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DISPOSAL OF DISCARDED MUNITIONS BY LIQUID STREAM

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Professional paper

The paper deals with a possibility of abrasive waterjet application for disposal of discarded munitions. Based on the analysis of current state it has been found out that the surplus munitions and the discarded munitions are destroyed mostly by using conventional techniques such as dumping at sea, outdoors burning, outdoors detonation, mining detonation and also open burning with combustion neutralization. The main aim of this paper is to present a new way of munitions disposal with a view of increasing both the operator safety and environmental protection. In terms of material, discarded munitions are composed of several components and valuable materials that need to be evaluated as efficiently as possible. Special attention is given to the abrasive water jet application in technological line for disposal of discarded munitions.

Keyword: *discarded munitions, hydroabrasive cutting*

Uništavanje odbačenog streljiva tekućim mlazom

Strukovni članak

Rad se bavi mogućnošću primjene abrazivnog vodenog mlaza za zbrinjavanje odbačenog streljiva. Na temelju analize trenutačnog stanja utvrđeno je, da je višak streljiva i odbačeno streljivo uništeno većinom uporabom tradicionalnih tehnika kao što su istovarom u more, spaljivanjem na otvorenom, eksplozijom na otvorenom, rudarskom eksplozijom i izgaranjem na otvorenom s neutralizacijom izgaranja. Osnovni cilj ovog rada je prikazati novi način zbrinjavanja streljiva u cilju povećanja sigurnosti kako operatora tako i zaštite okoliša. S motrišta materijala, odbačeno streljivo se sastoji od nekoliko komponenti i vrijednih materijala koje je potrebno procijeniti što efikasnije. Dana je posebna pozornost na primjenu abrazivnog vodenog mlaza kod tehnoloških linija za zbrinjavanje odbačenog streljiva.

Ključne riječ: *hidroabrazivno rezanje, odbačeno streljivo*

1 Introduction
Uvod

The major developments in the new types of munitions started after the 2nd World War and at the beginning of the "Cold War". During this time, the two world powers, the USA and the USSR, were competing regarding the number of produced munitions and their modernization. Later on, what to do with thousands of tons of surplus munitions has become a problem. The disposal of surplus munitions has historically been a relatively simple process with three alternate methods, burning, blowing and burying. Nowadays none of these methods is a long term acceptable solution in today's ecologically conscious environment [1, 3]. This is one of the main reasons why such a great number of companies around the world are dealing with this problem. It has become necessary to develop new environmentally friendly methods of disposal. In this paper the classical "old" and new methods of munitions disposal are described that already take into account the environmental aspect [15, 22, 23].

2 Current state
Trenutačno stanje

If we look at developed countries, the reasons for disposal of munitions are nearly the same, but the most important are: dealing with the surplus and obsolete munitions, incorrect storage and prohibitive costs of storage. Several armed conflicts are going on in different parts of the world, whether as short-time or long-time ones. In these conflicts some thousand tons of munitions are being stored incorrectly. These munitions are a high risk to population and environment and can be a great temptation for terrorists who often use improvised explosive devices (home made bombs), so they are responsible for most of the casualties among allied forces or civilians. These weapons can take many forms and can be used in several ways: as bombs in different types of cars (form passenger cars to trucks), as booby traps placed on roads, or specially adapted belts and vests with explosives for suicide attacks. As munitions have their life time, since 1990 the problems have increased with obsolete and surplus munitions. Warehouses full of munitions have a strong impact on the state budget and army. It is necessary to store and keep properties in running conditions. Army is forced to join in a progressive disposal of munitions. Documentation about manufacturing processes and how the rockets should be destroyed does not exist for Russian munitions in particular. In Slovakia, for example, three Slovak companies have been chosen by the Command of the Armed Forces of the Slovak Republic that should destroy munitions in an ecologically acceptable way – from rifle guns, bullets and artillery rounds through missiles. As the best company in this field has traditionally been The Military Repair Enterprise 015, Nováky. In addition, a chance was given to ZVS holding, a.s. Dubnica and Váhom and Konštrukta Defence a.s., Trenčín. Specialists for disposal of munitions have agreed that the later the munitions are destroyed, the more expensive it is. The process of ageing of the simple elements in munitions, or else inconvenient storage, carries the risk of unexpected reactions of the munitions. Since 1993 about 60 kilotons of munitions coming mostly from our warehouses, but also from abroad, have been destroyed in Slovakia. Components remaining after disposal of munitions are returned into production, particularly metal parts into smelting plants and only a minimum part of components goes back to a dump. The term munitions denotes all materials used for war that have the properties of explosive or pyrotechnic

Table 1 *Division of munitions*
Tablica 1. *Podjela streljiva*

Division according to the military type		
Army ground forces	artillery forces	bombshells, mortar shells
	engineer troops	antitank, anti-personnel mines
	for individual	hand-grenades, ammunition for small arms
Air forces	Air force rocket	missiles
	Air force aviation	aerial bombs, mounted weapons ammunition, controlled missiles
Division according to the specification		
Basic specification	fragmentation, blasting,	with a volume explosion
	penetrating	cumulative, concrete-piercing fuse, armour-piercing – full, nuclear, with blasting explosive
	grapeshot, bounding	
	incendiary	
	chemical	
	biological	
	radiological	
	nuclear	
	with combined effect	penetrating burnt, cumulative, scattering, cluster - explosive- burnt, chemical cluster, cluster-smoke
	containerized	
Auxiliary specification	smoke	
	illuminating	
	signalling	
	tracing	
	disturbing	
	special	
Special specification	training	
	reserve	
	half-sharp, blunt, blind	
	dummy	

Table 2 *Classic methods of discarded munitions disposal*
Tablica 2. *Klasične metode uništavanja odbačenog streljiva*

Method	Characteristics
Dumping at sea	In this way, munitions stored in boxes, metal canisters or containers are easy for dumping in the sea from ships. From an ecological point of view this method is the most dangerous, because today no one will be probably able to tell, where, how many, and what kind of munitions were dumped at sea.
Outdoor burning	Outdoor burning is carried out in the place where there is no danger of fire spreading. The area, in which explosives are burnt, must be removed from all flammable objects. Its dimensions are governed by a number of burnt explosives, but it must be 20×20 m at least. Around the combustion area needs to be an excavated channel of 0,5 m width and 0,25 m depth. The combustion area is marked with warning tables as a demolition pit. The number of burnt munitions is governed by the instructions of the plant production and other military explosives (also unknown origin) are disposed following the instructions drawn up by military service.
Open detonation	Disposal of explosives that cannot be burnt for security reasons. It is performed only sporadically, it can be used as an auxiliary charge for mass destruction and blasting in a blast chamber. The explosion is caused by a detonator and primer, according to their sensitivity.
Detonation in mine tunnels	Old and useless mines are mostly used, characterised by hard rock with a depth of about 900 m. These mines must be equipped with emergency bunkers with their own air conditioning that is independent from the main ventilation system. Furthermore there must be separated divisions for disassembling of munitions still before their disposal.

composition, especially power, either directly (especially to the destruction of life or inanimate forces) or indirectly – for transporting of means to a target.

Munitions can be divided into two main groups, for civil use and for military forces. Munitions can be divided into several groups, especially according to the type of military it is addressed for, then according to the specification of use and also according to the pyrotechnic components being used (Tab. 1).

3 Methods of munitions disposal
Metode uništavanja streljiva

When choosing a method of munitions disposal, we need to take into account some basic questions: what kind of munitions are expected to be destroyed, who will do it (armed forces, police, private security company), where it will take place (in a company facility, in a place outside residential areas or in case the transferring of munitions is risky, on the place of its finding), how many of the

***Table 3** Conditions of selecting*
***Tablica 3.** Uvjeti selekcije*

Technology	Technological conditions of application
Open detonation	There is no other technology available Transport not possible High security risks in the field of munitions disposal Large and medium
Open burning	There is no other technology available Limited quantity of munitions
Rotary furnace	A large number of small and medium munitions After adjustment applicable to large calibrated munitions
Fluid combustion	A large amount of bulk explosives and fuel Possible energy use
Hot gas decontamination	A large amount of contaminated waste metal
Detonation chambers	Limited quantity of munitions
Separation technologies	Recycling and reuse
Experimental conversion technologies	A specific application for hazardous materials as a prevention of highly toxic substances for environmental protection.

munitions need to be destroyed (one or a few thousand). Only after answering these questions can we find the best method of disposal, whereby we must also take into account the cost and environmental consequences of any type of disposal [23, 25]. Nowadays the ways of disposal can be divided into two basic types, the classic one and the new methods (Tab. 2).

In terms of environmental impact and human health, the classic methods have a very disastrous impact: heavy metal emissions (lead, antimony, and barium), toxic gas emissions (HCl, SO_2, HCN), emission of highly resistant toxic substances (asbestos), and contamination of groundwater and soil [24]. For the staff dealing with munitions disposal and also for inhabitants of nearby cities it means an increased risk of carcinogenic diseases and heavy metal poisoning [4, 5, 15]. The conditions for selecting one of appropriate methods are described in Tab. 3.

4 Unconventional methods of discarded munitions disposal
Nekonvencionalne metode uništavanja odbačenog streljiva

Methods for processing of discarded munitions are used in a wide range of mechanical, electrical, thermal and chemical processes for material removal, together with own innovation within the framework of single technologies. In addition to the "conventional" disposal technologies responding to a need for machining of new materials e.g. using new cutting materials (cutting ceramics), new technologies also help with the problems of materials difficult to be machined, known as progressive (unconventional) technologies [2]. Among the new ways of discarded munitions disposal are included: laser cutting, burning in plasma furnaces, cryofracturation, smelting, leaching, ammonia cutting, and hydroabrasive waterjet cutting [17, 21, 22]. Thermal methods are mostly used, but it is also possible to use a liquid for disposal of munitions, either for cartridges leaching or for division of munitions. Fig. 1 shows the distribution of liquid streams used in industry according to Sitek.

Fig. 1 describes the types of streams according to the medium, the possibilities of modification and the ways of creation. Water jet cutting of materials is a non – thermal method, in which there is no heat added to the material. Using of appropriate medium (fluid) may be due to its chemical properties to achieve adequate results. Ammonium has shown suitable properties. Ammonium is a colourless irritating gas at room temperature. Nowadays it is one of the most produced chemicals with the volume of production of 90 million tons annually. It is used as a fertilizer, for gas cooling, for air – conditioning and heating. Ammonium is used for cutting of M60 and M61 missiles that are like copies of the M55 chemical missilery, for the total elimination of chemical substances by alkali metals dissolved in ammonia gas and to clean the other parts of munitions due to their reuse or recycling [25, 26].

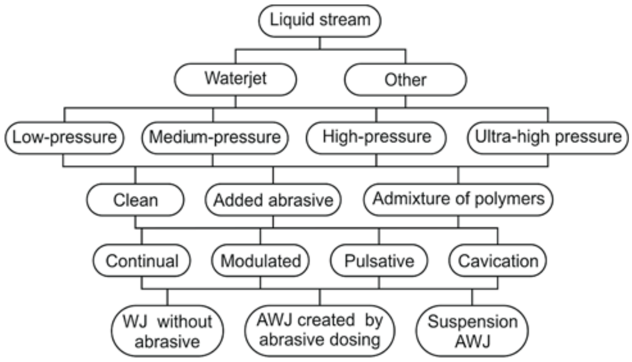

***Figure 1** Distribution of liquid streams according to Sitek*
***Slika 1.** Raspodjela tekućih tokova prema Sitek-u*

This rocket is made of aluminium; there is a head with chemical in the front and an engine in the back. When attempts were made, there were destroyed more than 20 rockets without serious shortcomings. Therefore this method was specified as the most suitable for chemical weapons disposal, where as the traditional methods (burning, open burning, dumping at sea) present a high degree of environmental load. Attempting chemical neutralization ammonia was specified as the most ideal solvent of substances such as soman, sarin, tabun, VX gas, lewisite and others. For disposal of munitions a closed pressure vessel was built in which munitions were stored in the rotating chucks and in stationary position, the front nozzles were used for cutting off a striker and a detonator, nozzles in the middle were used for bore drilling due to chemical leak. The nozzles in the back were used for engine cutting. Additional nozzles can be added as needed. The entire system is remote-controlled from a cover of 200 meters away. Due to ammonium driving two types of pumps were tested. One was a direct drive pump with the power of 18,6 kW using pressure of 276 MPa, that was not approved. More suitable was a pump with the power of 150 kW with backing up, amplifying pumps, providing more stable power with a greater flow of ammonium. Later, by its testing, some shortcomings were discovered, that were removed, especially the replacement of all brass, copper parts by the steel ones, and the removal of accumulated heat incipient by gas ammonia pumping. The study of results has shown that abrasive cutting by ammonia is slightly faster compared to hydroabrasive cutting system.

5 Munitions disposal by hydroabrasive cutting
Uništavanje streljiva hidroabrazivnim rezanjem

Materials cutting technology by hydroabrasive jet was developed in the second half of the 19th century, but a sufficient pressure for wood and plastic cutting was reached at the beginning of 70's. The technological process used the transformation of a high- pressure jet to a high – speed waterjet as a tool for materials cutting. By adding some fine abrasive (solid particles) better efficiency of cutting was achieved, thus expanding the possibilities of waterjet use [2]. The technology referred to as Abrasive Water Jet (AWJ) has been industrially used since 1983. A rapidly moving stream does not provide sparks or dust, there is no heat affected zone on the surface [8, 9, 10, 11, 12] there is no need to generate a heavy force onto the cutting material and consequently there is no material deformation during cutting process [7, 16, 18, 19]. The cooling effect of AWJ process allows cutting some multicomponent materials in all directions, with simple shape cutting. The main advantages are: ability to cut some compound materials, use on soft and hard materials [14], no need of fixed workpiece, shape heterogeneity, no sparks by cutting, high accuracy, reliability and simplicity of operation, possibility of ending (starting) to cut at any spot, possibility of multilayer materials cutting.

AWJ is used in pyrotechnic robots [27, 28] that are primarily designed for disposal, searching and detecting of trap systems. In most cases they are cable or radio controlled. Automatic lines use the process of hydroabrasive waterjet cutting.

These lines can be made as static or mobile. As these lines use the waterjet, that is referred to as unstable, flexible, defects can occur in the geometry of a cutting gap (cutting gap extension, normal deviation, trace of a cut delay deviation, irregular depth of cut) [20], that we do not have to take into account when disposing of munitions. Munitions disposal by hydroabrasive jet is presented in Fig. 2. Section of an artillery shrapnel shell is shown.

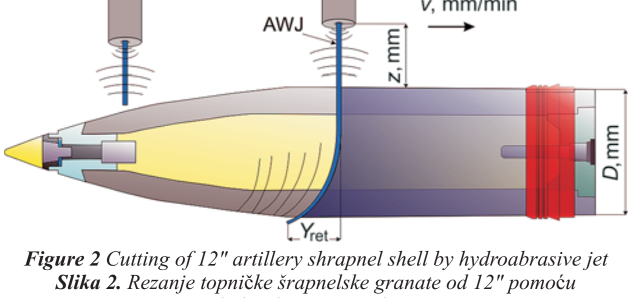

***Figure 2** Cutting of 12" artillery shrapnel shell by hydroabrasive jet*
***Slika 2.** Rezanje topničke šrapnelske granate od 12" pomoću hidroabrazivnog mlaza*

Fig. 3 shows a cross-section of the projectile created by a hydroabrasive jet.

Another example can be disposal of landmines. The presence of mines represents a significant risk to people living in the areas of military conflicts around the world. They can be easily divided into two groups: antipersonnel (with a size of 5 to 10 cm, mainly made of plastic, wood and metal), and antitank (with a size of more than 30 cm, mostly made of metal but now more and more made of plastic). As the searching device is used as a detector, which can capture a gram of metal, it can cause a large number of false reports. Therefore a metal probe is often used for mine searching. Such a procedure is quite dangerous and lengthy. A system operated by a high-pressure pulse stream has been proposed [13]. It can penetrate to a depth of 30 cm. The proposed system uses a pressure of 35 MPa and a flow rate of 19 litres per minute.

***Figure 3** Cross-section of the projectile*
***Slika 3.** Poprečni presjek projektila*

In the Toro company in Minneapolis a small unit using water nozzles for landscape scanning was developed. The principle of this system is shown in Fig. 4. This system can be used both by a robot and by an operator. The unit excites every second a pulse lasting 0,1 seconds. It contains 11 nozzles with a spacing of 7,5 cm to 15 cm, so the operator can provide a mine sweeping operation of a one meter wide road by a single cut. The depth of water penetration depends on the water pressure, on the nozzle diameter and soil. A minimum penetration is 20 cm. To find a mine it is needed to listen to an audio signal by water penetration into the ground, as well as to strokes into objects above the ground. This signal is captured using a microphone (Fig. 4), that should be with each nozzle for better detection [20], while there is only one for all nozzles. The evaluation of the captured sounds is carried out on computer that generates information about what object is in question. In the current stage of development the data from the microphone are evaluated using LabVIEW from National Instruments. It does not only capture the data, but is also used for manifold signal capture which produces a specific spectrum. Specification of the spectrum allows identification of various targets. One microphone can run a program to find out how a single spectrum of every pulse varies from each other and how closely it agrees with the spectrum of known mines.

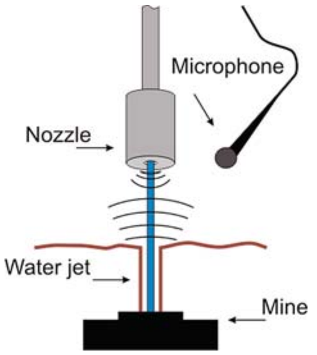

Figure 4 *Searching unit using a waterjet and acoustic signals*
Slika 4. *Jedinica za pretragu pomoću signala mlaza vode i akustičnog signala*

Another alternative technique for disposal of munitions uses the ability of hydroabrasive mine cutting. This can be achieved by connecting a pump to the system and by adding an abrasive to it. Security is provided in several ways, as today are available series of studies about the impact of hydroabrasive cutting to the sparks creation causing the firing of munitions. This system was originally designed for mines cutting from vertical position. It has shown that a mine cutting from horizontal position is a better solution. This is applied to the large anti-tank mines, where there may be more safety fuses. It is more difficult to ensure the safety fuses destruction by vertical cutting. If there are small anti-tank mines, it is better to hold them using a special shoulder with tentacles in which can be integrated a nozzle for hydroabrasive cutting [6, 7].

6 Conclusion
Zaključak

This paper deals with the disposal of munitions according to the type and specification. It describes different types of division and their subgroups. As the threat of terroristic attacks remains as real throughout the world, where some parts of discarded munitions are frequently used, munitions need to be professionally stored and it is necessary to start with a professional disposal. Therefore some basic safety measures for the disposal of munitions are mentioned in the paper. These classic ways should be used only sporadically because of ecological load caused by large amounts of toxic substances and heavy metals. They have a great impact on the pollution in nature, and endanger human life and health. The new methods are much friendlier to the environment. Waterjet method has a great potential and in the future more attention should be paid to this method of waterjet or hydroabrasive waterjet disposal of munitions.

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