	10^{-7} 10^{-8} 10^{-9}
Legend: M-high risk; S-significant risk; Me-medium risk; Mi-small risk.					

The concept of risk assessment is a sequential process that involves both the quantitative assessment of risk estimation based on available data and information (accident history and statistics, test and trial results, technical-scientific information, safety data sheets, technical product specifications , the experience and technical expertise in the field of the experts), as well as the qualitative evaluation regarding the risk assessment taking into account the subjective aspects and the perception of the way of manifestation and generation of specific effects, according to Tab. 2.

Tab. 2. Risk assessment matrix

Evaluarea riscului	Calitativă	Exemplu	**Clase de gravitate, G**	**Clase de probabilitate, P**				
					Frecvent	**Probabil**	**Ocazional**	**Rar**	**Improbabil**
				Catastrofică	M	M	M	M	Me
				Critică	M	M	M	Me	Mi
				Medie	M	Me	Me	Mi	Mi
				Neglijabilă	Me	Mi	Mi	Mi	Mi
	Cantitativă	Exemplu	1 x 10^{-6} – estimarea valorii probabilității anuale de deces, P_{deces}						
Legendă: M-risc mare; Me-risc mediu; Mi-risc mic				--►sensul de reducere a parametrilor de risc P și G					

Assessment of the Risk of Accidental Initiation/Detonation of Semi-Finished Products Containing Pyrotechnic Articles with a Technical Destination in the Automotive Field

Analysis of the risk factors for the accidental initiation/detonation of pyrotechnic devices intended for autovehicles

In the case of the pyrotechnic actuator, the risks are represented by the following technical factors: an electrical discharge occurs with a potential higher than 25 kV; a current greater than 0.4 A flows through the two ignition pins; the products are heated to a temperature higher than 165 ° C; mechanical shock. All three risk factors were analyzed and the necessary measures were taken to avoid them by equipping them with adequate monitoring and execution equipment. In order to avoid the formation of static electricity and the possibilities of its manifestation within the objectives subject to risk analysis, the following are carried out: the technical equipment of the technological installations are connected to the earthing installation; all technical equipment is equipotentialized to ensure electrical continuity; individual protective or work equipment used, are made of materials free of electrostatic charges;

In order to create an image of the dynamic destructive effects and the degree of human injury, generated by accidents caused by explosions, Tab. 3 shows the dynamic effects observed on buildings and Tab. 4 the effects and traumas produced on humans, from the specialized literature, depending on the overpressures applied, although other factors, such as the notab. impulse, may play an important role for these effects. Following the correlation of the degree of human injury, depending on the overpressure in the front of the shock wave, the specialized literature specifies the value of 0.2 bar as the "maximum allowed limit" of the overpressure for humans. As can be seen from the data above, man is particularly resistant to the action of shock waves. The main cause of injury to people in the area of action of the pressure front is not the pressure from the wave front, but the air current moving after it, the speed of which reaches 60 - 80 m/s, for pressures of 0.3 - 0.4 bar. A person cannot resist such speeds of the current, and with all the short duration of action of the current, it causes trauma, as a result of falling and falling off rigid surfaces. In addition, usually after the shock wave, shrapnel moves fragments of the destroyed objects that cause trauma [7], [8].

Tab. 3. Dynamic effects of an explosion on constructions

Overpressure in the shock wave front, (bar)	**Effects**
0,04 - 0,07	Broken windows, sometimes dislocations of wooden frames
0,07 - 0,15	Cracks and bends (bends) of plaster walls; asbestos-cement tiles. Dislocations, swelling (bumping) of partitions (light walls) and ceilings made of corrugated iron, wooden panels.
0,15 - 0,25	Cracks, breaks (fragmentation) of concrete or stone walls, unreinforced, with a thickness of 20 - 30 cm.
0,2 - 0,5	Ruptures of overhead tanks (hydrocarbons, etc).
0,5 - 0,6	Bombardment or destruction of unreinforced brick walls 20-30 cm thick.
0,7 - 1	Overturning loaded wagons, destroying reinforced concrete walls. Blowing (throwing) brick walls.

Tab. 4. The dynamic effects of an explosion on humans

Overpressure in the shock wave front, (bar)	Effects
0,2 - 0,3	Minor trauma (contusions, tinnitus)
0,3 - 0,5	Medium traumas (contusions, deafness)
0,5 - 1,0	Serious trauma (fractures, internal bleeding)
1,0	Very serious traumas, practically incompatible with life
4,0 - 6,0	Certain death

Computer simulation of accident scenarios that can occur in work areas with this type of product

For the computer simulation of accident scenarios caused by the accidental initiation/detonation of pyrotechnic devices due to their exposure to a hazardous external stimulus: current leaks (when a current greater than 0.4 A passes between the two actuator initiation pins), electrostatic charging/discharge (for a potential greater than 25 kV), high temperature (greater than 165 ^{0}C), mechanical shock, manifested in the discharge area of pyrotechnic devices, various amounts of explosive materials expressed in ETNT (trinitrotoluene equivalent) were used, located in different work areas, according to the technological flow within the manufacturing process (Fig. 2). The configuration of these accident scenarios is carried out by entering specific data and information, both for the dangerous structure of the PES type (intended for the temporary storage of pyrotechnic slides - metal container), and for the exposure structure of the ES type (intended for carrying out specific operations with pyrotechnic devices), in view of the computerized assessment of the risk of accidental initiation/detonation of pyrotechnic devices (Fig. 3-7).

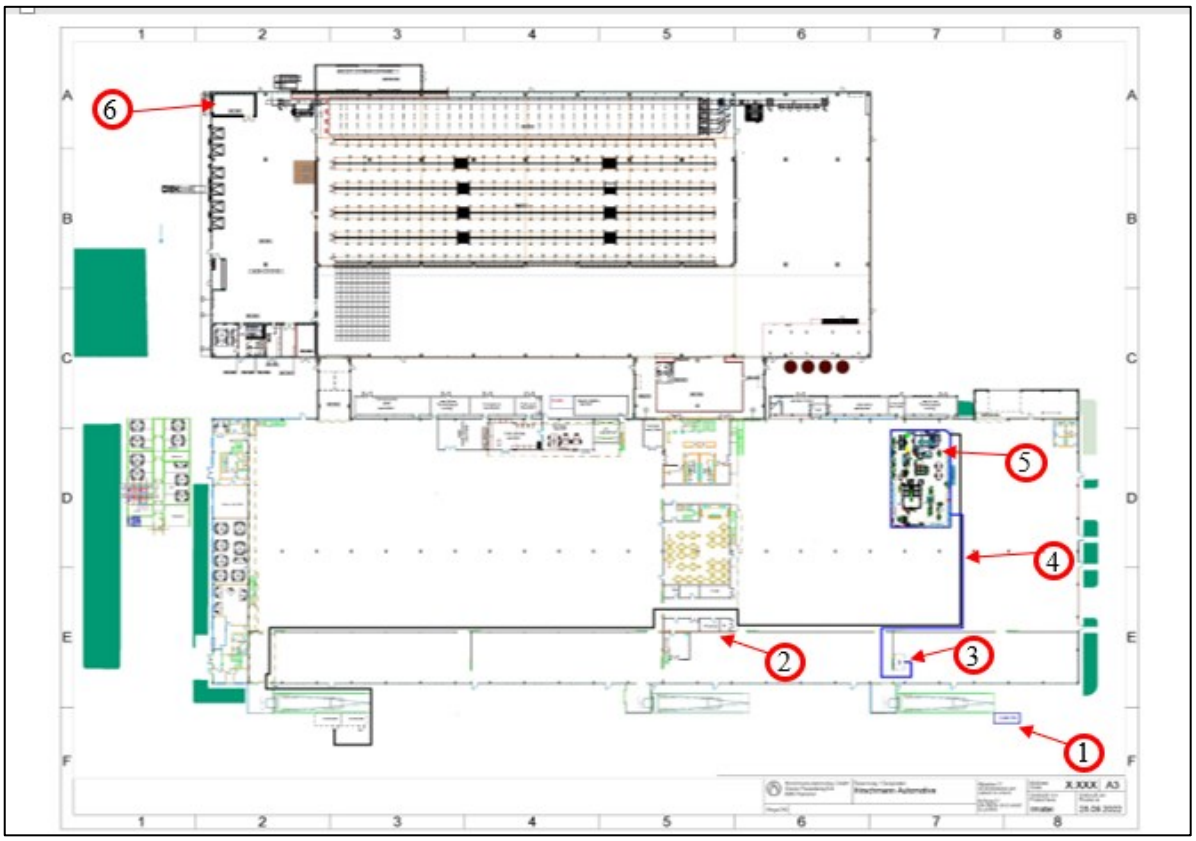

Fig. 2. Highlighting the unloading area

1-Storage area of pyrotechnic devices in the metal container located outside; 2-Reception area; 3-Storage area in the metal container located inside, specially designed (consumption warehouse); 4-The area of the predefined route intended for the transport of pyrotechnic devices with equipment authorized at the Production Section; 5-Production section; 6-Bunker

I. The accident scenario manifested in the storage area of pyrotechnic devices (1.35 kg ETNT) in the metal container located outside

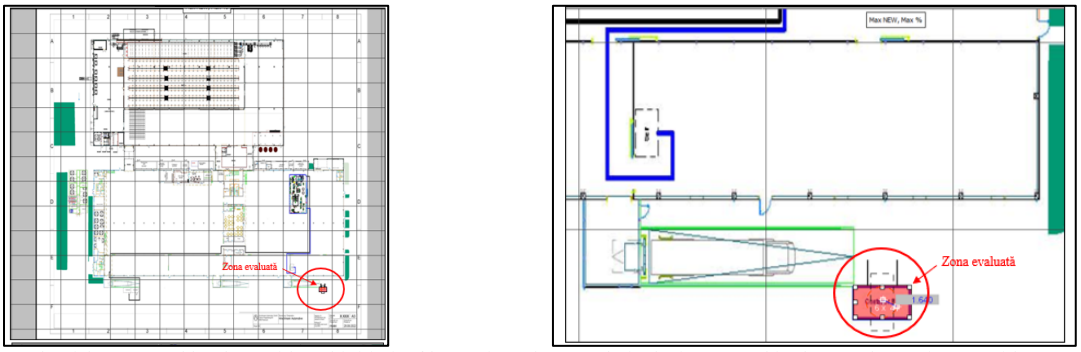

Fig. 3. The risk generated by the accidental initiation/detonation of pyrotechnic devices stored in the metal container outside, which can affect, through the thermal effect, the personnel who handle these products
(risk generated by exposure of pyrotechnic devices to a dangerous external stimulus: current leaks - when a current greater than 0.4 A passes between the two start pins of the actuator, electrostatic charge/electrical discharge - with a potential greater than 25 kV , high temperature - greater than 165 ^{0}C, mechanical shock)

II. The accident scenario manifested in the storage area of pyrotechnic devices (1.35 kg ETNT) within the consumption warehouse (metal container inside)

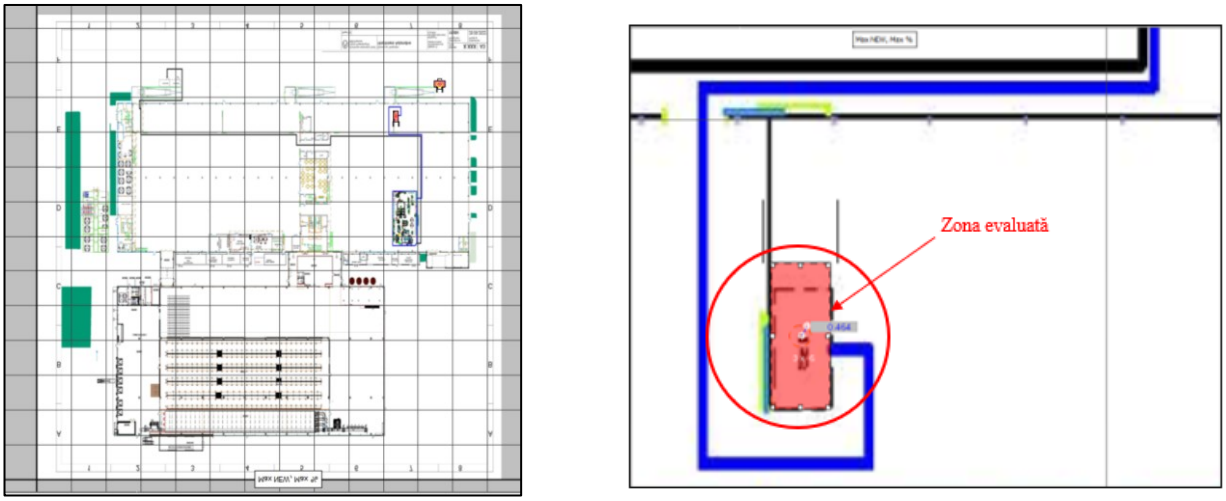

Fig. 4. The risk generated by the accidental initiation/detonation of pyrotechnic devices which can affect, through thermal effect, the personnel who remove these products from the consumption warehouse, in order to transport them to the Production Section *(due to their exposure to a dangerous external stimulus: leaks current - when a current greater than 0.4 A passes between the two actuator initiation pins, electrostatic charge - with a potential greater than 25 kV, high temperature - greater of 165 ^{0}C, mechanical shock)*

III. The accident scenario manifested in the area of the predefined route intended for the transport of pyrotechnic devices (0.0027 kg ETNT)

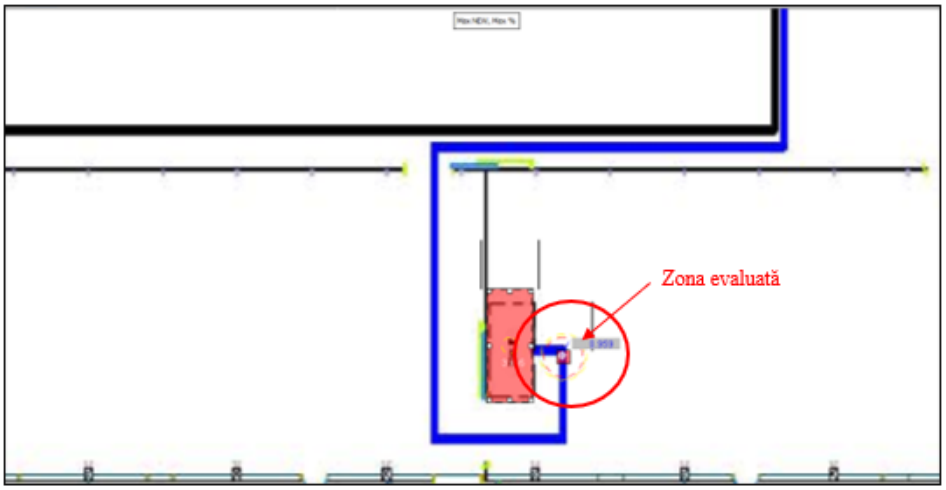

Fig. 5. The risk generated by the accidental initiation/detonation of pyrotechnic devices removed from the consumer warehouse, which are intended for transport to the Production Section *(due to their exposure to a dangerous external stimulus: leaks current - when a current greater than 0.4 A passes between the two actuator initiation pins, electrostatic charge - with a potential greater than 25 kV, high temperature - greater of 165 ^{0}C, mechanical shock)*

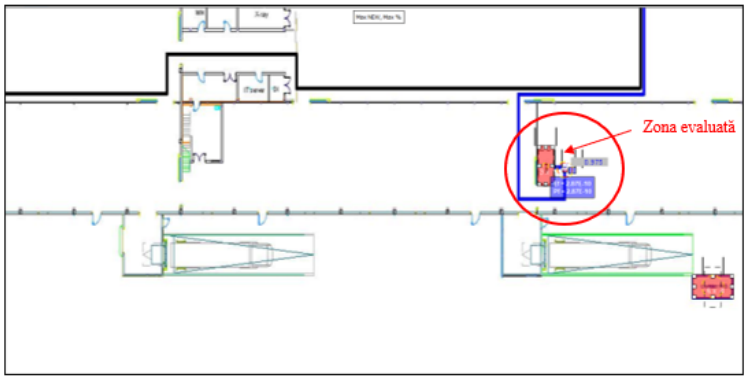

Fig. 6. The risk generated by the accidental initiation/detonation of pyrotechnic devices removed from the consumer warehouse, which may affect, through the thermal effect, the personnel who carry out their transport along the predefined route to the Production Section *(due to their exposure to a dangerous external stimulus: leaks current - when a current greater than 0.4 A passes between the two actuator initiation pins, electrostatic charge - with a potential greater than 25 kV, high temperature - greater of 165 ^{0}C, mechanical shock)*

IV. The accident scenario manifested at the Bunker intended for the storage of finished products (0.1913 kg ETNT)

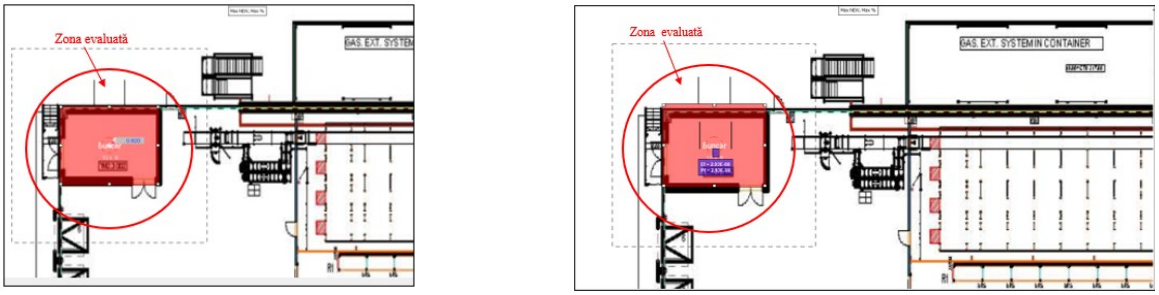

Fig. 7. The risk generated by the accidental initiation/detonation of pyrotechnic devices stored in the bunker which can affect the personnel on duty through thermal effect *(due to their exposure to a dangerous external stimulus: leaks current - when a current greater than 0.4 A passes between the two actuator initiation pins, electrostatic charge - with a potential greater than 25 kV, mechanical shock)*

The centralization of the risk assessment results is highlighted in Tab. 5.

Tab. 5. Centralization of risk assessment resul

No. crt.	**Scenario**	**The risk of damage by thermal effect as a result of the initiation / detonation of pyrotechnic devices**		**Radius of the affected area [m]**	**Type of affect / effect**
1.	I. The accident scenario manifested in the storage area of pyrotechnic devices (1.35 kg ETNT) in the metal container located outside (PES1)	Risk of fire generated inside the metal container located outside due to the accidental initiation / detonation of pyrotechnic devices as a result of their exposure to a dangerous external stimulus (leaks current, electrostatic charge/discharge, high temperature, mechanical shock)		1,64	Destruction of the space inside the container placed outside, by thermal effect.
2.	II b. The accident scenario manifested in the reception area of pyrotechnic devices (0.0054 kg ETNT) (PES2 - ES1)	The probability of damage by thermal effect Pf *	Nr. Of damages /unwanted effects Ef *	1,131	Affecting the human component through burns caused by the thermal effect of the unwanted event, resulting in a fire.
		$9{,}48\times10^{-8}$	$1{,}01\times10^{-7}$		
3.	III. The accident scenario manifested in the storage area of pyrotechnic devices (1.35 kg ETNT) within the consumption warehouse (metal container inside) (PES3)	Risk of fire generated inside the metal container (consumption deposit) due to the accidental initiation / detonation of pyrotechnic devices as a result of their exposure to a dangerous external stimulus (leaks current, electrostatic charge, high temperature, mechanical shock)		0,464	Destruction of the space inside the container placed inside (consumption deposit) by thermal effect.

No. crt.	Scenario	The risk of damage by thermal effect as a result of the initiation / detonation of pyrotechnic devices		Radius of the affected area [m]	Type of affect / effect
4.	IV b. The accident scenario manifested in the area of the predefined route intended for the transport of pyrotechnic devices (0.0027 kg ETNT) (PES4 - ES2)	The probability of damage by thermal effect Pf *	Nr. Of damages /unwanted effects Ef *	0,975	Damage to the human component by burns caused by the thermal effect generated both by the caloric flow resulting from the fire inside the metal container (consumption deposit) if the access door inside it is open, as well as by the thermal effect generated by accidental initiation of pyrotechnic devices removed from the container to be transported to the production section.
		$2,87x10^{-10}$	$2,87x10^{-10}$		
5.	V a. The accident scenario manifested at the level of the Production Section, in the area of the metal dumpster intended for the collection of pyrotechnic waste devices (max. 0.0054 kg ETNT) (PES5)	Risk of ignition of waste pyrotechnic devices stored in the metal bin as a result of their exposure to a dangerous external stimulus (leaks current, electrostatic charge, mechanical shock)		0,202	The fire produced inside the metal dumpster with a negative effect on the closing systems.
6.	V b. The accident scenario manifested at the level of the Production Section, in the area of the metal dumpster intended for the collection of waste pyrotechnic devices (max. 0.0054 kg ETNT) (PES5-ES3)	The probability of damage by thermal effect Pf *	Nr. Of damages /unwanted effects Ef *	0,202	Affecting the human component through burns caused by the thermal effect generated by the burning of pyrotechnic waste devices inside the metal dumpster, if its lid is open.
		$2,25x10^{-5}$	$2,25x10^{-5}$		
7.	VI a. The accident scenario manifested at the Bunker intended for the storage of finished products (0.1913 kg ETNT) (PES6)	Risk of ignition of pyrotechnic devices stored in the bunker as a result of their exposure to dangerous external stimuli (leaks current, electrostatic charge, mechanical shock)		0,82	Destruction of the space inside the bunker by thermal effect.
8.	VI b. The accident scenario manifested at the Bunker for the storage of finished products (0.1913 kg ETNT) (PES6-ES4)	The probability of damage by thermal effect Pf *	Nr. Of damages /unwanted effects Ef *	0,82	Affecting the human component through burns caused by the thermal effect generated by the caloric flow resulting from the ignition of finished products consisting of pyrotechnic devices that can be initiated accidentally.
		$2,93x10^{-8}$	$2,93x10^{-8}$		

**Note:*

-$Pf_{acceptable}=3,0x10^{-5}$ *(for the workers who serve the PES type structures)*
-$Pf_{acceptable}=1,0x10^{-5}$ *(for workers who serve ES structures)*
-$Pf_{acceptable}=3,0x10^{-6}$ *(for visitors)*
-$Ef_{acceptable}=3,0x10^{-4}$ *(for the workers who serve the PES type structures)*
-$Ef_{acceptable}=1,0x10^{-4}$ *(for workers who serve ES structures)*
-$Ef_{acceptable}=3,0x10^{-5}$ *(for visitors)*

Conclusions

Protection against detonation due to accidental initiation is of particular interest for safety because these detonations endanger the life and health of workers due to the uncontrollable effects of detonation and pressure, the presence of toxic reaction products and the consumption of oxygen from the ambient air, which workers must to inspire him. At the same time, it must be taken into account that material losses caused by explosions can be particularly high.

The organizational aspect of explosion protection must adapt to the technical problems specific to the workplace, so that weak

points do not appear in explosion-protected installations.

In order to evaluate the risk factors that can lead to the accidental initiation / detonation of semi-finished products containing pyrotechnic devices, the locations where technological processes are carried out that also include the use of pyrotechnic devices and where there may be risks of their accidental initiation / detonation were analyzed.

The pyrotechnic actuators type 8057-01, classified in the P1 category, having a net mass of explosives of 0.000045 kg TNT equivalent, is intended for equipping motor vehicles and has the role of interrupting the electrical circuit in which it is connected following its initiation by an electrical signal generated at the impact of the vehicle. This product is certified according to the requirements of Directive 2013/29/EU, having registration number 2463 – P1 – 000069 and EC Examination Certificate number PIP14 – P1 – 069.

The accidental initiation / detonation of the pyrotechnic actuator can occur by exposing it to the following dangerous external stimuli: electrostatic charge/electrical discharge – with a potential greater than 25 kV; leaks current – when a current of 0.4 A passes through the two actuator initiation pins; temperature - higher than 165 ºC; mechanical shock.

The risk assessment of the accidental initiation / detonation of semi-finished products containing pyrotechnic devices used in the technological flow of production was carried out taking into account the technical factors of their exposure to dangerous external stimuli (stray currents, electrical discharge, high temperature, impact). Thus, for the computerized modeling of the event scenarios, the specialized software package for probabilistic risk assessment specific to industrial sites in the field of the use of explosive materials, type IMESAFR version 2.0, was used.

The main event scenarios that have been established at the level of specific activities involving the use of pyrotechnic devices are the following: *The accident scenario manifested in the storage area of pyrotechnic devices (1.35 kg ETNT) in the metal container located outside; The accident scenario manifested in the storage area of pyrotechnic devices (1.35 kg ETNT) within the consumption warehouse (the metal container inside); The accident scenario manifested in the area of the predefined route intended for the transport of pyrotechnic devices (0.0027 kg ETNT)); The accident scenario manifested at the Bunker intended for the storage of finished products (0.1913 kg ETNT).*

The analysis of the 6 scenarios resulted in the fact that following the accidental initiation / detonation of pyrotechnic devices, only their ignition can occur with a local burning effect.

In order to prevent and combat the risks of an accidental initiation / detonation of pyrotechnic devices identified and analyzed at the specific activities carried out, were established prevention and protection measures of a technical and organizational nature in order to eliminate / reduce the effects produced in the event of the occurrence of unwanted events.

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