Best Practice Guide on the Destruction of Conventional Ammunition

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This Guide was drafted by the government of the Netherlands.

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I. Introduction

As stated in the *OSCE document on stockpiles of conventional ammunition, FSC.DOC/1/03, 19 November 2003,* the presence of ammunition always poses certain risks to human security. The ultimate solution to this problem is the destruction of all surplus ammunition. This document will discuss the best practice methods for the destruction of conventional ammunition.

1. Objectives

The objectives of this best practice guide are to provide guidance for the effective destruction of surplus ammunition that remains, for instance after conflicts, or is identified as a result of armed forces restructuring during defence reform.

It is anticipated that this guide will contribute to and facilitate the development and application of high common standards in this field. For the recommendation, planning and conduct of specific destruction projects, further detailed guidelines should be developed within the boundaries of national regulations and procedures. Such additional guidelines might take into account best practices available.

2. Scope

This best practice guide limits itself to the destruction of conventional ammunition. The neutralization of Nuclear weapons as well as of Chemical and Biological Weapons is excluded; however some references are made to chemical ammunition. Also excluded are the destruction of UXO (unexploded ordnance) and range clearing.

The physical destruction techniques available range from open burning and open detonation techniques to highly sophisticated industrial processes.

The arguments in favour and against each process are discussed in this paper. Appropriate destruction techniques in a certain area will depend primarily on:

1) The resources available in the area,
2) The physical condition of the stockpile, in other words is the ammunition transportable,
3) The quantity of ammunition and explosives in terms of economies of scale,
4) National capacities, and
5) National explosive safety and environmental legislation.

In general, the greater the amounts of ammunition to be destroyed, the larger are the economies of scale and therefore the wider range of affordable and efficient technologies.

3. General process for demilitarization activities

The process of developing a demilitarization project plan starts with the ammunition and the responses to the following basic questions:

3.1 Is it safe to move the ammunition?

If no, then the ammunition is not suitable for demilitarization by other than controlled “on-site” demolitions.

3.2 Can the ammunition be internationally transported in accordance with the United Nations Recommendations on the Transport of Dangerous Goods, and the associated inter model requirements, such as The European Agreements Concerning the International Carriage of Dangerous Goods by Rail (RID) and by Road (ADR), and the International Maritime Dangerous Goods (IMDG) Code?

In order for ammunition to meet the fundamental requirements for international cross border movements it must have been classified as Dangerous Goods Class 1 and the packages Type Tested and approved in accordance with the UN requirements. To undertake this time consuming and potentially costly process for ammunition that is destined for disposal would normally only be appropriate for large quantities [1].

3.3 What are the transport cost implications?

For budgeting purpose any cross border transportation should be assessed at 30% to 40% of the total foreseen demilitarization cost.

3.4 How much ammunition, by specific designation, is there?

The quantity of ammunition to be demilitarized is a deciding factor when there is overriding budgetary constraints. Unless the owning organisation has ready access to an existing demilitarization facility that already has in place the required infrastructure, tooling and competent staff the unit cost per item will be disproportionally high. The answer to this question has to be considered in the light of the response to paragraph 1.3.2.

3.5 Is there sufficient technical information?

The significance of this requirement is best illustrated by the following example. A demilitarization project includes high explosive filled projectiles. Various options are available to demilitarize these projectiles. The preferred one is to melt out the explosive filling using hot water (above 81° Celsius) for subsequent re-use in the production of commercial blasting explosives. It represents the best re-use and recycling option, and has a minimum environmental impact. However it is not that simple. Of the potential explosives fillings only TNT has a low melting point. The most common alternative filling is RDX which cannot be melted at below 205.5° Celsius. At the same time RDX, wax and aluminium are added to TNT for various operational reasons. It still has a low melting point and is relatively simple to fill the projectile by melt pouring. It can also be melted and removed, but there is a significant potential hazard from any recrystallized RDX. The addition of the fine powdered aluminium further exacerbates to the problem. This kind of technical information is essential in order to define what demilitarization technique is the best option. For the abovementioned example without the information regarding the explosive filling it may not be possible to decide on the optimum demilitarization process which can lead to the choice of a process that is inherently hazardous.

3.6 Will the work be awarded following a competitive bidding process or as a sole source allocation?

If the latter it an independent cost appraisal may be required.

3.7 Are there any time constraints?

There may be operational, logistic or funding time constraints. These may well have an impact on the project budget and funding time-lines.

3.8 Are there any security implications?

With the growing increase of precision guided munitions and the use of electronic guidance systems munitions may contain confidential embedded electronic data. Such components will require special handling and destruction verification.

3.9 Are there any environmental constraints?

The aim of any ammunition disposal should be to minimizes, or even eradicate, any adverse environmental impact it. However such aims are expensive to achieve, and may not be justifiable, or even possible, for small quantities.

3.10 Are there any restraints on the re-use and re-formulation of recovered materials?

National legislation may prohibit or limit the re-use and re-formulation of recovered materials, especially explosives and propellants.

4. Environmental impact

Although there are no completely ecologically safe procedures in the destruction of ammunition and explosives; where ever possible steps must be taken to minimize the impact on the air, the soil and the water environment. Pollution control measures must always be considered in destruction planning. The collection of scrap and residues would assist in minimizing the impact on the environment [2]. Specific local environmental legislation must be taken into account.

5. Economics of demilitarization

Comparing the costs of different demilitarization methods is difficult and potentially misleading, because there are so many variable factors such as transportation, capital investments, labour, energy, waste disposal and the value of recyclable materials.

6. Monitor of demilitarization process

It is necessary that the demilitarization activities are monitored and verified during the course of the project. This is done to ensure that the task is undertaken in accordance with the agreed schedules and that proper and accurate records are maintained. Where scheduled payments on deliverables are being made the associated disposal certificates should be countersigned by the accredited Validation Authority. The extent and frequency of the validation will normally be dictated by the scope and complexity of the project. In the case of large scale projects over long time periods it is not uncommon to have a resident on-site verification presence.

7. Destruction process

This document uses the ammunition classification terminology as defined by the OSCE in the above mentioned reference. In this document, the following classifications are allocated:

(i) *Ammunition for small arms and light weapons (SALW);*
(ii) *Ammunition for major weapon and equipment systems, including missiles;*
(iii) *Rockets;*
(iv) *Landmines and other types of mines;*
(v) *Other conventional ammunition, explosive material and detonating devices.*

The exact technologies used for ammunition destruction will further depend on the amount of ammunition that has to be destroyed and the local technologies that are readily available.

This handbook will give an overview of the most used technologies. Starting with the dumping of ammunition (Chapter 2), this book will give an historical overview or sequence of technologies used. Chapter 3 discusses open burning and detonation, and Chapter 4 the closed burning and detonation of ammunition. In Chapter 5 the necessary reverse engineering technologies will be discussed, while Chapter 6 focuses on the separation of metal parts and explosives. Although this handbook focuses on the destruction of the ammunition, within Chapter 6 also the reuse and recycling of materials can be a major factor to be considered.

Special attention will be given in Chapter 7 to the destruction technologies of those chemicals originating from ammunition that might lead to problems during the incineration process.

The conditions in favour of the different technologies are discussed in Chapter 8, and the best practice methods are listed in a table. Finally, Chapter 9 summarizes the major conclusions of all methodologies that can be applied for the destruction of ammunition.

II. Dumping of Ammunition

1. Sea dumping

The dumping of ammunition is forbidden by law, for those countries that have ratified the various agreements and conventions. (The London convention of 1972 and the 1996 Protocol [3], OSPAR 22 September 1992, [4]). Most Western European countries are signatories.

Beside this the dumping may lead to undesired situations, as the governments no longer have control over the ammunition.

2. Landfill

When ammunition is dumped in lakes or landfill sites, the toxic chemicals leaching from the ammunition over a long and unpredictable period of time will pollute the environment. A large number of the components used in the ammunition are harmful for the environment. These components will include heavy metals (e.g. Lead, Antimony, Zinc, Copper), explosives (*e.g.* 2,4,6-trinitrotoluene (TNT), nitro-glycerine (NG) and RDX), and components from propellants (*e.g.* dinitritoluene (DNT), Diphenylamine (DPA) and dibutylphtalate (DBP). Components of pyrotechnics like hexachloroethane and barium/strontium salts in tracers and compositions for illumination are also harmful to the environment.

Due to the uncontrolled migration of toxic chemicals leaching from dumped ammunition, mainly by the ground water, large areas will be polluted including the drinking water supplies for the people living in those areas.

III. Open Burning/Open Detonation

1. Open Detonation

The destruction of ammunition by open detonation (OD) and open burning (OB) is still widely used, commonly referred to as OBOD.

In open detonation, ammunition is packed together and destroyed by sympathetic detonation, using donor charges of serviceable explosives. This is achieved by the explosion of demolition charges in close contact with the densely packed ammunition items. It is therefore only viable for ammunition with a relatively high explosive weight ratio.

Figure 3.1: Ammunition prepared for destruction

Due to the detonation shock wave generated by the donor charges, the ammunition will be detonated. The advantage of open detonation is the ability to destroy large quantities of ammunition efficiently. The demolition range must have sufficient area to ensure that the effects of blast, noise and fragmentation are limited to the site. In general most ranges in non-combat areas are significantly limited.

Open detonation also enables the destruction of ammunition without the need for special equipment.

The disadvantages of open detonation are:

- The risks of uncontrolled pollution of the soil, (ground) water and air [5];
- The risks originating from shock wave and fragments;
- The possibility that not all the ammunition articles will be destroyed properly, and that UXO will then result in the immediate area;
- Production dependant upon daylight hours and suitable weather conditions.

To prevent the uncontrolled migration of any potential pollution, the open detonation has to be performed preferably at locations that are not vulnerable towards leaching out of the pollutants to the ground water table.

The shockwave and fragments can be mitigated by the restriction of the total amount to be detonated at one time or by the proper shielding of the location. These additional safety measures will depend on the vulnerable infrastructure in the neighbourhood.

Because of the uncontrolled pollution, the open detonation of large stocks of ammunition is prohibited in most Western European countries.

Open detonation should however be performed with personal protective equipment, to prevent the exposure of EOD personal to the pollutants [6]. This can be achieved by simple skin and breathing protection by the use of (disposable) overalls, gloves and dust masks.

2. Open Burning

Open burning is mainly used for the destruction of surplus (bulk) propellants and pyrotechnic compositions. Also non-confined (bulk) explosives may be destroyed by this technique preferably in small quantities, due to the risk that burning explosives and propellants might transfer into a full detonation.

Figure 3.2: Bags filled with propellant, ready for open burning

The open burning of ammunition containing smoke, flare, and dye or irritating agents is forbidden in the USA and many other countries, because of the high concentrations of hazardous products that are formed during the open burning [7].

Open burning is generally conducted on engineered structures such as concrete pads, or metal pans to avoid contact with the soil surface, and leaching out to the ground water table. OB pans should be made of a material sufficient to withstand the burning process, and should be of sufficient depth and size to contain treatment residues. The pans may be elevated slightly above the ground to enhance cooling and to allow inspections for leaks. The pans should be covered when they are not in use [8].

In conclusion it can be stated that the use of open burning and detonation should be limited to locations that are not vulnerable to the leaching out to the ground water table. In cases that leaching out (OB) might be a problem the use of a watertight construction is mandatory, such as concrete or metal pans. Those engaged in the destruction should be equipped with the proper protective means, like (disposable) protective clothing and breathing protection.

IV. Closed burning

1. Rotary Kiln

The rotary kiln is characterized by the controlled thermal destruction of ammunition or explosives during a predetermine time, and the treatment of the exhaust gases.

The type of furnace that is most frequently used for the destruction of ammunition is the rotary kiln type.

The ammunition is transported by a feed hopper (at the left) that regulates the amount of ammunition (from a separated room) per unit of time to be introduced to the furnace.

Figure 4.1: Outside view of a rotary kiln furnace (courtesy NAMSA)

This is an important safety issue that will prevent too high concentrations of ammunition in the kiln. The ammunition will react to the high temperature in the furnace which is achieved by burners at the end of the furnace. These burners can be heated by gas or oil burners. The rotary kiln incinerator is a thick walled rotating cylindrical steel drum with an internal Archimedean screw. The controlled rotation speed causes the ammunition to move through the heated drum. As different types of ammunition require different residence times the rotating speed of the kiln has to be adjusted. At a certain residence time the explosives will ignite. The reaction products are mixed with excess air to burn completely in the post combustion chamber (after burner), for a complete combustion. The solid reaction products are collected by the ash remover, the cyclones and filters, these may be bag or ceramic filters. The gaseous products are treated with water washers and denox installations. The latter is of special importance in the case of the burning of explosives like TNT, because of the high NOx concentrations that will be generated. In this way the emission of exhaust gases will be in compliance with the stringent demands from national environmental authorities [9].

According to their size and performance criteria rotary kilns can be used for the burning of bulk explosives and propellants; small calibre ammunition (up to 20.000 rounds an hour), fuzes, detonators and other igniting devices, especially in large quantities. If suitable large and medium calibre ammunition should undergo a pre-treatment step, to expose the explosive filling. Suitable pre-treatment methods are to be discussed in later chapters.

Rotary kiln furnaces have been extensively used on a commercial basis in USA, Germany, France, Italy, UK, Albania and Ukraine. In conclusion it can be stated that the rotary kiln is especially suitable for the destruction of a large variety of ammunition types and demilitarization arising.

In Bosnia UNDP is using a containerized Transportable Ammunition Destruction System (TADS). This system can be placed at any location, at 25 % of the costs of the full scale rotary kiln. Such mobile systems can be used to destroy small calibre ammunition up to larger quantities.

Figure 4.2: Containerized Ammunition Destruction System as used by Bosnia UNDP

2. Fluidized Bed incinerator

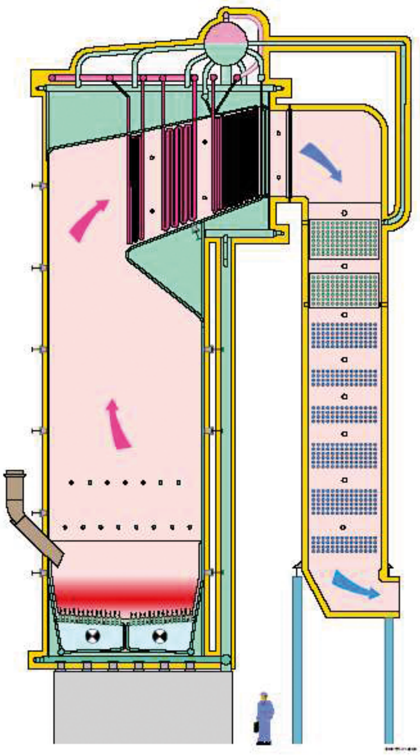

Figure 4.3: Fluidized Bed incinerator

The explosive waste is pumped as non detonable slurry [10] into the bed (the red area). The bed consists of sand (mainly silicon oxide) particles of a well defined particle size. Due to the action of the hot air flow the sand particles start to float and act as a liquid.

This is a very safe concept to incinerate explosive waste.

The fluidized bed can be realized in any size. Figure 4.4 shows a large industrial set up. For the incineration of explosive waste small installations with a diameter of 0.5 meter are sufficient.

The major advantage of the fluidized bed furnace is the low energy consumption. This makes it possible to extract the excess heat from the furnace to heat a separate cabinet / furnace for the heat treatment of medium sized ammunition parts in small quantities. (see also 4.3 Car Bottom Furnace)

The Fluidized bed incinerator is especially dedicated for the destruction of bulk explosives and propellants in the form of slurry, consisting of energetic materials and water.

The disposal of pyrotechnic compositions by fluidized bed incineration is not always possible due to the formation of products that will react with the sand particles of the bed. This may lead to the formation of lumps that will disturb the proper functioning of the fluidized bed.

3. Car Bottom Furnace

This type of furnace is used for the heat treatment of small calibre ammunition (parts) like igniters, detonators and fuzes. Characteristically the furnace is used for the treatment of small numbers; large amounts of these articles can be treated in the rotary kiln furnace. The CBF is also used for the heat treatment of metal scrap contaminated with small amounts of explosives. In general practice the furnace is used in combination with other installations, for example in combination with another furnace. The heat necessary to warm up the furnace comes from the excess heat generated by the large furnace.

Figure 4.4: Car bottom furnace with door half open

The ammunition is placed on the car (that can be rolled in the furnace on rails).

The ammunition or the metal scrap will typically be in the furnace with a residence time of 30 minutes. The gases coming from the furnace can be lead to the pollution control system (PCS) from the facility next by (e.g. the fluidized bed incinerator). After the heat treatment the metal parts that will remain on the car can be certified as Free From Explosives (FFE), packaged and transported to the scrap metal industry.

4. Hot Gas Decontamination Facility

The hot gas decontamination facility (in fact the enlarged version of the CBF) can be applied to process items that contain trace quantities of energetic material to a condition such that the items are assured to have no significant quantities of energetic material (Chapter 5). Items to be treated are loaded in baskets, banded to metal pallets, or secured directly to the surface of a specially designed railcar. The railcar is then moved into a decontamination chamber such that the railcar and the chamber form a sealed box. Hot air is supplied to hold the chamber at temperature of 300 degrees C for 1 - 2 hours.

Figure 4.5: Hot gas decontamination facility. The rail car is charged with metal baskets that are loaded with pre-treated ammunition.

The installation is especially suited to clean large amounts of contaminated scrap.

5. Contained or Controlled Detonation Chamber

This type of equipment is used for the destruction by sympathetic detonation. The principle uses the sympathetic detonation of a small explosive charge of explosives, mostly plastic explosive, in close contact with the ammunition to be destroyed. The chamber is designed to withhold the overpressure generated by the detonating explosives, but cannot withstand the brisance force of nearby detonations. The maximum load of explosives that can be detonated at the same time depends on the design and size of the detonation chamber. The detonation chamber is ideally suited for the disposal of of small amounts of medium sized ammunition, including hand grenades and anti personnel mines. Larger calibre ammunition (> 105 mm shell) may need to be down sized before they can be destructed using the detonation chamber.

To avoid contamination of personal, simple protective measures have to be followed comparable to the open burning and detonation.

Figure 4.6: Mobile version of detonation chamber with expansion and air pollution control unit

V. Additional Techniques for Ammunition Disposal

In Chapter 4 some of the closed burning and closed detonation techniques have been discussed. In most of these techniques it will be mandatory to limit the amount of ammunition, or to mitigate the worst possible effect of the ammunition. For larger items it may be necessary to disassemble the ammunition. This reverse engineering will provide:

- Complete discrete explosive items suitable for subsequent disposal.
- Explosive items requiring mechanical downsizing.

Fig. 5.1: Manual disassembly of anti-personnel landmines (Donetsk, Ukraine)

1. Reverse Assembly

This process may be able to be conducted in factories that have been producing the ammunition. In the reverse assembly the ammunition parts are separated using equipment that is sometimes also be applied for the production of the ammunition. The equipment has to be adapted for the reverse process and has to be handled by qualified personnel. The process may include several operations.

- The initiating devices – fuses and igniters are removed from the round.
- The fuzes are removed from the projectiles.
- The boosters are separated from the fuzes.
- The igniters and the centre core igniters are removed from the cartridge.
- The propellant cartridges are separated from the projectiles and the propellant is removed

Down-sizing can be done by the proper combination of equipment and qualified personal. For mechanical disassembly mechanically operated systems are used to dismantle ammunition. In contrast to manual disassembly, mechanical disassembly has the advantages of high production rates; it is an efficient system of work and has low staff requirements. There will be a need for a wide range of equipment necessary to cope with all down-sizing requirements.

2. Mechanical downsizing

Mechanical downsizing makes use of different equipment like lathe, saw (especially band saw) and hydro-abrasive cutting. The cutting tool is used to open the ammunition, to separate the fuze from the projectile, to separate the cartridges from the projectiles etc, without the need for the wide range of specialized equipment needed for the reverse assembly methodology. However, the amount of labour and the amount of ammunition that can be destroyed will be comparable to the reverse assembly process.

In addition to the use of a lathe, the downsizing can be achieved by sawing or cutting the ammunition into smaller parts if proper precautions will be taken. These techniques can be applied all over the world. The application of these techniques to the reverse assembly of ammunition may create dangerous situations, as most explosive fillings are sensitive to friction.

Figure 5.2: Lathe for the cutting of 81 mm mortar

This method of downsizing can be chosen if the safety of the personal is guaranteed. The use of remote controlled processes will be in most cases sufficient as well as mandatory for a safe process.

Ammunition can also be sectioned by high pressure hydro abrasive technology, provided that the water pressure will not exceed the limit of 2000 bar. Typical operating pressures are generally 200 bars.

This technology originates from the off-shore business and was used to cut pipelines or open storage tanks that contained vapours of hydrocarbons.

The advantage of the hydro abrasive cutting (HAC) technique is the flexibility that allows the cutting of all ammunition from 40 mm to large aircraft bombs and torpedoes. Another advantage is the proven safety of the technique within its safe pressure limits. The HAC system is especially suited for the cutting of ammunition containing plastic bonded explosives.

Figure 5.3: Equipment for hydro abrasive cutting, insert picture 155 mm cutting result

In conclusion, mechanical downsizing is a suitable process, when it is performed remotely controlled.

3. Cryogenic Fracturing

This technique was developed for the demilitarization of chemical munitions. [10] The ammunition is cooled down in a container filled with liquid nitrogen. The steel of the projectiles becomes brittle due to the low temperature. Subsequently the projectiles are transported to a hydraulic press and fractured to recover the explosive or chemical agent, whilst converting the shells into smaller metal fragments.

Due to the low temperature the chemical warfare agent in the projectiles could not evaporate so the metal fragments and the chemical agent were treated in a special furnace with exhaust cleaning.

Cryo fracture is widely used in Europe for the commercial demilitarization of small contained explosive units and components. The freezing of the item desensitizes the explosives so enabling it to be safely crushed and subsequently processed in a kiln. Many tens of thousand of cluster munition bomblets have been disposed of using this technique.

Fig. 5.4: Cryofracture plant at Alsetex, France (courtesy NAMSA)

VI. Separation Techniques

Techniques to separate the explosives content from the metal containers that are usually practiced include:

- melt out techniques;
- high pressure water washout;
- solvent washout.

1. Melt out techniques

Melt out techniques are widely used to remove the explosives and fillings from ammunition that is filled in the molten state. The most common example is TNT and TNT derivatives, such as TNT/RDX, that are melt poured at a temperature of 80.35º Celsius or above. Melt out techniques are suitable for all TNT based munitions. Due to its high melting point (205,5º Celsius) melt out is not suitable for RDX filled ammunition.

The ammunition is heated using hot water/steam or induction furnaces. The explosives will melt at temperatures above 80,35° Celsius, and will flow out of the casing. Subsequently, the molten explosives can be collected for further treatment or disposal. Commercially it is often used in the production of commercial blasting explosives.

Figure 6.1: Melt out of TNT with autoclaves at munition disposal factory Ankara (courtesy NAMSA)

- TNT vapour has to be removed by proper exhaust;
- Residual layer of explosive makes it necessary to give the ammunition an additional heat treatment (Car Bottom Furnace or hot gas decontamination (Chapter 4).

The melt out technique is also used for the demilitarization of ammunition containing white phosphorus (WP). This ammunition is immersed in a bath of warm (50°C) water. The phosphorus melts at 42°C and can be collected under water. This procedure is necessary because of the violent reactivity of phosphorus towards the oxygen in the air. The recovered WP has a commercial value.; Small quantities of WP filled munitions can be disposed by OD but expert advice should be sought due to the problems of environmental contamination.

Figure 6.2: Recovery of white phosphorus using melt out

2. Water jet washout

The principle of water jet washout of explosive fillings is the use of a high pressure water jet. The water jet is focused on the explosive filling by means of a rotating nozzle. With high pressure water washout it is possible to remove all kinds of explosive fillings out of the metal casing of the ammunition. The wash out is especially suitable for the removal of plastic bonded compositions (PBX) and other non melt cast explosives.

The installation depicted in Figure 6.3 can washout 2 articles simultaneously. All 8 articles are washed out in this installation in half an hour.

Characteristics of water jet washout are:

- The water jet will completely remove all kind of explosives (not only the melt cast types/no thin layer of explosive material will remain);
- Less pollution in the buildings, less TNT vapour means better labour hygienic conditions;
- The water in the washout process is recycled (no waste water problem);
- The explosives can be separated from the water for reuse;
- The explosives can be transformed into slurry that can be classified as class 4.1 [11].

Figure 6.3: Water jet washout of 155 mm shells

The water jet washout installation can be very effectively combined with the hydro abrasive cutting system (Chapter 5.2).

3. Solvent Washout

This technique makes use of a solvent that readily will dissolve the explosives. Since most explosives, like TNT and RDX, are not (or at least very poor) soluble in water, other solvents have to be chosen. Most explosives will be dissolved in solvents like methylene chloride, methyl alcohol, acetone or toluene. It should be emphasized that large amounts of solvent will be needed; large recovery and storage facilities for the solvent will be mandatory. The solvent washout enables the recycling of the explosives. This technique will be preferable for the reuse of high valuable military explosives. This technique is limited to small amounts of ammunition.

The solvent washout can also be used for the cleaning of contaminated metal parts, e.g. the shells after removing the explosive by melting out. The solvent will dissolve the thin layer of explosives that is left in the shells after the melt out step.

This type of processing has to be conducted under appropriate safety conditions; some solvents have high vapour pressure and could form explosive mixtures with air, while other solvent could be harmful to people because of the toxicity (toluene, methylene chloride).

VII. Experimental Conversion Techniques

In Chapter 3 and 4 the combustion of explosive waste have been discussed as a conversion technique. During the last two decades new experimental technologies have been tested for the conversion of explosive waste. These technologies include:

- Super Critical Water Oxidation
- Plasma Arc Pyrolysis
- Electrochemical Oxidation
- Chemical Reaction
- Biological Degradation

These small scale techniques are designed and used for very specific types of waste.

1. Super Critical Water Oxidation

Supercritical water oxidation (SCWO), also known as Hydrothermal Oxidation, destroys toxic and hazardous organic wastes in a compact, totally enclosed system. This makes it an interesting technology for the destruction of pyrotechnic compositions containing chlorine (*e.g.* hexachloroethane, polyvinyl chlorine), but also irritating agents and chemical warfare agents. It is a high tech process for the destruction of chlorine containing compositions, avoiding the formation of dioxins.

2. Plasma Arc Pyrolysis

The plasma reactor consists of an internal centrifuge in which the hazardous waste material is heated up by melting torches, producing a plasma arc with a temperature of about 20000°C. The waste water of the off-gas cleaning system will be treated in a water evaporation unit. Thus, no waste water will be released into the sewers. Due to its toxic contents (toxic metals) the dry residue from the evaporator has to be disposed of in a hazardous waste storage site.

The plasma arc technology was developed to destruct hazardous waste like chemical agents containing arsenic. As the product of the reactor will be a glazed composition in which the toxic compounds are captured, the final product has to be stored in a hazardous waste storage site.

Energetic compounds (explosives, propellants and pyrotechnics) in the presence of a small amount of oxygen are oxidized in a plasma reactor into gaseous products consisting principally of carbon monoxide, carbon dioxide, and small hydrocarbons such as methane, ethene, and ethane. Arc furnaces have very short start-up times (of about 5 minutes to stable operation) and shutdown times. The process needs a high amount of energy, is very costly, but dedicated to the neutralization of certain types of chemical munitions. Furthermore, plasma arc pyrolysis is well suited for the decontamination of metal parts.

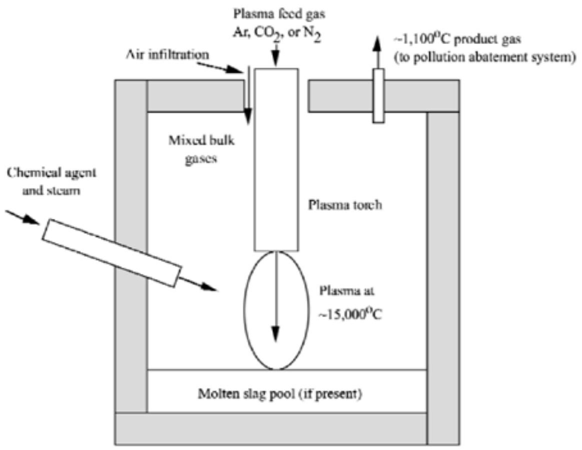

Figure 7.1: Schematic drawing of a plasma reactor.

3. Electro-Chemical Oxidation

The AEA Technology (AEA) SILVER II™ technology is based on the highly oxidizing nature of Ag2+ ions, which are generated by passing an electric current through a solution of silver nitrate in nitric acid in an electrochemical cell similar to those used in commercial electrochemical processes. The electrochemical reactions used in the SILVER II™ technology belong to a class of chemical processes collectively known as mediated electrochemical oxidation (MEO). MEO processes have been offered as an alternative to conventional incineration for destroying hazardous wastes. Because they are also relatively new in development and application, experience with these processes is limited.

The process can be used for the neutralization of primary explosives such as lead azide and lead styphnate.

4. Biodegradation

Biodegradation makes use of the ability of micro-organisms to consume ammunition related chemicals such as TNT and other explosives or propellant components. Biodegradation can be practiced like a chemical process in reactor type equipment.

Figure 7.2: Biodegradation equipment

Because of the slow reaction rates, large storage facilities will be necessary; therefore it might be better to use the technology of land farming. A lot of micro-organisms that can convert chemicals are already present in the soil. The land farming will create the optimal conditions in the soil for the micro-organisms in order to convert the organic energetic compounds:

- Percentage of oxygen;
- pH of the soil;
- Percentage of water in soil;
- Extra nutrition for micro-organisms.

The reactor type is better suited for the treatment of explosive waste in large concentrations, whereas the land farming can be used for the in situ remediation of contaminated military sites (with low concentrations of energetic materials). Biodegradation is not recommended for the treatment of propellant (waste) containing heavy metals (as additives for gun barrel erosion or burning rate inhibitor).

VIII. Discussion

A large number of different technologies are in use for the destruction of ammunition. In order to be able to evaluate the best practice methods some criteria can be mentioned as a guideline.

1. *The applied technology should lead to the irreversible destruction of the ammunition and its containing explosives, propellants and pyrotechnics.*
2. *The applied technology should be environmentally benign and be safe for personnel to implement. The principles of complete environmental system analysis should be applied.*
3. *The applied technology should be economically sound, with minimum energy requirements needed for destruction, leaving minimum of waste behind.*
4. *The applied combination of technologies should be suitable to destroy most ammunition types.*
5. *Sometimes the applied technology should render the ammunition safe at the location where the ammunition encountered. This holds for ammunition that is not safe to transport.*

The choice of the most suitable technology for the demilitarization of ammunition will strongly depend on the local situation. In general practice it will be not one technology but a combination of technologies. Therefore a list is given with the most frequently used demilitarization technologies and the conditions of application.

Technology	Technology Conditions of application
Open detonation	No other technology available or not financially viable Transport not possible High security risk with ammunition in area Large and medium calibre ammunition
Open burning	No other technology available or not financially viable Preferably limited amounts of explosives
Rotary kiln	Large amounts of small and medium calibre ammunition After down-sizing may be suitable for large calibre ammunition
Fluidized bed	Large amounts of bulk explosives and propellants Energy recovery possible Combination with CBF
Car Bottom Furnace (CBF)	Small amounts of igniters, detonators, fuzes, pyrotechnics
Hot gas Decontamination	Large amounts of contaminated metal scrap
Detonation Chamber	Limited amounts of ammunition
Downsizing technologies	Used in combination with reuse options As pre treatment for other technologies
Separation technologies	Recycle and reuse
Experimental conversion technologies	Specific applications for hazardous materials to prevent formation of highly toxic substances and protection of the environment

In practice the demilitarization of ammunition will always be a combination of the above listed technologies. The technologies have to be available at the local situation. More important is the availability of qualified personal.

If a large amount of ammunition has to be handled, it will be cost effective to build a fixed facility. If the amounts of ammunition are moderate it will be advisable to use a mobile facility. A promising issue can be the local transformation of ammunition into class 4.1 waste. This can be realized by the separation of the explosives from the metal parts and the subsequent mixing of the explosives with water and additives [10]. This conversion, however requires sophisticated technologies, access to Hazardous Waste Disposal facilities – including HW from EWI etc.

For special application the use of experimental technologies can be recommended. This is the case when by using conventional incineration technologies highly toxic chemicals could by produced like dioxins.

IX. Conclusions

Best practice methods can mitigate the risks of ammunition demilitarization with a minimum of costs and environmental impact. The applicability of the individual techniques strongly depends on the local situation and the economy of scale.

When explosives cannot be recycled, they have to be destroyed. A promising technology will be the transformation of the explosives in 4.1 waste products. This can be achieved by mixing the energetic material with water and additives, the resulting class 4.1 wastes can be safely incinerated in commercial installations elsewhere.

A limited number of components in ammunition should be handled by specific methods as described in Chapter 6. This holds especially for chemical warfare agents and smoke compositions containing hexachloroethane or white phosphorus. These types of ammunition should be treated separately with additional safety measures.

X. List of abbreviations

CN	Chlooracetofenon
CS	O-chloorbenzilydeenmalonitril
CW	Chemical Weapon
DBP	Di Butyl Phtalate
DNT	Di NitroToluene
DPA	Di Phenyl Amine
NG	Nitro-glycerine
OB	Open Burning
OD	Open Detonation
RDX	Hexogene (Research Department X)
SCWO	Super Critical Water Oxidation
TNT	2,4,6-Tri NitroToluene
UXO	UneXploded Ordnance

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