

# Overview, Analysis and Research of the Possibilities of Application of New Technologies in The Process of Demilitarization of the Explosive Ordnance

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The classic methods of demilitarization of ordnance are high-risk operations, primarily for working personnel and operators, and then for the entire pyrotechnic security system. In addition to the security factors, high level of adverse effects of conventional demilitarization practices emits on the environment. Classical demilitarization procedures greatly limit the disassembly of ordnance due to outdated technology, so a large number of items are removed by the destruction process. The methods of destroying ordnance from the aspect of eco-system protection are completely unacceptable. The development and deployment of new technologies that are widespread in other fields today is an opportunity to solve key problems. In the field of unconventional processing procedures, water jet based technologies, which represent non-thermal methods, do not lead to thermal changes of the material during the process. An important factor in these technologies is that they are, as such, fully developed and known, with all the influencing factors that can be varied. For the application of this technology for the purposes of deliberation, existing systems need to be modified and aligned with the requirements of the deliberation process. Analyzing and reviewing existing research in the world, there is a trend towards the adoption of new and environmentally friendly technologies. With the development of new technologies, the assortment of ordnance has been expanded, reducing the need for destruction of these assets significantly. The main goal of this paper is to look at all influential factors that are critical in the process of disassembly using classical methods. Based on the identified critical factors in the area of classic deliberation processes, it is necessary to consider the possibility of applying new technologies in order to modernize the deliberation process and, above all, to make it safe and environmentally friendly.

*Key words:* explosive ordnance, demilitarization, water jet, explosive safety, environment.

## Introduction

**E**Xplosive ordnance (EO) are subsystems that perform the executive function of the armed systems of weapons for which they are intended. EO are disposable material. The term explosive ordnance (EO) covers any material that contains at least one explosive substance (ES), or any other hazardous substance for military use [1]. Due to the nature of its life cycle, which encompasses phases from production, transport, handling, storage, maintenance to final use or disposal and destruction, EO represents a specific item in regard to other material assets [1, 2]. Demilitarization process of explosive ordnance is the process of translating ordnance into a state where they can no longer perform the basic function for which they are intended [3]. Removing obsolete or defective EO has been a growing problem lately. Within EO, complex physicochemical processes occur over time, which increases the risk and likelihood of an unintended accident. Events of this type can be hazardous to human safety and the environment and can lead to unintended consequences on a large scale [3, 4].

For the needs of military organizations, EO are manufactured as a mass production item to provide sufficient quantities needed to carry out operations, both in peacetime and in war. During its life cycle, the condition of EO can be disrupted for a number of reasons, such as the natural aging process, or may be declared redundant due to the development of new weapons systems. Also, international conventions and agreements on large quantities of ammunition can be programmed with surplus [2, 5]. After the 1990s, the Serbian army has been faced with the problem of the surplus of various EO that were no longer reliable for further storage or use. In addition, there is a problem with the large number of unexploded ordnance (UXO) left behind after the 1999 NATO bombing [6]. Large quantities of EO in this condition are not safe, harmful and very expensive to store. For this reason, there is a need for demilitarization, that is, disassembly and destruction, depending on the type of EO and the state it is in [5, 7]. The process of demilitarization of the EO is primarily intended to enable the safe handling and manipulation of a device that is being disassembled or

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destroyed. In addition to safety, the process must be cost effective and environmentally friendly. Demilitarization of EO is an integral part of its life cycle, which aims to include the process of demilitarization as a basic requirement at early stage of EO development [8]. The NATO STANAG 4518 standard defines that any development of the EO must foresee and provide the process of disassembly of that asset after the end of a lifespan. However, these guidelines provided by the standard, are not sufficient to fully define the demilitarization process [10]. Consideration of the deliberation process in the EO development phase (Design for Demil) should provide [5, 8, 11]:

- easy disassembly of subassemblies and elements of EO,
- easy access and removal of ES,
- reclaimed materials and components can be recycled,
- minimizing the use of special tools,
- process automation and reduced human resource engagement.

The demilitarization methodology consists of several phases, each phase consisting of a series of processes. In order to achieve the most favorable demilitarization process, a number of factors, such as available technologies, safety and environmental factors, and all other factors that may affect the process are taken into account [3]. In paper [12] defines that the goal of each demilitarization process is to maximize safety, maximize recycling and minimize waste generation. Explosive ordnance consists of elements made of expensive metals such as copper, aluminum, steel, brass, which can be put to reuse by the disassembly process. In addition to metals, explosives contained in EO can also be disassembled and can still be used for the production of commercial explosives. The process of disassembly of EO by the phase is shown in Fig. 1.

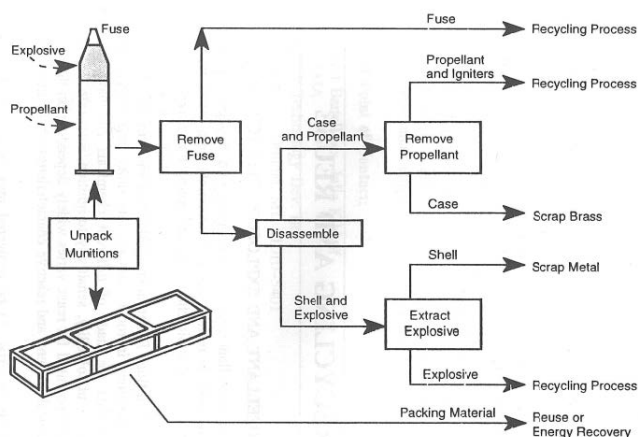


Figure 1. Disassembly process of EO [5]

Disassembly process of projectiles using existing conventional procedures is a high risk operation. An indicator of the level of risk is the occurrence of accidents and adverse events that led to a large number of human casualties, and to serious damage to infrastructure, monetary losses and other consequences [13]. The entire process of disassembly and destroying projectiles is monitored by an explosive safety system [14]. The system is a set of organizational and technical-technological measures and procedures aimed at minimizing the possibility of occurrence and possible adverse consequences of the fire and explosion of EO [15]. There is no absolute security and one part of the risk is always present [16].

Security is achieved by reducing the risk to an acceptable level defined by the standard. A practical example is ammunition storage whose storage, handling, disassembly and destruction processes can never be completely secure [17]. Also, the most represented chemical compound in most of EO

is TNT (trinitrotoluene), which largely contaminates the environment and the work environment. In the process of production and disassembly, working personnel which are exposed to high concentrations of TNT in the air often have problems with their immune systems, organs, and other physical disabilities [18]. Research [3] presents studies that have shown that TNT is potentially carcinogenic to the human body.

The classic methods of destruction, which primarily involve detonation and incineration in the open air, cause the release of heavy metals, which significantly contaminates and damages the environment (Fig.2).



Figure 2. Environmental contamination during the destruction process of EO [14]

Elements such as lead, antimony, and barium (Pb, Sb, and Ba respectively) and toxic gases contained in combustion products such as hydrogen chloride, carbon monoxide, nitrogen monoxide, nitrogen dioxide, and hydrogen cyanide (HCl, CO, NO, NO<sub>2</sub>, HCN) easily reach and remain in soil, groundwater or remain free in the air, thereby permanently polluting and damaging the environment [19]. Some studies [3] show that in the case of detonations or incineration in the open air, the amounts of toxic nitrogen oxides and carbon monoxide polluting the atmosphere increase by up to ten times compared to modern methods of destruction.

Table 1 shows the results of the emission of toxic gases over the NO<sub>2</sub> equivalent.

Table 1. Emission of air polluting particles expressed through NO<sub>2</sub> equivalent [20]

Demilitarization method	Process emissions (gram NEQ per kilogram MEM)
Open burning	285
Open detonation	141
Closed detonation	14
Fluidized bed oven	70
Rotary kiln	25

\*NEQ - equivalent concentration of air pollutants having equal toxic impact as the same concentration of NO<sub>2</sub>,

\*MEM - mass of energetic material

According to the data in the table above, neither method meets the requirements of the European environmental standards [20]. In the continuation of the paper, the classic methods of disassembly listed in the previous table will be discussed, as well as the modern methods and technologies of destruction and disassembly of EO with an improved level of safety and a degree of environmental protection. The considered disassembly technologies have a primary objective of the disassembly of large-caliber artillery ammunition, air bombs and anti-personnel mines.

## Classical procedures for the disassembly and destruction of explosive ordnance

The application of the classic projectile disassembly and destruction methods involves several interdependent methods and processes. The choice of method is made based on the parameters of the condition in which EO is located. The disassembly process consists of the phases schematically shown in Fig.1. The disassembly of EO by classical methods can be partial and complete. The complete disassembly is the disassembly of EO into its subassemblies and further disassembly into individual elements, the extraction of explosive and other substances by which these items are assembled. In case where the removal of explosives, gunpowder, artifacts and other charges from the elements or parts of the bullet is dangerous, risky and uneconomical, they are technically destroyed [21, 22]. The end product of the full disassembly is metal and other materials, explosives and gunpowder.

Only the process of full disassembly will be considered as a subject of study in the paper, with a focus on the stages:

- disassembly and pre-treatment,
- removal of the explosive from the casing.

In a classic disassembly processes, the two phases mentioned are technologically most demanding and risky.

**Disassembly and pre-treatment** - this phase allows the assembly to be disassembled into subassemblies and individual elements, thereby allowing access to explosive charge and other elements. This is preceded by unpacking, removing bullets and placing them on the desk. It is important throughout the process that there is no accumulation of EO in the room. The disassembly of the bullet is done manually [5] or on semi or fully automated devices (Fig.3) [23].



**Figure 3.** Illustration of an automated process for disassembling EO into subassemblies and elements [24]

Unwinding and dismantling of elements can be done on premises with or without cover necessary for this phase. The choice of disassembly method depends on the condition in which the EO is at the time being. Unscrewing devices are most often in a tilted or vertical position to prevent the possibility of gunpowder grains entering between the bushing and the liner, which can become crushed and ignited during separation. Particularly applicable to ammunition up to 120 mm in which the gunpowder is freely filled. This disassembly method of ammunition requires specially specialized devices and tools that differ for each caliber and type of ammunition and have difficulty adjusting to different configurations. The main advantage is that it can be applied to most EO items where it is possible to disassemble the explosive charge by a further process [25, 26]. Disadvantages in the case of manual

disassembly are low productivity and a high level of risk for engaged personnel, while for semi or automated processes the cost of developing specialized tools is high. Considering the cost of producing specialized tools, the general task of designing an automated EO disassembly line is very important [27].

**Removing explosive charges** from projectile grains and warheads is the most technologically demanding operation in the disassembly process. There are several methods of removing explosives, and the choice of each depends on the type of explosive material, the type of grain as well as how it is assembled (casting, pressing). With conventional methods, the removal of explosive charges can be performed by one of the following methods [28]:

- mechanical removing,
- hot water melting process,
- overheated steam melting process,
- combustion and firing process.

**Mechanical removing** can be used when the explosive is pressed or cast outside the projectile and then inserted into the projectile. In order to remove the explosive from the projectile in this way, it is a prerequisite for it to be fixed in the projectile case by cardboard and other coasters, fixed between the projectile case and the fuse. Explosive charges labored in this way are the easiest to remove from the projectile case. However, in most cases the fixation is done using shellac, varnish or paraffin. Explosive charges that are fixed by shellac or varnish are not being disassembled, but are directly destroyed. The reason for this application is to use a solvent that is necessary to dissolve the fixers, which is complex and uneconomical. In cases where the explosive charge is fixed with paraffin, the projectile are heated to a temperature of 61 °C. Then the paraffin melts and releases the charge from the projectile case. Further, the explosive charge is removed from the projectile by turning the projectile downwards, removing the explosive charge through the opening, gently holds it and falls into the crate with as little height as possible. A maximum of 5 kg of explosives can be contained in a crate, from where it is carried further to the place of packing and the crate returns empty. Empty projectile cases are inspected in detail, after which they are packed in crates and transported further [21].

**The melting of explosives by hot water and steam** can be applied to the filling of assembled TNT. A large number of conventional EO are assembled with TNT or one of the mixtures where the TNT content is sufficient for the melting process. Explosive charges that melt at relatively low temperatures are [29]:

- composition B - mixture of TNT and RDX (rapid detonating explosive) (80°C),
- TNT (80°C).

The choice of disassembly method of the explosive charge depends directly on assembly type of the explosive mixture, its type and its composition. The assembly can be performed by:

- casting technology,
- pressing technology,
- injection technology.

For explosives to be assembled with casting technology, the mixture must have low sensitivity to mechanical impulses, have good mechanical casting properties, and have a melting point in the range of 70 to 120°C. TNT as an explosive is most commonly used as a base explosive for producing cast mixtures, primarily due to its low melting point and high decomposition point. The addition of a powerful and sensitive explosive (pentrite, hexogen, octogen)

results in an explosive mixture of significantly better characteristics, increased reactivity compared to TNT, and at the same time a decrease in sensitivity compared to pure high-explosive. Larger-diameter explosive charges, such as artillery and rocket missiles, aircraft bombs, explosives, etc., are predominantly assembled [30].

The assembly using pressing technology is used to produce explosive elements such as primers, amplifiers, transmitters, deviators, detonators. Also, small-diameter explosive charges, such as warheads, mine-explosives, various amplifiers and detonators, are made [30].

The technological process of injection is based on the principle of transport of explosive material using a screw mechanism, which rotates at a speed of 11 rpm. A major disadvantage of this technology is the ability to assemble only those explosives with a melting point below 100°C [30].

The melting of an explosive mixture can be accomplished in two ways, which is primarily related to mixtures assembled by casting:

- direct heating (Fig.4) and
- indirect heating (Fig.5).

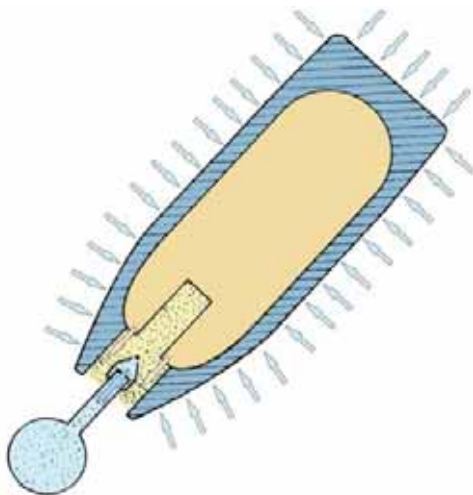


Figure 4. The principle of direct heating of explosives

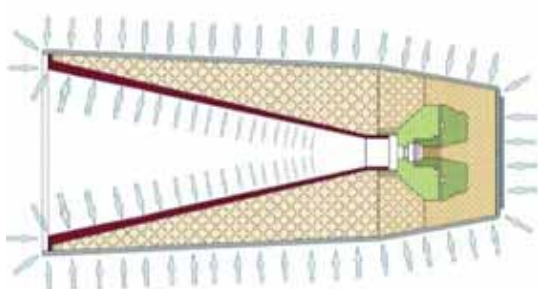


Figure 5. The principle of indirect heating of explosive

Immediate steam heating predominantly melts explosive projectile charges whose explosive discharge port (where the fuse is threaded) is smaller than the maximum charge diameter. In this way, explosive charges labored with pure TNT (melting point 81°C) or mixtures with other explosives (hexogen, octogen, pentrite) can be disassembled where the TNT content is sufficient to allow the mixture to melt to the level required to pass through the opening.

In case of indirect steam heating, explosive charges with a leakage opening greater than the diameter of the charge are involved. In this way, the entire explosive charge is obtained because only the surfaces touched by steam are melting the explosive. The blend of TNT with other explosives in this

way is very easy to disassemble. In this way, the entire cumulative explosive charges are disassembled. Also, agents where explosive filling is pressed and assembled in projectile cases and paraffin-fixed, are easily removed.

Heating can also be done by inductive heating [31], where a magnetic field is applied around a metal casing, where the resulting changes in the magnetic field induce electricity and thus heat the casing [23].

Melting operations of explosives are very difficult and inconvenient for working personnel. Vapors in the form of toxic gases occur during the process. During work, staff must wear protective gloves, aprons, boots, and the procedure is usually performed in summer, so working conditions are very difficult [14, 32].

Classical disassembly procedures are unable to demilitarize all EO. It is primarily necessary that explosive charge can be removed from the missile shell by any of the above methods. EO that have been assembled with PBX (plastic-bonded explosive) or other explosives whose melting point is high cannot be eliminated by conventional methods [33].

EO that are not subject to the disassembly process are destroyed by one of the methods provided for this procedure. EO that are destroyed are those items whose disassembly is not cost-effective or that there is no technology available to enable safe and efficient disassembly. Destruction procedure is the sole responsibility of the Serbian Armed Forces and the Ministry of Internal Affairs of the Republic of Serbia. The type and quantity of EO, the competent entity performing the destruction, as well as the location of the destruction shall be considered when selecting the method of destruction of the EO. In the selection phase, the security risks, environmental consequences and financial costs, must be considered.

The classic methods of destroying ammunition are [3, 23]:

1. open detonation (high security risk, environmentally unacceptable, limited quantities of EO),
2. open burning (high safety risk, environmentally unacceptable, limited quantities of EO),
3. closed burning (large amount of waste, possibility of destroying only small ammunition),
4. detonation in a detonation chamber (low security risk but extremely limited quantities),
5. disposal into the sea (environmentally unacceptable, legislation).

The limiting factors in terms of standards, regulations and regulations intensified the development of new technologies and procedures that would allow the disassembly of EO, which had so far been destroyed in the absence of technology (Fig.6).



Figure 6. Destruction of EO by conventional methods [23]

In addition to all the measures taken, the classic disassembly procedures are insufficiently safe and unproductive in many situations [34, 35].

**Application of new technologies in the process of EO disassembly**

The main goal in the process of implementing new technologies is to raise the level of security, environmental aspects, as well as to increase the capacity of the organizational unit and the possibility of disassembly of a number of different items. In this way, the possibility of recycling large quantities of explosives is achieved, as well as reducing the need for destruction. Given the aforementioned reasons, with the positive economic aspects, the introduction of new technologies is fully justified [2, 5, 23]. Among the new ways of discarded munitions disposal are: laser cutting, burning in plasma furnaces, cryofracturation, melting, leaching, ammonia cutting, and hydroabrasive waterjet cutting [2, 36, 37] and washout waterjet [14, 32].

The technologies that show the best results are based on the action of a water jet. In case of material cutting, an abrasive is used in addition to the water jet. Water jet based technologies are non-thermal methods, which means that no thermal changes of the material occur during cutting [38], which is one of the main advantages in the EO disassembly process. In addition to the absence of thermal changes in the structure of the material, during the cutting process, no evaporation occurs, but all the products formed during the cutting process are treated by the action of the jet and accumulated in water tanks [37].

The first (disassembly and pre-treatment) and second (removal energetic material) phase can be united by applying certain procedures [23]. Table 2 shows some of the new operations in the process of removing explosive charges from the projectile cases.

**Table 2.** Technologies for removing explosive material from projectiles [23]

Technique	Description	Usage
Disassembly and Pre-treatment		
Disassembly, robotic	Disassembly, punching, crushing or cutting remotely	Reduces personnel exposure to munitions Less flexible than manual disassembly
Abrasive Water JET	Sectioning by a high pressure Abrasive Water	Flexible and quick Generates waste water Useful with UXO and MEC
Cryofracture	Liquid nitrogen bath embrittles munitions before mechanical pressing	Ensures no high order event during incineration An additional process that may not be necessary
Removal energetic material		
Machining, mechanical	Dry machining of energetic materials by contour drilling	No waste water Typically only removes 95% of explosive so further treatment is necessary
Washout, high pressure water jet	Ablation of energetic material by a high pressure Water JET	Moderate pressures Generates waste water Difficult with small munitions

In addition to water jet based technologies, projectile cutting with a saw is used as an effective method in the disassembly process [38]. This method belongs to the classic metalworking methods of cutting, while with certain modifications it can be adapted to the process of disassembly of the projectile [39].

*Abrasive water jet cutting technology*

The application of Abrasive Water Jet (AWJ) technology involves opening of a projectile by cutting [Fig.7]. A controlled and focused water jet with abrasive particles cuts the material, in this case explosive-charged projectiles [2].



**Figure 7.** Projectile case after cutting with AWJ

AWJ cutting as a non-thermal method does not primarily lead to the heating and structural changes of the material at the action of the jet, but rather cutting is being done by the kinetic energy of the water jet and the abrasive particles [40]. AWJ enables projectile cutting of different geometries and complex surfaces, types and calibers without first adjusting the workbench (Figures 8 and 9). AWJ has been tested on 20 mm calibers up to large-caliber of the EO [5, 41]. In this way, a high degree of versatility and flexibility is achieved with respect to opening different types of EO [2].



**Figure 8.** AWJ application for 260 mm projectiles [42]

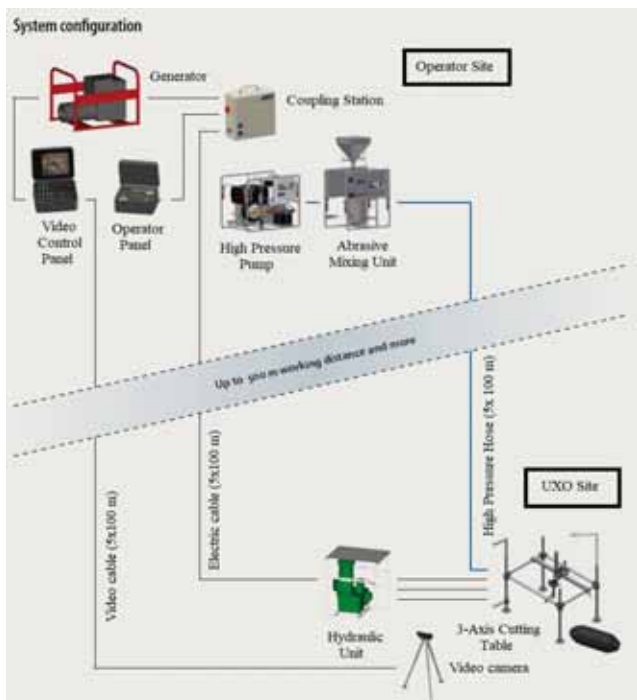


**Figure 9.** AWJ application for 155 mm projectiles [43]

Water contaminated with explosives can be filtered and used in the re-process [26, 44], but at the end of the process it is treated as wastewater containing explosives at permanent disposal. [45] The main advantages of AWJ, in addition to the disassembly universality of EO, are high degree of automation, high accuracy, reliability and the ability to cut multilayered heterogeneous materials. The whole process as a whole can be managed from a room that is separated from the place where only the cutting of the EO is realized, which makes the process completely safe [37, 46].

In addition to the stationary station, mobile facilities (mobile stations) for the disassembly and destruction of EO are being intensively developed [47]. Mobile workstations are of a particular use in UXO. UXO are considered high-risk assets and any handling, manipulation and transportation of these assets is prohibited. They can be caused by large accidents within work facilities or warehouses, due to inclement weather, accidents during transport, inactivity during use. In these situations, the use of mobile workstations has a number of advantages, of which the safety of the operator and his environment are the primary ones. In the process of destruction, it is not necessary for the operator to be in contact with the UXO (unexploded ordnance) item, which depends on the level of automation of the workstation itself.

The apparatus and main systems of the workstation are located at a safe distance from the site of destruction, while only the cutting head that performs the cutting process is remotely contacted with UXO, that is, puts UXO in a safe state for further process control (Fig.10) [28, 47].



**Figure 10.** Schematic representation of the mobile workstation for the UXO disassembly [47]

With the use of mobile stations in the function of the disassembly of UXO, items that were exclusively destroyed before the appearance of these stations can now be successfully disassembled (Fig.11).

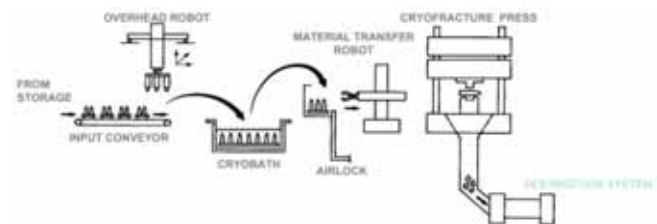
The dual benefit is primary due to the much safer handling and handling of these devices, while the eco-system is protected because no contamination of the work environment occurs during the process.



**Figure 11.** Implementation of AWJ cutting in the disassembly process of the UXO [47]

### Cryofracture

The EO cryofracture process is the destruction of agents by cooling the liquid nitrogen in baths and tubs specially prepared for these purposes. After lowering the temperature in the bathroom, the tool breaks it on the hydraulic presses and thus destroys it. Low temperature significantly reduces the risk of performing this operation. The basic purpose of the cryofracture procedure (Fig.12) is to disassemble small and medium-sized ammunition, such as hand grenades, mines and other devices. These items are difficult to disassemble by hand because of the dimension and complex geometry of the elements, which significantly raises the level of risk when handled with these agents. These agents are generally destroyed by the grinding process, which poses a high risk in performing these operations and has a very limited application due to the amount of EO that can be destroyed in one cycle and the adverse environmental effects [48, 49].



**Figure 12.** Procedure for deletion of EO by cryofracture [49]

The cooling time of EO lasts from 30 min to 4 hours, after which they are further destroyed according to the procedure shown in the previous figure. The products of such destroyed EO can be separated by melting or separating the parts by the action of a magnetic field, thus separating the fragments of the case from the fragments of explosive material. The whole process can be partially or fully automated [50].

### Sawing technology

One of the procedures used to remove the explosive charge from the projectile grain is to cut the projectile with a saw. In paper [38], cutting of EO with saws are presented. The experiment involved over 3,000 cut pieces, with no incidents. During the process, the temperature of the projectile shell and the explosive charge were monitored (Fig.13).



**Figure 13.** Monitoring of temperature during the sawing of the projectile and explosive charge [38]

Throughout the process, no major changes in temperature occurred, that is, the maximum temperature did not exceed the ambient temperature [38]. The main advantage of cutting a projectile with a saw is a significantly faster projectile cutting rate (4-5x faster than AWJ technology). An important factor is also 75% lower cost of developing and implementing this technology compared to AWJ. Fig.14 shows the cutting of a large caliber projectile with a saw (Esplodeti Sabino device).



**Figure 14.** Large-caliber projectile sawing [51]

However, it is important to note that the sawing procedure cannot be applied to all types of EO unlike the AWJ procedure, this is primarily related to UXO [38].

Fig.15 shows the explosive charges after the projectile cutting process with AWJ or saw technology [24]. The essence of the process is to heat the projectile to the temperature necessary to separate the explosive charge from the inner walls. The explosive charge, as previously emphasized, was fixed with paraffin with a melting point of 60°C.



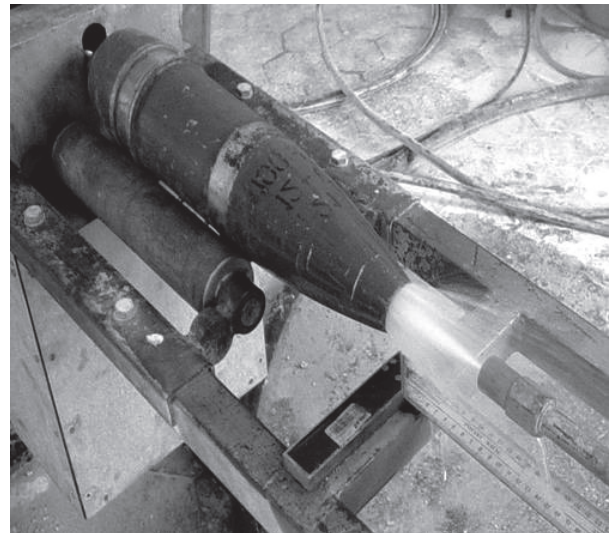
**Figure 15.** Explosive charge upon removal from projectile [38]

In this way, the process time is significantly reduced, which directly affects the productivity of the whole process. In addition, the duration of the conventional process depends on the mixture of TNT with other explosive substances.

In studies [5, 29] it was emphasized that the removal of explosive charge is only possible when it comes to TNT or a mixture of TNT with another explosive substance that allows it to be liberated by the melting process. When this is not possible, these EO are destroyed because they cannot be disassembled by classical methods. As the temperature increases, the sensitivity of explosive materials increases significantly. The cutting process with AWJ and the saw does not increase the temperature, which allows the process of removing explosive charge at a much larger number of different EO. Therefore, there is an extremely high interest in the development of these technologies for a number of reasons. Primarily for the purpose of environmental protection, as it would reduce the amount of EO that are destroyed by harmful methods (Open detonation and Open Burning) and then because of the possibility of regeneration of explosives and its reuse [26].

### Water jet washout technology

The application of Water JET Washout (WJW) technology is presented in [28, 52]. The tests were performed on replacement materials used during the experiment, which have the same physical and mechanical characteristics as TNT. The tests were carried out for 85 to 125 mm calibers. The basic setup of the experiment is shown in Fig.16.



**Figure 16.** Application of Water Jet Washout in the process of disassembly [28]

The primary objective of this technology is to increase the operator safety over the conventional EO disassembly methods [54, 55]. An explosive that is removed from a projectile during the WJW process (Fig.17) can be used as a commercial explosive in the further process, most commonly in the field of mining.

Depending on the granulation and size of the pieces of explosives obtained during the process, classification is performed [52]. The application of WJW technology reduces the need for operators near the place where the process takes place. As previously identified, substances that evaporate during the explosive heat are extremely harmful to human health and the environment. WJW as a technology allows for a high degree of process automation, thereby enabling a "cleaner" disassembly process [14, 32].



Figure 17. Explosives extracted from projectile by application of WJW [52]

### Conclusion

The classic EO demilitarization procedures represent the most common procedures in their process of disassembly or destruction. In most cases, classical methods can achieve the primary goal, which is the demilitarization process itself, but due to the specificity of EO as an item, a number of side effects and adverse effects occur. Most of the EO that are being exploited today are manufactured over the last century and by themselves contain mixtures of explosives that make it possible to apply the classic evacuation procedures. Although classic methods achieve the primary goal of demilitarizing EO, disrupting the pyrotechnic security system, disrupting the degree of protection of the environment does not allow or significantly limit the further application of these procedures.

Due to the aforementioned circumstances, research and experiments in the field of application of new technologies in the function of the demilitarization of EO are becoming more and more current. The implementation of new technologies should first and foremost enable a safer demilitarization process and then a much lower level of pollution and of the work and environment. Also, classical procedures significantly limit the possibility of disassembly of a newer EO due to the content of explosive charges, so they are generally destroyed as such. The application of water jet based technologies is one of the applicable solutions for the demilitarization processes of EO with more complex configuration and contents of explosive material. Current research in the world is aimed at identifying all influential parameters that can at any time impair the stability of the process and lead to adverse events. In order to suppress these events, it is necessary to define precisely all the parameters of the process, which first of all requires the realization of a large number of experimental tests. Abrasive water jet and high pressure flushing technologies with high pressure water jet give the greatest chance of application and their introduction into the process of mass destruction of EO. Depending on the composition of the explosive charge, one of these two technologies is applied. The main advantage of this method is that it is a non-thermal method and does not change the temperature field during the cutting or washing out process. Also, the application of technology enables a high degree of process automation and remote control of the whole process. Another advantage is the adaptability to different calibers and configurations of EO, which has so far been an aggravating circumstance because it required the modification of existing ones or the design of completely new tools, which

significantly increases the cost and slows down the process.

In addition to water jet based technologies, sawing procedure is an application in the disassembly process. The use of sawing technology is basically cheaper than water jet based technologies. However, the limiting factor is the number of different configurations that can be exploited, the composition of the explosive charge and the condition in which the EO is located. The use of sawing in UXO is completely excluded. The experiments carried out on thousands of articles did not lead to the initiation of explosives, which shows the practical possibility of application.

In order for these technologies to be applied, that is, to replace the existing classical disassembly procedures, it is necessary to carry out experiments and to define precisely the conditions and regimes of the process. Also, for certain operations, it is necessary to educate all participants in the disassembly process, from the machine operator, to the executives and other staff involved in the overall implementation of the EO disassembly process.

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## **Pregled, analiza i istraživanja mogućnosti primene novih tehnologija u procesu demilitarizacije ubojnih sredstava**

Klasični postupci demilitarizacije ubojnih sredstava predstavljaju operacije visokog rizika, primarno za radno osoblje i operatere, a zatim i za ceo sistem pirotehničke bezbednosti. Pored faktora bezbednosti, visok nivo štetnih dejstava klasični postupci demilitarizacije emituju na eko sistem i životnu sredinu. Klasični postupci demilitarizacije u velikoj meri ograničavaju delaboraciju ubojnih sredstava zbog zastarele tehnologije, pa se veliki broj artikala uklanja postupkom uništavanja. Metode uništavanja ubojnih sredstava, sa aspekta zaštite eko sistema u potpunosti su neprihvatljive. Razvoj i primena novih tehnologija koje su danas široko rasprostranjene u drugim oblastima predstavlja mogućnost rešavanja ključnih problema. Iz oblasti nekonvencionalnih postupaka obrade svakako prednjače tehnologije na bazi vodenog mlaza koje predstavljaju netermalne metode i tokom procesa ne dovode do termičkih promena materijala. Bitan faktor kod ovih tehnologija je što su one kao takve u potpunosti razvijene i poznate, sa svim definisanim uticajnim faktorima, koje je moguće varirati. Za primenu ove tehnologije za potrebe delaboracije potrebno je postojeće sisteme modifikovati i usaglasiti sa zahtevima procesa delaboracije. Analizom i pregledom postojećih istraživanja u svetu izražen je trend težnje usvajanju novih i ekološki prihvatljivih tehnologija. Razvojem novih tehnologija znatno se proširuje asortiman ubojnih sredstava koji se može delaborisati, čime se potreba za uništavanjem ovih sredstava znatno smanjuje. Osnovni cilj ovog rada je sagledavanje svih uticajnih faktora koji su kritični u procesu delaboracije primenom klasičnih postupaka. Na osnovu identifikovanih kritičnih faktora iz oblasti klasičnih postupaka delaboracije, potrebno je sagledati mogućnost primene novih tehnologija kako bi se proces delaboracije modernizovao i pre svega učinio bezbednim i ekološki prihvatljivim

*Ključne reči:* ubojna sredstva, demilitarizacija, vodeni mlaz, pirotehnička bezbednost, eko sistem.