Green manufacturing of munitions

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Sammanfattning

Handboken är avsedd att användas av inköpare, designers och försvarsmakter för att bättre förstå hur tillverkning av mer miljövänlig ammunition kan ske. När ammunitions utformas på detta sätt uppkommer flera fördelar. När en handbok som denna används är syftet att förbättra kontrollen av produkterna och på så sätt minska de totala kostnaderna, miljöpåverkan och andra problem.

Syftet med handboken är att ge en komplett bild, en systemvy av hur ammunition kan tillverkas på ett mer miljömässigt anpassat sätt. Därför diskuteras i denna handbok olika frågor, som till exempel konstruktion och val av material, målet att ändra förhållningssätt eller åtminstone öka medvetenheten om hur miljöanpassad ammunition kan designas.

Nyckelord: Miljö, Grön Design, Ammunition, Grön ammunition, Livscykel tänkande

Summary

This manual is aimed to be used by procurers, designers and armed forces in order to better understand how to manufacture munitions that are better for the environment. As can be seen when designing munitions in this way there are several benefits for different stakeholders. When you use a manual like this the general idea is to enhance the control of the products and in that way reduce the overall costs, environmental impact and other issues.

The purpose of the manual is to provide a complete view, simply a system view of how ammunitions can be manufactured in a more environmentally adapted way. Therefore this manual discusses topics, for example construction issues and choice of materials, aimed at changing the ideas, or at least raise the awareness, of how to design environmental adapted munitions.

Keywords: Environment, Green Design, Munitions, Green Munitions , Life cycle thinking

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1 Background

All armed forces possess and use large quantities of munitions. The manufacture, use and disposal of these munitions make a contribution to the overall environmental impact. Handling of munitions with energetic materials requires great care and considerable cost. The environmental impact of the processes must be acceptable to an increasingly critical general population to avoid anti-military backlash. It is also a considerable amount of funds that is used to clean up and restore areas where military activities have polluted the ground or water. Past practices such as dumping at sea or land-fill sites are no longer generally acceptable. There is a need to know and minimise the environmental impact from munitions in order to handle and manage our land properly.

Governments have a duty of care to the members of their armed forces and all reasonable precautions must be exercised to ensure safe use of munitions. For example, some weapons system spread over 70 % of their propellant into the environment around the shooting range. This is a health risk with the hazard of fires after prolonged use of the shooting range and a work environment hazard. It is also an environmental and health hazard due to the propellant's environmental impact based on the final combustion products, for example solid particles.

The design of new weapons must include disposal procedures and an environmental impact statement. The understanding of munitions' disposal is lagging behind its´ design requirement. It is important to fully understand the environmental issues so that they not constraint the design of weapons.

FOI has had research projects on Life cycle assessment and disposal of munitions. FOI is also engaged in the international community discussing these things. FOI has thus learned a great deal and this report is a way of sharing the information with the general community committed to these issues such as munitions designers etc.

2 How to use the manual

This manual is aimed to be used by procurers, designers and armed forces in order to better understand how to manufacture munitions that are better for the environment. As can be seen when designing munitions in this way there are several benefits for different stakeholders. When you use a manual like this the general idea is to enhance the control of the products and in that way reduce the overall costs, environmental impact and other issues.

The purpose of the manual is to provide a complete view, simply a system view of how ammunitions can be manufactured in a more environmentally adapted way. Therefore this manual discusses topics, for example construction issues and choice of materials, aimed at changing the ideas, or at least raise the awareness, of how to design munitions.

For designers the manual can be a useful guide to life cycle thinking and to understand the environmental aspects of the material and design choices that are about to be made.

From a buyer's perspective, the manual gives an indication of what to consider when procuring, and particularly in the case of the changes or design of new munitions. In the appendix there is an example of a process flow derived from discussions with FMV of how to use this in procurement. And from a user perspective the manual can be a great way to gather the knowledge acquired through research over the years and to use as a support when making decisions on matters relating to munitions.

3 Life cycle thinking

At a first glance life cycle thinking applied to a product like munitions can appear as nonsense. However, if we think that most of the munitions are not used in war scenarios but either used in training or disposed, then life cycle thinking begins to make sense. Beyond the questions related to the production of munitions, life cycle thinking should also consider the use phase and the disposal of munitions. This is of course difficult but by no means impossible. Often it is most difficult in the beginning but when you have started the process you will see that a lot of benefits can be achieved from using a life cycle perspective, such as lower manufacturing cost etc. What you actually get is a larger understanding and control of your product.

When looking at the environmental impact of the whole life of munitions, the overwhelming largest part of the impact comes from the manufacturing process. Apart from the manufacturing phase the end of life is the second most environmental important phase. In most cases the end of life has only a small environmental impact due to diligent handling of the end of life. Beside these two stages the storage and transportation phases need to be considered even though their contributions are small in this context.

When looking at the manufacturing process we see a very conservative thinking, which mostly wants to continue to produce munitions in a traditional way. Designs of many kinds of munitions have in fact not changed in a very long time and the mindset is not to change that which works. In essences there is nothing wrong with this but it is time to start to think about certain decisions we have made in the past and thus perhaps change the design of munitions. Questions to think about could be why one uses aluminium instead of steel or just why we use brass cases. Most of the manufacturing of munitions today is based on choices made in a world that had different priorities than the world has today.

A good example of older priorities is the Area Denial Artillery Munitions Mines (ADAM mines). This mine contains an extremely small amount of Depleted Uranium (DU) but is still not categorized as “DU ammunitions”. The resin which forms the body of the mine wedge contains a small amount of DU in the “hardener” portion of the resin. The DU is less than 0.15% (0.68 gram) of the total resin and is present only as a chemical agent that allows the resin to cure at less than 70°C in less than 12 hours. These cure characteristics are required to efficiently produce the mine and to protect the electronic components during manufacture. The solution to use this DU resin was the right decision at the time. The trouble today is to perform the demilitarisation of these items due to the content of DU. This has cost the government in the US several millions of dollars in research of new methods of demilitarisation.

To avoid a situation like the one with the ADAM mines you need a life cycle perspective and think about the end of life phase already in the design phase.

We need to think about where the materials we use comes from, are they abundant, do they demand a large amount of energy etc. Other relevant questions are how the materials are produced, how they are used in the munitions, how the munitions are going to be used and the end of life phase.

Choices of materials and designs in the beginning can have very large impacts in later stages. The design of the munitions is crucial for how well and safely it can be disassembled. Disassembly is critical for the recycling, recovery and reuse of the different constituent material.

Another issue that also needs to be addressed in the life cycle perspective is that munitions should not cause any environmental problems after use. This applies both in terms of safety, considering the problem of locating unexploded ordnance (UXO), as well as from an environmental toxicology standpoint.

4 Environmental aspects of munitions design

All these considerations mentioned in the previous chapter are important and should be carefully taken into account during the design of the specific munitions in a life cycle perspective. Nevertheless, these principles can be discussed in case of the practical application for an ordinary type of munitions when considering the environmental aspects as follows (9):

a. Toxicology level of the munitions components need to be examined and dangerous ones should be eliminated or reduced in quantity as much as possible. However this is not an easy task, the fact is that, a substantial number of the munitions components are toxic, and replacements of most of the components do not exist. The number of poisonous components should be reduced in time by advances in science and technology.

   Today, most of the materials used in munitions can be reused, recycled or destroyed at the end of munitions' life. These processes should be performed in a way that the impact on health and environment should be minimised. This brings a responsibility for the munitions design team to learn material toxicology and disposal technologies to reduce the impact. Since the design team consist of many experts from different engineering disciplines, it would be too optimistic to expect all these engineers to have enough knowledge about toxicology, demilitarisation and disposal in many cases.

b. At the end of the service life the munitions should be in a condition that munitions is not affected by aging in a way that demilitarisation and disposal are still possible by ordinary methods. Design engineers face problems especially with highly corrosive chemical munitions ingredients. Limitation of the use of these corrosive substances can reduce the disposal problems of related munitions.

c. Reducing the size of the stocks during training is an easy and very inexpensive way of disposing munitions. The performance of munitions can be at an unacceptable level at the end of its service life, but it can still be operable. This kind of munitions is quite desirable. On the other hand, the meaning of the word "operable" consists of other meanings such as, "safe to use" and "reliable in operation" which are difficult tasks for the design engineers to achieve with an aged munitions.

d. The design engineers should be capable of designing the munitions for safe disassembly and ease of useful material recovery as well as ease of component and package re-use or re-cycling.

e. In addition, design engineers should be capable to maximize service life. An advance in technology to extend service-life of agreeable material is also necessary. The tools for maximizing the service-life are limited. However, it is easier to design the munitions in such a way that aged components can be replaced with the new ones to extent the service-life period. Modularity and reparability features of the munitions increase the service life.

f. Reuse of the munitions components or parts for other alternative munitions applications with limited remanufacturing is another possibility, and this option should be considered during design phase.

An example of a practical dilemma regarding the design where the area of use may be in conflict with environmental concerns is described by M.R.Walsh et. Al (4) when looking at the residues in deposits from firing of AT4 rockets.

According to M.R. Walsh weapon systems with longer barrels, riffled barrels, or larger propellant loads generally have a lower percentage of their propellant deposited as residues. This is likely due to the higher temperatures and pressures generated in these types of armaments. By contrast, a recoilless design such as the shoulder-fired rockets has a short, non-riffled, open-ended design, meaning pressures and temperatures can only build up within the rocket motor, which means that a larger amount of propellant is deposited as residues. The propellant is obviously burning much more efficiently in long riffled barrels than propellant used in short, non-riffled barrels. (4) Long, riffled barrels are from an environmental point of view the best alternative but maybe not always the most practical option.

5 Construction for greenness

Based on the situation today, three driving forces can be identified which motivate the need of taking life cycle aspects into account concerning new munitions, both regarding design in general and design for disposal.
These are: (1)

- Environmental laws
- Economy
- Sustainable development

The public and the procurer are sensitive about environment, safety and health hazard issues, which force the engineers to obey the basic principles of the design for disposal concept. Since these are general "principles", not rules, the greenness of munitions is case dependent. However, it is a must to have principles rather than rules, because each different munitions development project has its own nature and the rules cannot be applied in the same way.

The need for application of design for disposal principles during the munitions development phase to obtain greener construction is obvious. These principles are standardized in NATO by STANAG-4518. (3) These principles were grouped under the name of "Design Safety Principles":

a. Select materials that are not inherently toxic and can either be reused, recycled, destroyed with minimum impact on health and the environment at the end of munitions' life.
b. Select materials and design features that will minimize the adverse impact of credible service-life of environments and aging on demilitarization and disposal processes and by products.
c. Select materials and design features that allow old operable stocks to be consumed in training.
d. Configure munitions for safe disassembling and ease of useful material recovery.
e. Configure munitions for ease of component and package re-use or re-cycling.
f. Design munitions to maximize service life.
g. Design munitions to permit significant life extension modifications and, consequently, reduce the need for demilitarisation and disposal.
h. Design for ease of alternative munitions applications with limited remanufacturing.

In addition to safety principles given by STANAG-4518, there are some more considerations that can be taken into account by the design engineers:

a. The low cost of the demilitarisation and disposal.
b. Ease of disassembly.
c. Use of available disposal facilities and technologies.
d. Increasing the reliability level of the fuses and initiation systems.

STANAG-4518 also gives information about demilitarisation and disposal process and disposal assessment process to be followed. The STANAG-4518 recommends the agreed countries to prepare a demilitarisation and disposal plan in the munitions development program which includes all necessary information related with demilitarisation and disposal of the munitions under development.

5.1 Recommendations for Practical Design Improvements of Munitions

In the demilitarisation and disposal facilities, many different problems can be faced for demilitarisation and disposal of any munitions. However, the main concern arises from mechanical disassembly of munitions which may need expensive tooling and excessive labour force. These are:

a. Easy dismantling and easy access constituents are necessary.
b. Removal of explosives and propellants should be easy; i.e. melted explosives easily be taken out or energetics have enough access for easy washout.
c. Good documentation of the munitions such as Demilitarization and Disposal Plan if available, technical drawings, description of parts etc. are beneficial.

Robust design is a primary aim for the munitions design team. During the development phase, the designer should avoid the followings:

a. Small holes, which prevent access to the propellant and explosives,
b. Screw lockers (glues, inconvenient set-screws etc...).
c. Glues for any adhesion purpose of parts.
d. Any preventers which make dismantling difficult.

Since munitions contain explosives and pyrotechnic constituents, the following items are important:

a. Use of hazardous chemical compounds in pyrotechnics should be limited.
b. Safe dismantling and easy access of pyrotechnic constituents are necessary.
c. Advanced methods (such as cryofracture) should not be required for disposal in order to prevent excessive disposal cost.
d. Today thermoset binders are widely used. There are technologies for recycle of such propellants and explosives, but these are expensive and not used by industry yet mostly. Thermoplastic binders should be preferred instead.

Suitability for R3 (Reuse, Recovery and Recycling), modularity, service life extension capability are the other valuable principles:

a. Design of munitions should be modular to allow service life extension modifications.
b. Design possibly allows reuse of munitions with modifications.
c. The selected materials allow service life time of munitions as long as possible.
d. Materials (including energetics) suitable for R3 (Reuse, Recovery and Recycling) should be selected during the design phase. The impact on environment, safety and health hazards should be a minimum.
e. Design should allow easy and safe disassembly and easy material recovery.
f. Maximum material recycling should be aimed.
g. Variations in munitions components by design updates should be limited.

The design engineers should also concentrate on the important phenomena: the influence of manufacturing on public health and environment in design stage. For example, a component can be environmentally friendly but its manufacturing process can be dirty such as TNT explosive. Manufacturing processes of each component should be carefully examined and potential risks should be eliminated or reduced.

The necessary care should be given for testing. During development phase some explosive or propellant residue may appear after the tests. Low detonation of the test specimen or the need of blow in place can be some of the many reasons. The test area should be carefully chosen to minimize environmental and public risks. Some precautions can be applied for a better test area. Also some additional equipment can be employed, such as bullet catchers, in order to prevent contamination of soil and underground water with lead and antimony. Not only for development phase but also after the development of the munitions the same care should continue.

New weapons must have an integrated flexibility which enhances disassembling and exchanging parts of the weapon. It also has to be easy to remove parts and destruct these. (2)

What also needs to be considered during the design phase is the possible UXO-rate and how to find possible unexploded munitions because of its effect on the environment. The munitions should be easy to find once it has been fired away. It is also important to be able to find again unexploded ordnance in international operations. It is also important to continue research in the munitions that destroy themselves after a certain time. Indestructible marking/labelling of the ammunitions is important. (2)

UXO in a firing range is a growing area of concern especially in cases where firing ranges are to be released for other socially beneficial purposes.

UXO may lie at different depths in the soil but it is not certain that UXO forever will remain at their original depth due to frost heave. This means that the UXO, which today lies beneath the surface in a number of years may have come up in the day.
Explosives from corroded, leaking or damaged UXO will affect the ground depending on the location of UXO. Within the shallow soil sections will mainly corrosion affect surrounding land sections. For deep UXO the corrosion is less significant. For more superficially placed UXO which also ends up in an acidic environment (low pH) under oxidizing conditions, the corrosion is of particular importance.
Corrosion of munitions will be affected by local conditions and possible damage to the projectile. The soil parameters that control the corrosion include:

a. Soil type
b. The water content
c. The pH of the soil
d. Concentration of oxygen
e. Microbial activity
f. The groundwater table

5.2 Life extension

Since the major environmental impact comes from making new items, it is a great benefit not to have to produce new items. There is much research looking into life time extension. The main purpose is to monitoring how the munitions are handled such as shock, heat, cold etc. to be able to predict the life time with better accuracy. By getting better accuracy of the prediction items can be in service longer then when the accuracy is low and you need to take items out of service due to safety reasons. This monitoring is today mostly focused on the nitro cellulose propellant since it has a tendency to self-ignite and thus cause a serious safety risk.

What is often missed is what parts in the munitions which limit their life. In some cases it can be small items such as igniters that set the life time of the whole munitions. In some cases it does no limit the life time because of safety but due to unpredictability. In general, if you get a high dud rate the munitions have to be taken out of service. Thus it is important to know which items that limit the life time and to design the munitions so that if there is small part that limits the whole item, it can be easily exchanged. This change can then save both the environment and money for the user.

Prolonged life span for munitions gives less new production (most valid for staple items/goods and not consumable items/goods). (6)

5.3 End of life and design for disposal

"Design for Demilitarisation and Disposal" or shortly "Design for Disposal" is a new concept, which should be applied for obtaining greener munitions from the beginning of design phase. "Design for Demil" or "DfD" are other names for the concept which can be found in literature. The concept leads to a methodology for applying the principles in reaching greener munitions objective.

Since the performance and the robust design is the main driving force for the design engineers, the need of demilitarisation of the munitions at the end of service life generally is not a design criterion. In fact, the procurer pays the overall cost, which is not only the cost of procurement but also the cost of demilitarisation and disposal. When the design engineers consider some simple criteria related to design for disposal concept during design phase, important cost savings can be possible for disposal of this munitions.

The question of demil should be considered early in the development of a new system in order to lessen the risk of the costs for demil exceeds the total costs for the system. (1+2)

6 Production/manufacturing

The manufacturing of munitions is a large part of the total environmental impact of munitions. Munitions have very specified manufacturing process due to a conservative standpoint from the manufactures. Munitions have been made in almost the same way for 100 years. This chapter will try to give specific guidelines to how a manufacturing process can be changed so that environmental considerations come into account in this phase as well.

6.1 Recycled and Virgin materials

As has been discussed it is important to use the right material, it is often from an environmental standpoint better to use recycled materials instead of virgin. Of course this depends much on the specifications, but there has been a long tradition in the manufacturing of munitions to use virgin materials instead of reused just to be on the safe side. Many national and other standards say that virgin materials have to be used in munitions, even though it should be the specification that decides which material to be used.

As for many chemicals, energetic materials is no exception, it is the specification of the substances that limits how it can be used. Virgin materials can be exactly the same as recycle materials. In some cases the recycled is actually better since you can take out by-products from the production when you recycle it. You also have the possibility to decide particle sizes etc. when recycling the materials. Here it is important to look at the material's specification itself and not focus on where it comes from.

The advantage of using recycled material in general and specially recycled metals is that the environmental impact for the production phase can be reduced quite extensive depending on the type of munitions. Yet another benefit is that recycled materials are often not as costly as the virgin alternative.

If the use of recycled materials is not possible for production of new munitions, at least, care should be taken to choose materials that, at the end of life of the munitions are easy to recycling for other applications.

6.2 Energy consumption

The energy usage in manufacturing of munitions involves the energy spent in the production of the raw materials, the energy spent in the transportation of the materials and the energy spent in the production of components and assembling.

As is well known metals and other materials uses very high amounts of energy when manufactured. It is here important to make the right decisions about which materials that are to be used in the munitions. Perhaps a part can be made of plastic instead of virgin aluminium? It is also important to look into the energy usage for each component in the munitions and decide the process and material used hence.

6.3 Scrap

As in all production, small or large amounts of residues or scrap are produced when producing munitions. It is necessary to look at the amount of residues produced and how much of this that can be reused or recycle for other applications. Depending on the shape of the starting material, the final shape and the shaping process used, the amount of scrap produced can vary quite a lot. It is known that a piece of aluminium when shaped, the final product can be 30 % of the initial material weight. This in itself is not an issue but the issue is if there could be another way of shaping the final product with less scrap formation. This could be done either by choosing another starting shape or material, changing the shaping process or editing the end shape. By minimising the amount of scrap or residues, the total environmental impact of the munitions can be reduced and a better economic performance of the munitions either as a lower price or higher profit could be obtained.

6.4 Choice of materials

Choosing materials can make a large difference in the environmental performance of the munitions. Munitions are typical heavy on metals. This is a necessity since many systems rely on shrapnel as the main damaging effect. There is a need to think carefully when choosing materials in the systems since it can have consequences for the environment both now and in the future. It is also wise to consider that many of these materials will be in systems that are going to be in use for a very long time (about 20-30 years). As we have seen from the past this time is enough to go from safe material to unsafe.

A common approach in 'green design' is to replace a potentially hazardous material or process by one that appears less problematic. This seemingly reasonable action can sometimes be undesirable, however, if it results in the rapid depletion of a potentially scarce resource or increased extraction of other environmentally problematic materials (7). There are some issues that should be considered when choosing materials:

a. The resource scarcity issue

As we move towards an increasing consumption, production and need of energy, energy and environmental limitations to resource supply will become increasingly constraining.

b. The recycling issue

… once resources are placed into use there is a significant lag time before they are available for recycling. In a growing world economy using increasing amounts of resources, recycling can moderate the need for primary resources but cannot eliminate it.

c. The substitution issue

This argument is obviously valid in some cases (e.g., synthetic rubber). It is obviously invalid, however, for materials whose physical or chemical properties uniquely serve a need. A further concern is the time required for suitable substitutes to be developed and deployed.

Relying on substitution to solve resource shortage problems thus involves three assumptions:

a. that suitable substitutes can be developed;
b. that the substitutes themselves do not come with their own baggage of supply limitations, environmental harm, and high energy costs;
c. that the substitutes can be developed and deployed on the time scale needed.

6.4.1 Metals

As said above munitions constitute mainly of metals. This is of course dependent on the type of munitions. As one can see, munitions typical reliant on metals for their effects such as artillery shells have a high level of metals content. More advance munitions such as missile systems has a (relatively) lower amount of metals. The most usual metals are steel, aluminium, copper alloys, lead, tungsten and uranium.

There are several issues with metals in an environmental point of view. Some metals have properties that can damage the environment if they are left in or interact with the environment. If the metals, particularly the heavy metals, act as environmental pollutants are largely determined by the metal's own characteristics and the environment. One metal may exist in several more or less environmentally unfriendly forms. Some metals, such as copper, can be harmful to the natural nutrient turnover in forests but can in small amounts be a welcome addition to arable land. Another example is lead, which not in itself is that environmental unfriendly but in a wet environment it can degrade and become more hazardous.

From the production point of view the biggest issue related with the metals is the energy use in their process that is especially true for virgin aluminium.

Every single gram of virgin metals that can be replaced by recycled metals or by plastics is expected to reduce the environmental footprint of the munitions.

Beyond the energy consumption, the production process of some metals, like steel, has a non-despicable impact at an ecotoxicological level.

6.4.1.1 1 Steel

Steel, which is iron alloyed with carbon and with minor amounts of vanadium, silicon and manganese as alloys substances, is the most usual component in munitions. In fact it is the base for conventional munitions. Steel or iron in itself is not such a big concern but there is a considerable amount of energy needed to manufacture steel. So if it is possible, recycled steel should be used in the production. In the manufacturing of steel you often add other metals to get different qualities, such as better strength. Here it is important to be careful about which other metals or substances that are used. One example is chromium. The environmental hazard of chromium compounds depends primarily on the amount of chromium ion that is released. Most chromium compounds are classified as carcinogenic, mutagenic or toxic to reproduction and are environmentally hazardous, have long lasting effects and are allergenic.

6.4.1.2 Copper

Copper is also rather abundant in conventional munitions and is often used as a driving band. Copper is environmentally harmful as ions and the toxicity is controlled by the amount of free copper ions. As a designer/constructor it is important to be aware of copper's possible negative effects on soils, lakes and streams. The substance is also very toxic to microorganisms. For humans, excessive exposure to copper has negative effects on the eyes, lungs, kidneys, liver and digestive system.

6.4.1.3 Brass

Copper is the main ingredient and zinc is used as an alloying element. The environmental impact from brass is identical with the one from copper.

6.4.1.4 Aluminium

Aluminium is a very versatile metal; it is light and easily handled. It exists in many munitions and in many it can be a large part of the munitions.

Solid state aluminium has one very big issue, virgin aluminium is very energy demanding to manufacture. That's why it is so important to design the munitions so the aluminium can be recycled in an easy way. This means that different materials should not be mixed together if it is possible to avoid it. Aluminium is also very suitable for recycling since it keeps its´ quality after it has been melted.

6.4.1.5 Lead

Lead is a classic example of a heavy metal that can occur in a more or less harmful form. Lead can be both metallic lead, such as the one in munitions, and lead in organic form, such as the one that used to be mixed in gasoline. Metallic lead is relatively poorly soluble under normal conditions in nature. It is only at very low pH values when lead ions are released from the metal and are available in the environment.

Lead occurs in igniters in the form of lead compounds. Examples of lead compounds that may be present are lead tricinate, lead oxide and lead azide. The lead is vaporized in the igniter when detonated. The lead fumes follow, to some extent, the gunpowder gases from the barrel while some condense in the pipe or seep out the back when the gun is fired. The risk of exposure is dependent on the ventilation. Shooting indoors is known to result in elevated levels of lead in the blood, but the risk of exposure might be negligible at outdoors shooting.

Lead is a proven hazardous substance that gives chronic effects from exposure. Prolonged lead exposure can cause damage to the blood and blood production, kidneys, peripheral and central nervous system with effects on memory, reaction time and perception. The lead ion (lead acetate) is also classified as a suspected carcinogen.

Another issue with lead is its effect on animals, especially birds. Birds that live in wetlands, especially ducks, have for a long time been exposed to munitions, especially lead shot. This is mainly the reason why they have been poisoned, by having consumed lead shots in the belief that it was food.

6.4.1.6 Chromium

Chromium is used as an alloying element in steel. It is environmentally hazardous as an ion but is oxidized in nature to hardly soluble substances. It has both allergic and carcinogenic properties and is classified as environmentally hazardous.

6.4.1.7 Nickel

It is used as an alloying element in steel. Nickel can cause allergic reactions in the skin and is carcinogen in the respiratory tract. Nickel is also classified as environmental hazardous.

6.4.1.8 Tungsten

Tungsten carbide is the most common component of hard metal. It is known or suspected carcinogen in certain alloys.

6.4.2 Plastic

There are quite a few plastics in munitions, everything from rubbers to hard plastic casing.

6.4.3 Energetic material

Energetic materials are believed to be the most environmental hazardous materials in munitions. So, when manufacturing munitions it is important to know what you add in your munitions for several reasons. The two issues that should be considered due to environmental reasons are the end products and the manufacturing process.

Besides these two issues one also need to consider the expected life time of the munitions. The importance of the time of life is related with duration of the life cycle of munitions. As short as this duration will be as bigger the environmental impacts will be. It may be a good idea to have a, from a production point of view, not so environmental friendly energetic material if it has a life duration twice the one of an environmentally friendlier one.

The manufacturing of energetic material is often a complicated chemical process. Each energetic material has its unique manufacturing process. The process can be very different between different energetic materials. Here it is important to see the big picture and look at what kind of residues and the amount of waste products that are generated per unit of substance.

For example earlier stages of ADN production processes produced more waste materials than ADN and this by a very large factor. ADN was produced in kg scale and the waste was produced in tonnage scale. This has changed with newer production processes.

Another issue with energetic materials is where they are produced and the kind of waste treatment systems used. It is for example known that the production of TNT without proper waste treatment has a very large impact on the environment. The red water from this production is highly toxic both for animals and plants. With the right waste treatment this impact can be significant reduced.

In most countries with a developed environmental protection system this is mandatory. In some countries with less developed environmental protections systems this is seen as an unimportant extra cost and thus not done. So it is important not only to consider how a part or subpart is produced but also where.

6.4.3.1 TriNitroToluene (TNT)

6.4.3.1.1 Production

The production of TNT is not complicated but the liquid waste generated from the production is very hazardous. The so called red water that is generated from the production is highly toxic. The toxicity of red water can be reduced with treatment to pink water that can be handled in standard waste treatment facilities.

6.4.3.1.2 Eco toxicology

TNT (trinitrotoluene) is readily absorbed through the skin but the poisoning can also occur if swallowed or inhaled. TNT's toxic effects at high levels include damage to the kidney, liver and spleen with effects including jaundice and anaemia (anaemia caused when the red blood cells are destroyed).

TNT has low solubility in water and TNT and its degradation products, which are also suspected to be toxic, binds readily to the particulates in soil and sediment. Transport by water of TNT will therefore most likely occur with particles rather than the solute in the water column. In a water and sediment systems TNT are converted, and its transformation products are adsorbed quickly and bind tightly to sediment particles. This means that the risk of spreading and the biological effects of TNT from the sediment into the environment are low.

TNT can affect basic land and water operations, for example parts of the nitrogen and carbon cycles can be affected. In the case of the nitrogen cycle, it is primarily the denitrification that may be damaged as the enzymes involved are sensitive to TNT. Denitrification is a microbiological process in which bacteria can utilize the oxygen in nitrate (NO3) to break down organic matter in an anaerobic environment, with the result that the nitrate is converted into nitrogen (N 2) and finally returned to the atmosphere. Usually, this reaction occurs in wetlands, lake sediments or waterlogged fields, and this is the sea's most important process to get rid of excess nitrogen.

6.4.3.1.3 Recycle/reuse

TNT in itself is fairly easy to recycle since TNT melts at 80°C. It is then easy to let it dry and make new TNT of it. The problem with recycling is that TNT seldom is in pure form in munitions. TNT is often mixed with RDX and HMX to form explosives with better characteristics. Depending on the material mixed into TNT, the recyclability can change significantly.

6.4.3.2 RDX (hexogen)

6.4.3.2.1 Production

RDX is produced through several different methods. The primary method of production is through the nitrolysis of hexamine with nitric acid. Most of the RDX production process is environmental benign and with standard waste treatment should not be an environmental issue.

RDX is very seldom used in pure form but is mixed with binder and plasticisers to get a more useful form.

6.4.3.2.2 Eco toxicology

RDX has low solubility in water and is converted relatively rapidly by microorganisms under anaerobic conditions.

RDX is adsorbed weakly to the particles in the soil, why this substance for the most part probably is transported dissolved in the water masses and can very easy follow with infiltrating rainwater and pollute the groundwater. It binds better to clay and other minerals. RDX is also mobile in terrestrial plants and is concentrated mainly in leaf and flower tissue. It is likely that it blocks photosystem 2 in photosynthesis, which can cause symptoms such as chlorosis (lack of ability to produce chlorophyll, which gives "white plants") and necrosis (cell death that gives bright spots on the plants).

6.4.3.2.3 Recycle/reuse

RDX is as mentioned above very seldom in pure form as thus the recyclability of RDX is dependent on the other substances then the RDX. If RDX can be removed from the munitions and released from the binder there is no problem reusing it as such.

6.4.3.3 Nitroglycerin

6.4.3.3.1 Production

Nitroglycerin is made from glycerine and a mixture of concentrated nitric and sulphuric acid. Most of the RDX production process is environmental benign and with standard waste treatment should not be an environmental issue.

Nitroglycerin is almost never used in pure form due to the sensitivity; it is mixed with binder and plasticisers.

6.4.3.3.2 Eco toxicology

Nitroglycerin is toxic to aquatic organisms. It binds strongly to organic matter in the soil which gives it low mobility in soil. Water flows in the ground is not believed to bring it into groundwater.

6.4.3.3.3 Recycle/reuse

Nitroglycerin is only used in small amounts in mixtures with other substances. It is generally not recycled or reused in itself but can in mixtures be part of recycling of the whole material.

6.4.4 Electronics

In modern munitions electronic components get more and more advanced. Today munitions have to be able to strike over long distances with a very high precision. This places a very high demand on the electronic situation. The development in this field has gone much faster on the civilian side and the environmental legislation has changed the electronics market away from what in military terms are seen as robust. This means that military electronics often is not environmental compliant to the civilian laws and regulations. It is very uncertain if this is the way it has to be and perhaps just a conservative point of view of producing munitions. It has to be known for the designers that in the future it might not be possible to obtain that kind of electronics, in which case the civilian market is the only alternative. To look at the civilian alternative from the beginning could then be a very wise move.

6.5 Packaging

Packaging for ammunitions is also important from both an environmental and a safety point of view. It should not contain any hazardous substances and should not be unnecessarily bulky. It is important that the cargo compartment of a truck is used optimally since earlier performed life cycle assessments have showed that transport is an important part when it comes to the environmental impact. The packaging must also be resistant and must not give rise to dangerous splinters in the event of a detonation. (2)

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8 Appendix A

8.1 A procurement model

After discussions with FMV it was decided to try and produce a model that could be used in procurement. It is just an example and the detailed description of each aspect has to be worked out further. The model focuses on two areas, the amount of munitions procured and the environmental impact of these munitions.

8.1.1 Criteria document

The FMV has a criteria document for several different types of materials/products that they typical procure. The document gives the procurer a guide on which demands has to be set in the procurement. That could be information of materials, statements on not included substances etc. This is the first stage of our process.

8.1.2 Amount of munitions

The Amount of munitions procured can be either large or small. To determine if the amounts are small or large you can use a table such as Table 1. In that table each munitions type has a value, if the amount procured is higher than the value the amount is large and if it is lower than it is small. As is easily to understand the value has to be considered in great detail to make the right assumption. Table 1 is only an example and should not be used in an actual procurement.

Table 1, Types of munitions and amounts

Type	Amount
Small calibre < 12 mm	1 000 000
Medium Calibre 12mm >< 30 mm	200 000
Large Calibre 30 mm >< 130 mm	100 000
Very large Calibre > 130 mm	50 000
Pyrotechnic munitions	10 000
Torpedoes	2 000

8.1.3 Environmental impact

The last stage is to evaluate the environmental impact. This is done with a criteria based on the materials in the munitions. As in the amount above we have an example in TB 2 of criteria's for a large environmental impact. If any of these statements are true then the impact is large. Table 2 is only an example and should not be used in an actual procurement. It is important to gives these statements considerations before they are set.

Table 2, Statements for large environmental impact.

Statement
> 80 % of total munitions weight is energetic material
> 75 of total munitions weight is metals
> 25 % of munitions weight is pyrotechnic material
> 40 % of total weight is packaging and packing material is predominant metal
> 25 % of munitions weight is electronics
< 50 % of munitions weight is recyclable

8.1.4 Results

From these two evaluations you can get four possible outcomes from low-low to high-high dependent on the results you can follow different routes when preparing for procurement. If a procurement is believed to have minor or small environmental impact or if only a very small amount is procured it is not fitting to have large environmental demands. It has been decided to follow three routes as can be seen below. The following are suggested areas of consideration from each route.

8.1.4.1 Low-Low

The following things should be considered when the munitions are a Low-Low.

1. Recyclability

   How much of the munitions can be recycled and how difficult will it be?

2. Release to the environment from use

   What are the expected substances that are released to the environment both from normal use and accidents such as UXO?

8.1.4.2 High-Low or Low-High

In additions to the ones considered when the outcome is Low- Low the following things should also be considered when the munitions are High-Low or Low-High

1. Lifetime extensions possibilities

   What is limiting the munitions life? Is it possible to extend its life and how is such a life time extension done.

2. End of life

How will the munitions be demilitarised and what kinds of waste products will there be?

3. Energetic materials

   What kind of energetic materials are in the munitions, which of these are deemed environmental problematic. Are there possibilities to exchange problematic energetic materials either now or after procurement?

4. Energy consumption in manufacturing

   How much energy is used to produce the munitions?

8.1.4.3 High-High

When procurement is stated as High-High it probably will have a clear environmental impact. The following should also be considered when the munitions are High-High.

1. Manufacturing process

   How is the munitions manufactured, how is it optimised?

2. Metallic materials

   Which metallic materials is used in the munitions, is it possible to change materials to more environmental benign materials?

3. Plastic materials

   Which plastic materials is used in the munitions, is it possible to change materials to more environmental benign materials?

4. Electronics

   What kind of electronics are there in the munitions, is it possible to change it to something more environmental benign?

5. The amount and type of packing materials

   How is the munitions packed, how do we handle the packing materials after use?

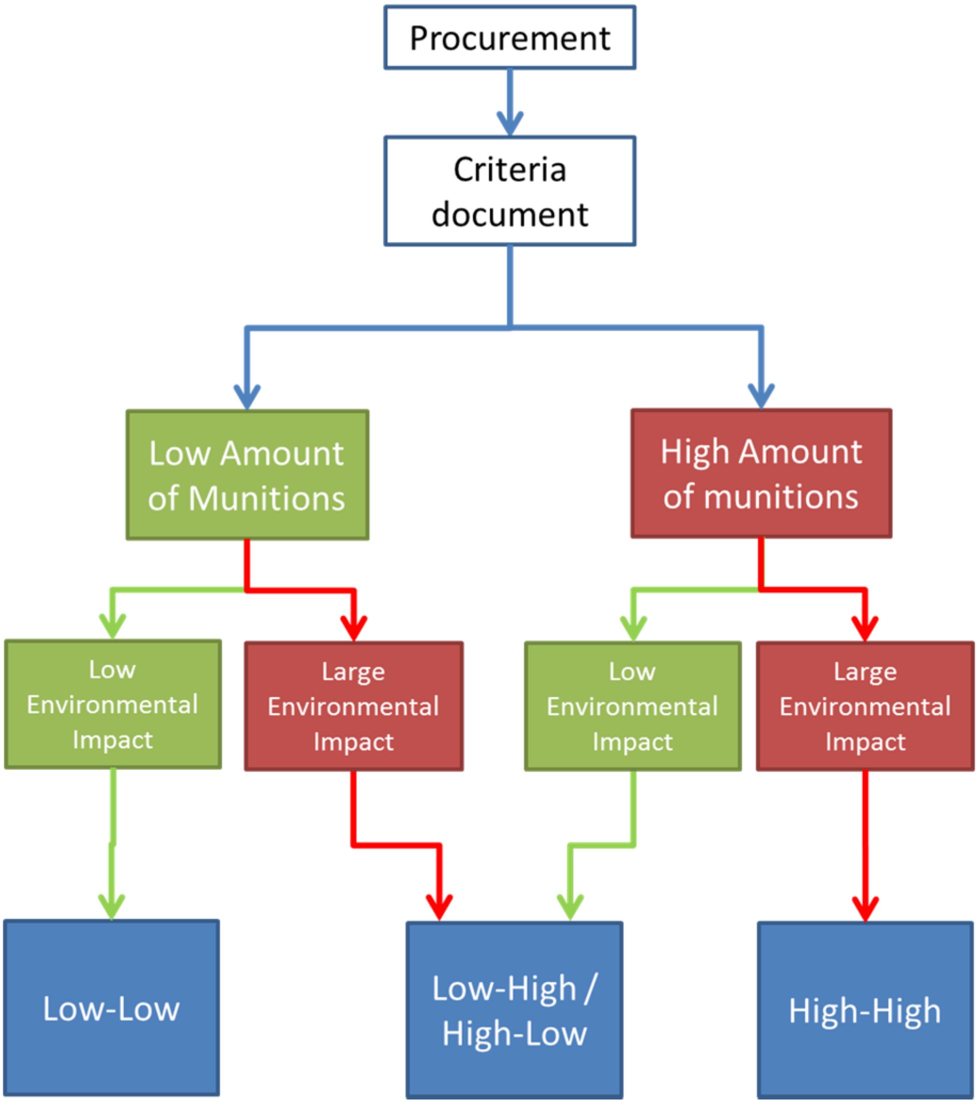

Figure 1, Suggested process for a procurement.