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PYROTECHNICAL SAFETY IN THE PROCESS OF DESTRUCTION OF MINES AND EXPLOSIVE EQUIPMENT (MER) AND UNEXPLODED ORDNANCE (UXO)

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Abstract: *This paper deals with the application of pyrotechnic safety in the destruction of MER as one of the riskier processes in working with MER. Knowledge and application of pyrotechnic safety measures, ie the entire pyrotechnic safety system, determination of protected systems, identification of hazards, hazards, risk management and its assessment, are the basic condition for any serious work with MER.*

Keywords: *Pyrotechnic safety; General overhaul of ammunition; Risk; Protection measures.*

1. Introduction

Since the first explosive material (EM), lethal means (LM) minsk explosives resources (MER) were found and produced, the problem of pyrotechnic safety has been topical. It is increasingly pronounced as the quantity and range produced for military use increases.

The state of pyrotechnic safety has not significantly improved to this day. Taking into account the real situation and the laws of statistical phenomena, if something is not done urgently, there is a high probability of new accidents.

In addition, it is necessary to emphasize that the existing legislation, which treats this issue, is outdated and outdated.

Having all this in mind, as well as the fact that the regulations they regulate are becoming stricter the issue of occupational safety and environmental protection, solving this problem is imposed as an imperative.

This paper deals with the application of pyrotechnic safety in the destruction of MER and unexploded ordnance (UXO) as one of the riskier processes in working with MER and UXO. Knowledge and application of pyrotechnic safety measures, ie the entire pyrotechnic safety system, determination of protected systems, identification of hazards, hazards, risk management and its assessment, are the basic condition for any more serious work with MER and UXO.

2. Technical and technological risks

A technical-technological accident is a sudden and uncontrolled event or series of events that got out of control during management certain means of work and when handling hazardous substances in the production, use, transport, transport, traffic, processing, storage and disposal, such as fire, explosion, accident, traffic accident in road, river, rail and air traffic, accident in mines and tunnels, cableway shutdowns for transporting people, demolition of dams, accidents at power, oil and gas plants, accidents in the handling of radioactive and nuclear materials, etc., and whose consequences endanger the safety and lives

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of people, material goods and the environment (Zakon o vandrednim situacijama, 2009).

Risk means any situation, ie the state of a specific system, which, with a certain probability, can cause an unwanted change in quality, ie loss of the system. There are a number of criteria for specification and risk sharing. Given the rate of change of system state, there are:

- Cumulative risks, which are characterized by slow development, slow degradation processes and gradual change in system behavior.
- Right-hand risks, which are characterized by high speed of development, fast deregulation processes, high speed of parameter changes and abrupt changes of system output characteristics (Keković et al., 2011).

The degree of risk is a function of the probability and consequence of a harmful event.

For certainty, we say that this is a situation in which we are sure of the outcome of an event. Therefore, there is no risk, ie the probability of occurrence of the event is equal to zero. When the certainty in the outcome of an event decreases, then we say that the risk increases. Uncertainty arises as the ultimate opposite, when we do not have the probability of the event happening at all.
Given the state of the environment in which an event takes place, there are:

- a state of certainty (definiteness, determinism), when the choice of a specific decision certainly leads to a concrete-expected result.
- a state of risk, in which the choice of a specific decision can lead to any of a set of possible outcomes (certain outcomes, outcomes known to us); The probabilities of occurrence of each of these outcomes are known; This state is often called the state of stochastic uncertainty.
- a state of uncertainty, in which the choice of a particular decision may lead to any outcome from possible outcomes, where the probabilities of occurrence of these outcomes are not known.

If there is no choice, there can be no talk of risk. In conclusion, risk is the effect of uncertainty of goals.

The concept of risk can also be understood by defining various concepts related to risks such as probability, hazard, danger, etc. Each of these terms describes risk in its own way and thus explaining these terms can reduce the risk or take appropriate risk management procedures (Keković et al., 2011).

2.1. Hazards

Hazards are conditions that lie behind an event that causes a loss. They increase the probability of losses, their degree or both. We call these conditions "gambling". The more "hazardous" these conditions are, the higher the probability and / or degree of losses (Keković et al., 2011).

There are two types of hazards (Baranoff, 2004):

- physical (material) and
- intangible.

Physical hazards are material environmental conditions that affect the frequency and degree of losses.

Intangible hazards are the direct action (or inaction) of people. There are two types of intangible hazards.

Intentional hazards are conditions that encourage individuals to intentionally cause losses. So, these are illegal actions (Keković et al., 2011).

Hazards with the attribute of unintentionality do not include unauthorized actions. The most common are: carelessness, negligence, omission, ignorance, carelessness, etc.

Hazard management (elimination or mitigation of hazards) is the most effective means of risk management because by neutralizing hazards we reduce potential risks and overall costs (Keković et al., 2011).

2.2. Danger

Danger differs from the concept of risk and is defined as the potential cause of damage and loss. Danger is something that can cause the loss of a value, when that value is exposed to the influence of a given danger. Hazards (such as fire, storm, explosion, heart attack, etc.) can act alone or cumulatively with another hazard. Hazards can be natural (extreme events in nature such as earthquakes, floods, droughts, etc.), biological (infectious diseases, genetic modifications, insect infestations ...) and industrial in nature (harmful materials from the production process, intentionally or unintentionally) pouring these substances, etc.).

Danger has a direct connection with the term failure, which means a change outside certain limits of at least one of the working, basic characteristics of the system or change only those working characteristics that result in loss of working capacity or injury or damage to material and natural assets (Keković et al., 2011).

2.3. Probability

Probability is the possibility of a certain event occurring. The complexity of probability is also indicated by the emergence of probability theory, which seeks to quantify a probable event. If it is certain that an event will occur, the probability is 1, and if it is certain that it will not occur, then the probability is 0. The probability of a risky event is between these two values, ie between 0 and 1 as shown in Table 1.

Continuous study and analysis of risk can lead to knowledge about measures and actions that can be taken to reduce risk, or increase the security of its implementation.

Namely, we take risks even if we do not react to future events.

Table 1. Values probability of event

A future event	Probability of event (p)
Certain	$p = 1$
Risky	$0 < p < 1$
Impossible	$p = 0$
Uncertain	r = unknown

2.4. Security

Standard MIL-STD-882 (MIL-STD-882, 1968) defines system security as: "The absence of circumstances that could lead to either injury or a disputed case, or to accidents with consequences that could lead to destruction or damage to tangible assets."

In mathematical terms, the security of a system is the probability that the system provides protection of people and material goods in the given conditions for a certain time.

3. Pyrotechnic safety system

The pyrotechnic safety system is an integrated set of organizational and technical-technological measures and procedures whose goal is to reduce the possibility of occurrence and possible damage as a result of fire and explosion of LM to an acceptable measure (acceptable risk). At the same time, this system should enable the designed - required degree of security of predetermined objects - subjects - systems according to predetermined priorities.The pyrotechnic safety system is the unity of the elements of the system and the measures that are taken according to its structure (Dimitrijević, 2015).

A graphical representation of the system and place of application is given in Figure 1.

3.1. Hazards

Hazards in this system are also conditions that lie behind the danger. They increase the probability of a dangerous event. For example, if a worker in the production of explosives is prone to alcohol or drugs, then he is a significant intangible hazard with the attribute of unintentionality. Similarly, if measuring equipment in the production of explosives (eg manometers or thermometers) is poorly or irregularly maintained then it is a significant material hazard.

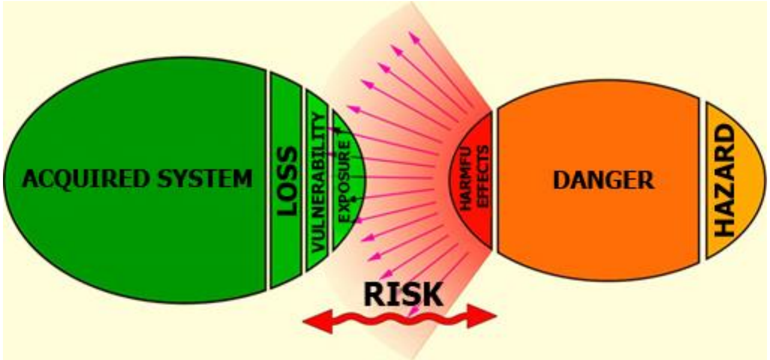

Figure 1. Scheme of pyrotechnic safety system (Dimitrijević, 2015)

3.2. Danger

Danger (dangerous event, harmful event, threat) is an event that with a certain probability can manifest harmful effects on the protected object. In the pyrotechnic safety system, the danger is fire and LM explosion (explosive substances, LM elements and assemblies). In a pyrotechnic safety system, the intensity of the hazard can be quantified relatively easily.

This is the amount of explosive substance (can also be expressed as the number of LM items) that can be affected by fire and explosions

Fire and explosion are essentially a unique and interconnected phenomenon. Both processes, fires and explosions, usually occur simultaneously. Accident-type events are mostly a continuous series of fires and explosions that can end even after a few days. The very process of initiating, developing and completing such an event is very complex, and often cannot be fully elucidated. From the point of view of pyrotechnic safety, it is more important to know in detail and analyze the possible harmful effects (harmful manifestations) of fires and UbS explosions.

3.3. Harmful actions

In the pyrotechnic safety system, harmful effects are the effects that occur with a dangerous event. The harmful effects of fires and LM explosions are diverse and completely depend on the type and amount of affected LM, as well as the manner of initiating the entire process. However, they can be systematized into several basic groups. Harmful effects can be quantified relatively easily: shock waves are well studied, the range and penetration of fragments as well, heat flux as well. The scattering of individual LM items is determined by their final ranges, etc. Adverse effects of fire and LM explosion are as follows:

- induction of shock waves in the air;
- induction of seismic waves in the ground (soil);
- scattering of various fragments created by projectile explosions or created in explosion processes from other LM assemblies and infrastructure;
- heat flux as a consequence of intense fires of explosive substances;

- scattering of whole or damaged LM items;
- induction of secondary fires caused by the explosion of whole or damaged LM items;
- emission of toxic substances (parts of explosive substances, parts of other toxic substances that were in LM, products of combustion and explosion of LM);

3.4. Exposure

In the system of pyrotechnic safety, the term exposure means the temporal and spatial position of the object (subject) when it is in the zone (range) of harmful effects. It is important to note that it is understood that the harmful effects are of such intensity that they can cause harmful consequences (loss) to the protected system. The characteristics of the protected object are also very important, ie the acceptability of the loss on the protected system. For example, cracking of window glass can be accepted at some storage and even production facilities, but it is completely unacceptable for particularly sensitive facilities where people live, e.g. schools, hospitals, etc.

3.5. Vulnerability

In the pyrotechnic security system, the term vulnerability (it can be said that sensitivity) means a property of a protected object (subject, system) that contributes to the occurrence of damage if the object is exposed. The question: "Is the protected object vulnerable?" Answers the question: "Does the degree of protection of the object correspond to the type of harmful effect and its intensity, if the object is exposed?". Or differently:

"Can harmful effects cause damage to an object (subject) if it is in the zone of action?" In essence, vulnerability is a weakness of the system that makes it particularly susceptible to harmful effects, ie damage to it. In the pyrotechnic security system, people are considered to be particularly vulnerable, as well as facilities in which people permanently or occasionally stay. Also particularly vulnerable are quantities of explosives and LM that are not affected by fires and / or explosions.

3.6. Protected system

Objects that are under direct harmful effects are different. These can be specific construction or infrastructure facilities, but also complex technical systems, as well as individual groups of people or entire communities. It can be said that the protected object is a pre-selected and planned object (system, subject, etc.) according to which protection measures against harmful effects are planned and implemented.

If an object from several of them is selected in advance, and protection measures are further planned and implemented, then there must be a certain list of priorities:

- The protection of the civilian population is an absolute priority. Furthermore, in that priority, a narrower list can be made according to the estimated exposure and vulnerability, but also according to other criteria.
- Humanity engaged in the process of production, storage or maintenance of LM is second on the list of priorities.

Large infrastructure facilities are third on the list. Especially if their damage can cause further accidents such as: hydroelectric power plants, nuclear power plants, power lines, chemical industry, etc. Next are the objects that represent value in the cultural sense - national cultural goods, national natural goods, etc.

The protection of other LM (explosive substances or assemblies and LM elements) is fourth. The spread of fires and explosions on these devices can lead to the transition of the incident into an accident. Precisely because of this possibility, it can happen that these funds get absolute priority, which depends on the correct determination of the worst possible outcome (MCE).

3.7. Loss

Under harmful effects, the protected system can react in the following ways:

- By changing the quality and
- By maintaining quality.

The loss is, in essence, a reduction in the quality of the protected system. A pyrotechnic safety system is formed to completely eliminate the possibility of loss, or, more often, to reduce the possibility of loss to an acceptable level. In the latter case, the system takes measures to determine the probability of the occurrence of a harmful event and the size of the loss in advance.

For example, the size of damage to protected objects is predicted - breaking glass windows in storage facilities, the volume of sound and air shock waves in places where people live, the strength of seismic waves in places of objects, the density of fragments and the like.

Therefore, the acceptability of losses in a specific pyrotechnic safety system is defined in advance, and according to these values, the entire system is configured, ie certain pyrotechnic safety measures are implemented.

3.8. Pyrotechnic safety measures

The term "pyrotechnic safety measures" should expediently mean the direct and planned influence of management on all elements of the pyrotechnic safety system. It affects the characteristics of these elements, but also their mutual relationship, ie interaction. All measures are taken with the sole aim of reducing risk.

All measures have only one goal: to reduce or completely eliminate losses of any kind. This goal cannot be achieved, or it is very difficult to achieve, by introducing or applying only one or one group of measures. On the contrary, only by introducing and implementing measures throughout the system can the risk be expected to be in the eligibility zone. So, all measures are fully integrated.

It should be noted, given the specificity of the hazard (fires and LM explosions), that the zones of acceptable and medium risk are very narrow. This means, for example, if only one new hazard occurs, the whole system enters a zone of great - unacceptable risk. Furthermore, the division and place of application in the system of pyrotechnic safety measures are not strictly delimited. Individual groups and types of measures can be applied in several places in the system, but their essence differs on those occasions. There are the following groups of pyrotechnic safety measures:

1) Preventive pyrotechnic safety measures are measures that directly affect hazards. Theoretically, preventive measures can completely prevent the occurrence of fires and LM explosions. However, in general, groups of preventive measures are related to individual hazards and as such it is best to analyze, introduce and apply them. For example, a typical preventive measure is a smoking ban in explosives and LM plants. Furthermore, a preventive measure that reduces static electricity in production facilities is to maintain the prescribed humidity or ground the production machines.
2) Hazard reduction measures. The danger itself can be acted upon by reducing its intensity. We have defined hazard intensities as the amount of explosive substance (can also be expressed as the number of LM items) that can be affected by fire and explosions. Accordingly, the reduction of hazard intensity is achieved by a simple reduction of the mass of explosives (or the number of individual articles of LM) in the observed process (production hall, reactor for synthesis of explosives, etc.).

A typical example is the introduction of continuous reactors for the production of nitroglycerin (NG), which significantly reduced the amount of NG that can detonate. Also, the intensity of the danger is reduced by the convenient distance of the LM item in line production, ie it prevents the detonation from being transferred from one item to another. Furthermore, suitable packaging of LM items also avoids the transfer of detonation, ie prevents specific LM from detonating in the mass (belonging to hazard group 1.1), etc.

3) Measures to reduce the intensity of harmful effects. Reducing the intensity of the danger directly reduces the intensity of the harmful effects. Other direct impact on adverse effects does not exist. There are indirect measures that can be conditionally divided into measures of directing and measures of stopping (mitigating) harmful effects. All harmful effects are essentially vector quantities because they have their own direction and intensity. Thanks to this feature, guidance measures can be taken relatively easily (but not necessarily economically).
    a) By directing measures, harmful effects are diverted and partially reduced so that they act in a direction in which no loss can occur - in a safe direction. Such measures are most often carried out with suitable solutions for buildings in which munitions or explosives are stored or produced.
    b) Stopping measures are measures by which the intensity of harmful effects is completely eliminated (or significantly mitigated) in all directions or in a safe direction.
4) Separation measures. In the system of pyrotechnic safety, the term exposure means the temporal and spatial position of the object when it is in the zone (range) of harmful effects. Taking measures that aim to move the protected system (object) out of the zone of action is called separation measures. A typical example of such measures is the determination of zones of prohibition of movement of people around a dangerous facility in which explosives are produced or processed. Also, for example, during the construction of explosives factories, the distances of individual protected facilities (administrative buildings ...) from the facilities in which explosives are produced or processed are projected in advance. Therefore, the basic parameter is the distance of the protected object from the danger. This distance depends on the size (intensity) of the hazard, the type of harmful effect and the characteristics of the protected system (object). For the harmful effects of the shock wave, the "QUANTITY-DISTANCE" ratio is often calculated for entire classes of protected systems.
5) In the pyrotechnic security system, the term vulnerability means a property of a protected object (subject, system) that contributes to the occurrence of loss if the object is exposed. Protection measures are measures by which we reduce or completely eliminate the vulnerability of a protected object. A typical example of a protection measure is the introduction of protective suits for deminers. Depending on the level of protection, these suits fully or partially protect against fragments and shock waves that occur during the explosion of anti-personnel or anti-tank mines. Therefore, these measures are directly related to the protected objects, that is, they are applied directly with them. Of course, the security of protected facilities can be increased by applying all other measures listed above.
6) The fire and explosion of explosives and munitions are of such a nature as to prevent any intervention during the very duration of the process. Therefore, only

loss reduction measures remain as subsequent measures. In the Republic of Serbia, this area is quite well regulated by several laws and bylaws (Zakon o vandrednim situacijama, 2009), (Dimitrijević, 2015). Loss reduction is implemented by applying two groups of measures:

- Readiness measure and
- Response rate.

4. Risk management

Different definitions of risk management are present in the literature (Keković et al., 2011), some of them are:

- Risk management is an aspect of quality management that has a supporting role in achieving the required quality of the system. The main goal of quality management is the implementation of a strategic management plan that ensures the required quality of the system, while the goal of risk management is to maintain the quality of the system in the event of risky events. Risk management should ensure the continuous existence of the system (Vauglan, E. J., 1997).
- Risk management means management that strikes the right balance between creating profit opportunities and minimizing losses (AS/NZS 4360:2004).
- Risk management is such an approach to management that is based on the identification and control of those areas and events that are potential causes of unwanted changes in the system (Sage, 1995).
- Risk management is a comprehensive decision support process in quality management, implemented as a program, integrated through defined roles and responsibilities in regulation, maintenance, engineering and quality management (Canadian Standards Association, 1997).
- Risk management is an organized process of identifying and measuring risk, selecting, developing and implementing options for risk treatment and risk monitoring (Systems Engineering Fundamentals, 2001).
- Coordinated activities that direct and control the organization in relation to risk (ISO GUIDE 73:2009, 2009).

4.1. Stages of the risk management process

In operational terms, risk management is defined as the process of identifying, verifying, communicating, measuring, and monitoring key risks that are critical to an organization's success or failure.

The risk management process includes the following stages:

- Communication and consultation with internal and external investors, for stakeholders, as appropriate (technologically) at each stage of the risk management process and consideration of the process as a whole.
- Determining the external, internal and risk management context in which the rest of the process will take place. The criteria according to which the risk will be assessed and the structure of the analysis should be defined.
- Risk identification means where, when, why and how events could be prevented, reduced, delayed or increased.
- Risk analysis is essentially the identification and assessment of existing controls, determining the consequences and probabilities and then the level of risk. This analysis

should consider the area of potential consequences and their occurrence.

In order to manage risk, it is first necessary to determine the context of the hazards and risks lurking in the system (Figure 2). After determining the context, a risk assessment is performed, which has the following stages:

- Identifying risks that involve identifying and recognizing hazards surrounding the protected system;
- After that, the identified risks are analyzed in order to identify all hazards and identify all possible harmful effects and determine the worst possible outcome;
- Risk assessment comes after identification and analysis as a phase dealing with the prioritization of hazards as well as protected facilities.
- Risk treatment involves the application of pyrotechnic safety measures in order to mitigate or direct risks, or if possible eliminate them completely.

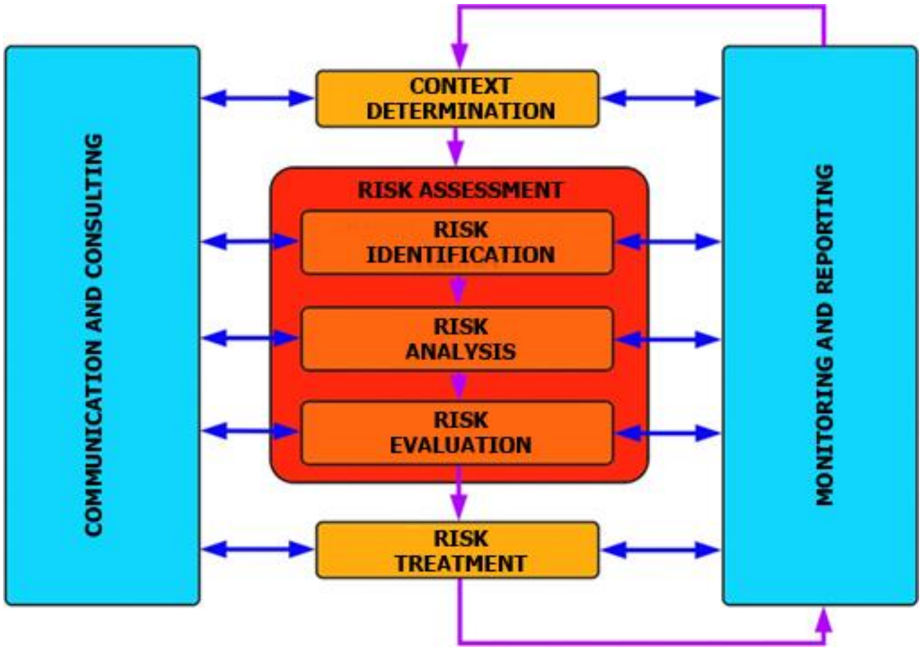

Figure 2. Risk management activities (Keković et al. 2011), (ISO 31000, 2009)

Communication and consultation are part of this process which is important for the complete picture of this process because for the proper execution of the above mentioned phases it is necessary to properly exchange information and consult in order to effectively assess and prevent risk.

Monitoring and reporting is also a big part of the process, because by properly monitoring all these phases, the risk can be identified in time and timely reporting in the event of an accident can reduce the consequences. The risk assessment process is shown in Figure 3.

Figure 3 shows how complex and serious the risk assessment process is. Considering the consequences of an incorrect assessment or a failed risk assessment, it is clear that the whole assessment process must be well performed.

Risk assessment must take into account risk identification, risk analysis, degree of probability and vulnerability of the system, criticality and possible damage. After that, the risk is assessed, after which measures for risk treatment are determined, as well as analyzes from the economic point of view. After all that, the complete process is reviewed and a decision is made.

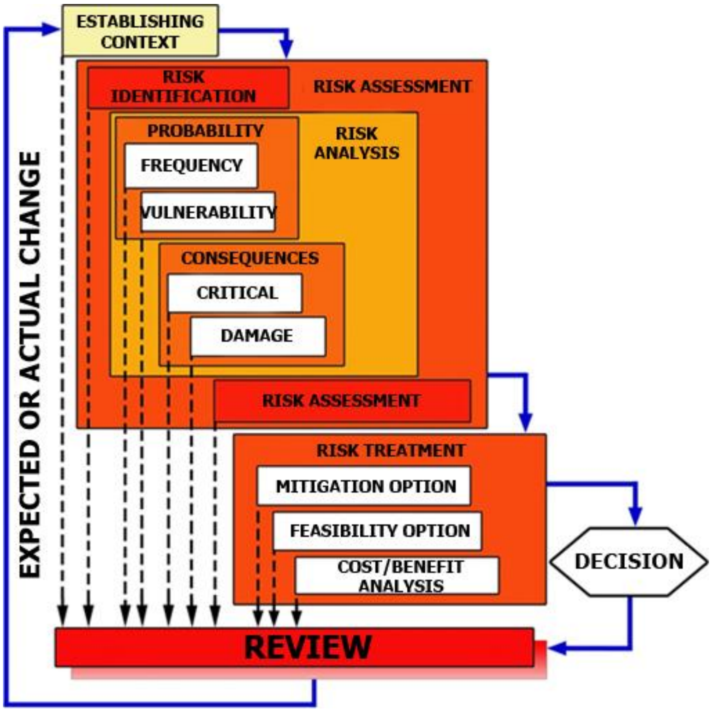

Figure 3. Risk assessment process (Keković et al., 2011), (SRPS A.L2.003, 2010).

5. Measures of pyrotechnic protection during the destruction of MER and NUS

In order to properly implement pyrotechnic protection measures during the destruction of MER and UXO, it is necessary to accurately define each of the elements of the pyrotechnic safety system.

As with any LM and UXO and MER, the basic hazards are explosion and fire, which are essentially a unique and interconnected phenomenon. The intensity of the hazard can be relatively easily quantified by knowing the amount of UXO and / or MER explosive observed individually or in groups.

Harmful effects derived from UXO and MER, as in other LM, are diverse and completely depend on the type and amount of affected LM, as well as the manner of initiating the entire process. However, they can be systematized into several basic groups. Harmful effects can be quantified relatively easily: shock waves have been studied a lot, the range and penetration of fragments as well, heat flux, etc. In addition to the basic groups of harmful effects of LM, ie UXO, there are also those that cannot be generalized and depend on various conditions, such as psychological effects on humanity, etc.

The priority protected objects during the destruction of MER and UXO are civilians and then the people engaged in the process. Depending on where the MER and / or UXO are located, other protected systems can be diverse, such as specific buildings or infrastructure, but also complex technical systems, as well as individual groups of people or the whole community. It can be said that the protected object is a pre-selected and planned object (system, subject, etc.) according to which protection measures against harmful effects are planned and implemented.

During the process of neutralization of MER and UXO, only those objects are exposed that must be, ie. the minimum number of people participating in demining. All other protected objects, in case of necessary exposure, must not be vulnerable. However, the characteristics of the protected object are also very important, ie the acceptability of loss on the protected system, and in accordance with economic and technological support in the process of destruction of MER and UXO, some protected objects may be in the zone of harmful effects if the risk is acceptable.

The vulnerability of protected facilities depends primarily on the technology and techniques used in demining. In the case of using mechanization, the vulnerability of protected objects that must be exposed is significantly lower than in the case of manual destruction of MER and UXO. The aim is certainly to keep the vulnerability, as a weakness of the system that makes it particularly vulnerable, as small as possible, so that the vulnerability of exposed personnel is reduced by providing protective equipment. Also particularly vulnerable are quantities of explosives, MER and UXO that would be affected by fires and explosions.

The losses of human lives are unacceptable. Losses in the form of reduced quality of some of the protected systems, such as cracking of glass on some of the surrounding buildings, are acceptable under certain conditions. Due to the sensitivity of the system, in the event of new hazards, a significant loss is possible in the form of a serious decline in the quality of protected facilities, in the case of protected facilities are material assets or used animals, or damage to health or loss of life when it comes to people.

UXO hazards are also conditions that lie behind the danger. They increase the likelihood of a dangerous event occurring. When working with UXO, hazards are known, such as mechanical damage to UXO, erosion of the soil in which they are located, the existence of microorganisms in that soil, etc. and there are many unknowns that working with UXO makes it very risky.

5.1. Preventive measures

a) Full training of deminers performing the job of destroying MER and UXO
   - Pyrotechnist must have: a diploma, certificate, attestation or any other act (certificate) in writing, on the basis of which the level of training and legal right to perform the work of destruction of MER and UXO can be seen.

b) Health status of workers performing destruction activities
   - The law specifies the persons my may be deminers.

c) Strict observance of rules and regulations in the destruction of MER and UXO
   - All rules and regulations given in the operational procedure must be fully complied with: before, during and after the destruction of MER and UXO
   - Independent and voluntary performance of work and activities is not allowed, regardless of the new situations and circumstances, unless it is provided by the study

d) Continuous supervision and control during the execution of MER and UXO destruction activities. Inspection, inspection and supervision during the inspection and inspection of means of ignition and destruction shall include the following procedures and actions:
   - Checking the slow-burning rod (on burning time and spark transmission)

- checking the correctness of detonating caps (DK No. 8)
- detonating rod control
- control of electric detonator caps
- control of electric (mining) cable
- check and control of other accessories of devices and tools for rod and electrical initiation.
- Overview of MER and UXO to be destroyed
- Inspection of land and space, at the place where the destruction of MER and UXO is performed
- Strict control of all actions during the destruction of MER and UXO
- Control of compliance and application of the procedures specified in the study of destruction of MER and UXO

e) Discipline during the destruction of MER and UXO:

- Strict adherence to rules and regulations
- Strict execution of orders of the MER and UXO destruction manager

Is not allowed:

- Smoking in places where the destruction of MER and UXO is carried out
- Arbitrariness and indiscipline
- Obstruction of deminers at work
- Use of alcohol and narcotics during, during and after the destruction of MER and UXO
- Work by unauthorized persons (Standardni operativni postupak, 2012).

5.2. Restrictive measures

Defining safety distances (m)

- Defining safety distances from the transmission of a detonation wave.
- Defining the safety distance from the shock wave.
- Defining the safety distance from the bursting action.
- Defining the safety distance from seismic action.

5.2.1. *Calculation of safety distances*

When carrying out destruction work, it is important to make a calculation of safety distances in order to adequately protect both its own personnel involved in the destruction process, as well as third parties and material property (AASTP-1, 2010).

The calculation of safety distances refers to the calculation of three important factors that can be a source of damage:

- Shock wave
- Spraying
- Seismic activity

5.2.1.1. Shock wave

The Rulebook on the Manner of Carrying Out Humanitarian Demining Operations (Pravilnik, 2007) gives the distances of the safety zone from the action of the shock wave that the process manager must adhere to.

The safety zone for the protection of material goods from the effects of the shock wave is calculated according to the formula:

- If MER and UXO have shelter:

$$D = kP^{\frac{1}{3}}$$

- If MER and UXO without shelter:

$$D = 1{,}5kP^{\frac{1}{3}}$$

where:

D – safety distance from the shock wave in meters,
P – net mass of pure explosive (TNT) in kilograms,
k – safety distance coefficient in m/kg.

The safe distance coefficient has the following values:

k=2 for distance from explosives storage facilities,
k=5 for distance from roads,
k=8 for distance from barracks,
k=15 for distance from populated areas,
k=30 for distance from hospitals, kindergartens, schools.

The safety zone for the protection of people from the effects of the shock wave is calculated according to the formula.
NOTE:
In the case of storage and storage of MER and UXO at a particular location, it is necessary to calculate the safety distance and the net mass of pure explosives from the transmission of the detonation wave, which is calculated according to the formulas:
a) MER and UXO in the shelter:

$$D = P^{\frac{1}{3}}\ ili\ P = D^3$$

b) MER and UXO without shelter:

$$D = 1{,}5P^{\frac{1}{3}}\ ili\ P = (D/1{,}5)^3$$

D – safety distance from the detonation wave in meters,
P - net mass of pure explosive (TNT) in kilograms.

5.2.1.2. Seismic activity

Seismic activity caused by the energy of the explosion is transmitted by the ground by sampling earthquakes that can damage objects that are at a critical distance from the epicenter of the explosion.
In general, damage to buildings can be caused by a combination of circumstances of various factors such as:

- Explosion power
- Method and order of activation
- Fill size
- Clogging
- Soil composition
- Soil irrigation
- Physical condition of the building

The area of seismic calculation is very complex and is carried out by trained people for this type of work. According to IMAS 10.50 (IMAS 10.50, 2013), there is a formula that gives a general calculation of the seismic impact zone within which damage to objects could occur:

$$D = 32P^{\frac{1}{2}}$$

5.2.1.3. Bursting

The scattering of fragments of MER and UXO shells, as well as the scattering of the surrounding material, represents the greatest danger for the perpetrators of destruction and third parties when performing destruction work.

The Ordinance on the manner of performing humanitarian demining operations provides a general table of explosion zones that may result in the individual destruction of individual MER and UXO in open-air mines (Table 2) (SRPS A.L2.003: 2010).

Table 2. Safety distances from bursting action for individual LM (SRPS A.L2.003: 2010).

Row. no.	Type of explosives	Safety distance, m
1.	anti-personnel landmines, hand grenades, tromblon mines, mines for hand grenades and other explosive devices whose shell thickness is up to 3 mm	200 - 300
2.	anti-personnel explosive mines	300 – 500
3.	anti-tank mines	500 – 1000
4.	projectiles, mortar mines up to 76 mm	250 – 500
5.	projectiles 76 - 105 mm, mortar mines 82 mm	300 – 600
6.	projectiles from 105 - 122 mm, mortar mines 120 mm	400 - 800
7.	projectiles 122 - 155 mm	600 - 1200
8.	missiles larger than 155 mm	750 – 1500
9.	air bombs weighing up to 500 kg	1000 – 2000
10.	air bombs larger than 500 kg	1250 – 2500

Zone fragment scattering zones during detonation of MER and UXO can be reduced by placing improvised handy shelters around the MER or UXO that is destroyed in the manner shown in Figure 4.

Another way to reduce the effect of fragments during the detonation of MER or UXO is to direct the detonation in the opposite direction from the place that is directly exposed to the burst zone of the same.

Destruction of a large amount of LM at once gives different results of burst zones and is shown in Table 3 (Technical Note 10.20/01, 2013).

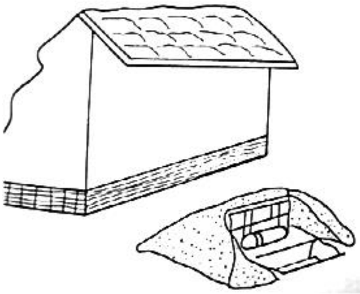

Figure 4. Improvised handy shelters (Keković et al., 2011), (SRPS A.L2.003, 2010).

Table 3. Safety distances from bursting action for individual LM (Technical Note 10.20/01, 2013).

AUW	R = 634 x $(AUW)^{1/6}$ (Metres)	R = 444 x $(AUW)^{1/6}$ (Metres)	R = 130 x $(AUW)^{1/6}$ (Metres)	REMARKS
(KG)	Public Access	Controlled Access	No Fragmentation Hazard	
(a)	(b)	(c)	(d)	(e)
1	634	444	130	
2	712	498	164	
3	761	533	187	
4	799	559	206	
5	829	581	222	
10	931	652	280	
20	1045	732	353	
30	1118	783	404	
40	1172	821	445	
50	1217	852	479	
60	1254	879	509	
70	1287	901	536	
80	1316	922	560	
90	1342	940	583	
100	1366	957	603	
150	1461	1023	691	
200	1533	1074	760	
250	1591	1114	819	
300	1640	1149	870	
350	1683	1179	916	
400	1721	1205	958	
450	1755	1229	996	
500	1786	1251	1032	
1000	2005	1404	1300	
2000	2250	1576		Controlled Range and Bare Explosive Range converge at this point.
3000	2408	1686		
4000	2526	1769		
5000	2622	1836		
10000	2943	2061		
20000	3303	2313		

Where they are:

NEC - net mass of pure explosive (for agents without fractionation action)

AUW - net mass of pure explosives

R - safe distance zone

Public Access - a safe distance from populated areas and other facilities

Controlled Access - zone of setting control points

No Fragmentation Hazard - a zone outside which there is no danger of bursting.

5.2.2. Determination of the maximum net mass of pure explosives (NMPE) during the destruction of MER and UXO

The net mass of pure explosive is the mass of the initial, high-explosive and propellant explosive substance in one explosive munition, and is calculated according to the formula:

$$NMPE = A + \frac{1}{2}B + V\ (kg)$$

A – mass of black powder (kg) in LM

B – mass of low-smoke gunpowder (kg) in LM

V – mass of high explosive (kg) in LM

NMPE does not count for infantry ammunition, smoke, flammable, marking and illuminating explosives and for parts of ammunition that contain a very small amount of the same (eg lighters and capsules)

For group destruction of MER and / or UXO in one explosive, the maximum amount of NMPE may be up to 50 kg. Depending on the safety distance, the NMPE in the explosive may be smaller..

5.2.3. Arrangement of work sites, before and after, destruction of MER and UXO

- removal of flammable substances and waste - before the destruction of MER or UXO
- determining and locating the place where the initiating means are stored
- Determining and locating the place where the means of destruction are stored
- determining the place of initiation and safety zones of work
- placing signs and markings in a visible place with warning signs
- locating ambulances
- locating shelters (shelters)
- locating fire protection
- designation of places for smoking, meals and rest
- inspection of the area after detonation in the circle of action (m) in accordance with the bursting zone.
- collection and removal of found parts of MER and / or UXO without explosive material and their disposal in the designated place

5.2.4. Going to shelters (shelters) during the destruction of MER and UXO

- mandatory use of shelters
- The minimum distance of a buried, fully protected and safe shelter from the means to be destroyed is 200 meters. In exceptional cases, if the natural conditions are met, it can be 150 meters.
- Do not leave the shelter for 2-10 minutes after the explosion
- Do not leave the shelter for 30 (thirty) minutes if there is no explosion
- Smoking is not allowed in the shelter, if there are MER and UXO in it
- workers who are not in the shelter and the local population must be in the safety zone, ie. outside the zone of action of: shock wave and fragmentation action.

5.2.5. Going to shelters (shelters) during the destruction of MER and UXO

- Strict adherence to all rules and regulations defined in the destruction plan
- operational procedures must be reported in order and correctly (Vuruna et al., 2005)

5.2.6. Special pyrotechnic safety measures Fire protection

- formation of a fire brigade.
- connection of the fire brigade with the nearest fire station.

Sanitary insurance

- must consist of one doctor or paramedic and an ambulance
- not to carry out the destruction of MER and UXO without medical insurance

Chemical-technical insurance

- material insurance required for work
- mandatory use of body armor and helmets

Physical insurance

- provides access to the site of destruction
- is located at the prescribed distance from the place of destruction
- prohibits and secures access to the place of destruction (Standardni operativni postupak, 2012).

5.3. Special measures of pyrotechnic protection during destruction of MER and UXO

- Destruction is carried out outside populated areas, whenever possible
- the most suitable places for destruction are polygons located in an area that provides all the requirements of safety distances
- the zone of safety distance from the center of the polygon is determined according to the calculations from point 5.2.1.
- when destroying, all access roads and roads within the specified distance must be blocked
- group destruction of MER and UXO in landmines, in populated areas, is not allowed
- if there are no shelters - it is necessary to create temporary shelters
- in the absence of adequate safe shelter, make temporary shelters that must be buried in the ground with a protective roof (dugouts) at a proper distance of at least 200 meters from the center of the detonation (in exceptional cases 150 meters)
- it is not allowed to put excessive NMPE in the explosive - over 50 kg NMPE.
- if the MER and UXO must be destroyed in a populated area: evacuate the population, install security and medical assistance, and form a wall of bags with protective sand around the MER and UXO that are being destroyed (Standardni operativni postupak, 2012).

5.3.1. Checking MER and UXO for destruction

- visually inspect MER and UXO
- MER and UXO, which are destroyed in landmines, must not have a reinforced lighter on them
- Throwing, hitting and abrupt overturning of MER and UXO is not allowed
- Any irregularity observed is reported to the destruction manager, who decides what to do with the device.

5.3.2. Checking the means of initiation

Checking the initiation tool is a standard operating procedure and consists of the following actions:

- checking the slow-burning rod
- check for spark transmission (transmission at a distance of 1 cm)
- check the burning time (1 cm W burns in 1 - 1.5 seconds)
- checking the detonating rod - checking for the transmission of the detonation
- perform the check according to standard operating procedures
- check of detonator caps no. 8 (DK no. 8) - visual inspection and control of correctness DK no. 8
- inspection of electric detonating caps (EDK) - Visual inspection and control
- check the electrical resistance with an OM meter according to standard operating procedures
- checking mining cables (electrical conductors)
- visual inspection does not allow interruption or damage of electrical conductors
- check the electrical resistance with an OM meter
- checking mining accessories
- mining accessories consist of: mining pliers, sharp knife, adhesive (insulating) tapes, boards, mining matches, OM-meter, other accessories that can be used for proper operation (eg multi-purpose means)
- before carrying out the operational procedure for the destruction of MER and UXO, all means of initiation must be correct

Is not allowed:

- work with initial means without the use of mining tools

5.3.3. Surgical procedures in the event of sudden (unforeseen) events

The procedure foresaw sudden events during the destruction of MER and UXO. Extraordinary events can be:

- Impossibility of placing explosives on the device to be destroyed - In this case, a larger quantity of explosives than the prescribed one is placed in the immediate vicinity of the explosive device (5 - 10) cm.
- Malfunction of initiation tools. Do not carry out destruction without proper means
- Poor properties of explosives (incomplete detonation) - change and placement of a new explosive charge with prior checking of the same
- Occurrence of lying on ignition (interruption on the mining cable or extinguishing of the slow-burning stick):

a) Electrical initiation:

- Short the mining cables in the shelter
- check mining cables
- rectify the error

b) Stick initiation:

Stay in the shelter for 30 minutes

- The manager and his assistant go to the place of destruction and determine the factual situation and eliminate the cause of the malfunction.
- Other deminers must be in the shelter during this time
- After correcting the fault, the manager and his assistant initiate a slow-burning stick and go to the shelter
- check mining cables
- rectify the error

Weather disasters - In case of weather disasters: storms, rain, thunder and hail, stop carrying out destruction.

Administrative problems - In case of incomplete administrative documentation, do not carry out destruction.

Other - In case of new situations, which may arise during the destruction of MER and UXO and are not described in the standard operating procedure; the decision is made by the destruction manager in consultation with the first superior.

6. Conclusion

The aim of this paper is to show the place and application of pyrotechnic safety in everything that accompanies the processes, and the processes themselves, destruction of (MER) and unexploded ordnance (UXO), as one of the most risky processes in working with LM.

The second chapter presents a theoretical approach to risks and technical-technological risks, gives definitions of terms that are general and necessary for further understanding of the pyrotechnic safety system.

The third chapter defines the theoretical approach to pyrotechnic safety, explains the meaning of pyrotechnic safety systems and the identification of all elements within the system through their definition. Definitions of pyrotechnic safety measures are presented and their division is given.

The fourth chapter deals with risk management as a practical application of the theoretical foundations of pyrotechnic safety.

The fifth chapter presents preventive measures, which make up the complete training of deminers, their strict observance of rules and regulations, constant supervision and control, maintenance of discipline, health condition, etc.

Restrictive measures for the calculation of safety distances include three units:

- shock wave calculation
- seismic activities
- bursting

Restrictive measures also include determining the maximum net mass of clean explosives, arranging work sites, going to shelters, organizing work, etc.

Thereafter, special pyrotechnic safety measures including:

- fire protection
- medical insurance
- chemical-technical insurance
- physical insurance

It defines special measures of pyrotechnic protection during the destruction of MER and UXO, which consist of checking MER and UXO and means of initiation. In the case of unforeseen events, employees must not be left to improvise, but even then there should be precisely provided instructions and measures such as operational procedures in the event of sudden (unforeseen) events. Contingencies can e.g. Being a malfunction of the means of initiation, weather disasters, inability to place explosives on the MER or UXO and so on.

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