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Reducing impacts from ammunitions: A comparative life-cycle assessment of four types of 9 mm ammunitions

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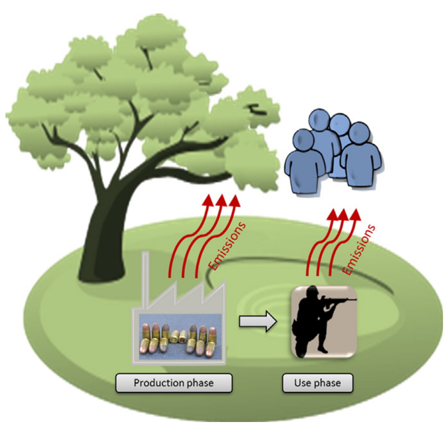
HIGHLIGHTS

- Assessment of benefits from lead replacement in small calibre ammunition
- Environmental and toxicological impacts assessed in a life-cycle perspective
- Production contributes to high environmental impacts, with lower influence by lead.
- Lead replacement in primer and projectile decreases toxicity impact (use phase).
- Lead free projectile show some concerns due to high ecotoxicity impacts.

GRAPHICAL ABSTRACT



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ABSTRACT

Increase of environmental awareness of the population has pressured research activities in the defence area to cover environment and toxicity issues, where have been considered appropriate manners to reduce the environmental and toxicological impacts of ammunition. One of the adopted approaches to achieve such goal involves the replacement of lead and other heavy metals by alternative materials. However, the consequences of using alternative materials in ammunitions manufacturing are uncertain for the other life-cycle phases and trade-offs can occur. The present paper describes the potential benefits from the replacement of lead in the primer and in the projectile of a 9 mm calibre ammunition. For that purpose, it is assessed and compared the environmental and toxicological impacts associated with the life-cycle of four ammunitions: combination of two types of projectiles (steel jacket and lead core; copper and nylon composite) with two types of primers (lead primer; non-lead primer). In addition, some potential improvements for the environmental performance of small calibre ammunition are also presented. To assess the impacts two Life-Cycle Impact Assessment methods are applied: CML for six environmental categories and USEtox to three toxicity categories. Results showed that the conclusion drawn for environmental and toxicological impact categories are distinct. In fact, ammunition production phase presents higher impacts for the environmental categories, whilst the operation phase has a higher impact to the toxicity categories. The substitution of lead in the primer and in the projectile provides a suitable alternative from a

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toxicology perspective; however, the composite projectile still presents some environmental concerns. The conclusions drawn are important for the procurement (and design) of environmental responsible ammunitions, in order to avoid (or decrease) the impacts for their manufacture and the effects on human health (e.g. shooters) and ecosystems near shooting ranges or hunting areas.

1. Introduction

Defence related activities and products, such as artillery training in shooting ranges and ammunitions, have been out of the environmental and toxicological concerns of populations and authorities. However, since the beginning of the century the situation has changed and environmental and toxicological issues of those activities are now covered (Hochschorner, 2004; Hochschorner et al., 2006; Alvebro et al., 2009; Ferreira et al., 2013; Ferreira et al., 2015). Research for military activities is now focusing on emissions associated to ammunition used on shooting ranges and the subsequent level of contamination; development of methods to manage and remediate that contamination; and the improvement of processes to mitigate the impacts associated with disposal activities (Certini et al., 2013; Duijm and Markert, 2002). Moreover, REACH regulation is also putting some pressure in research laboratories and companies, due to toxicity limits imposed for production and import of some raw materials that are used in ammunitions.

All life-cycle of military products are covered by the research activities mentions above, although efforts to reduce the environmental and toxicological impacts of those products are not carried out in a life-cycle perspective. For instance, emissions of heavy metals (such as lead, antimony, copper, nickel and zinc) during the use of small calibre ammunitions in military training and hunting have been identified as a major problem from an environmental and toxicological point of view (Ackermann et al., 2009; Tsuji et al., 2008). In fact, small calibre shooting ranges can contain concentrations of lead ranging from 7.3 mg/kg up to 54,000 mg/kg, depending on different soil and weather conditions (Hardison et al., 2004; Cao et al., 2003; Manninen and Tanskanen, 1993), that can be poisoning to birds due to unintentional consumption of lead particles or animals that are contaminated with fragments of lead bullets (Helander et al., 2009; Green and Pain, 2012; Fisher et al., 2006). The poisoning of wild game birds with lead and other heavy metals also presents a potential risk for human health due to consumption of meat contaminated (Green and Pain, 2012). Moreover, the direct inhalation of heavy metals and combustion residues by shooters is also a reason for serious concern (Bonanno et al., 2002).

The impacts related to the operation phase motivated the Armed Forces and research laboratories to search for heavy metals free (or reduced) alternatives to conventional ammunitions, with similar function but lower environmental impact (AVT-179, 2014). However, as mentioned before, the consequence of using alternative ammunitions, with expected lower impact associated with the emissions, are unknown for the production phase. In addition, the relative relevance to the total environmental and toxicological impact associated with production and operation phase of small calibre ammunitions is also uncertain. Therefore, the main goal of this article is to assess and compare the environmental and toxicological impacts associated with the life-cycle of four types of 9 mm ammunitions. The four types are combinations of two different projectiles (steel jacket and lead core; copper and nylon composite) and two types of primers (lead primer; non-lead primer). It is also an objective of this research to identify opportunities to improve the environmental performance of ammunitions. Environmental and toxicological impacts are calculated by employing two complementary Life-Cycle Impact Assessment (LCIA) methods: CML to assess six environmental impact categories and USEtox for three toxicity categories.

2. Material and methods

2.1. System description and functional unit

A life-cycle model is developed for the production and operation phase of four types of 9 mm ammunitions based on primary data from the Romanian company U.M. Sadu – Gorj S.A. (production phase) and from Rotariu et al. (2015) (operation phase). The data is representative for similar small calibre ammunition production in developed countries. Fig. 1 shows the life-cycle model of the production and use of small calibre ammunitions, including the recovery of the ammunition cartridge after firing. Direct emissions associated with the production phase, transport between different life-cycle phases and metal leaching associated with the projectile after firing is not included in the model. A 9 mm small calibre ammunition is defined as a functional unit.

2.2. Life-Cycle Inventory

A detailed Life-Cycle Inventory (LCI) for the production phase is implemented based on primary data collected from the Romanian company U.M. Sadu – Gorj S.A. A short description of the four types of 9 mm ammunitions follows:

#1) FMJ-TNRPb - ammunition with a steel jacket and lead core bullet (projectile) and a lead primer (TNR-Pb - lead trinitroresorcinate);

#2) FMJ-DDNP - ammunition with a steel jacket and lead core bullet (projectile) and a non-lead primer (DDNP – diazodinitrophenol);

#3) Frang-TNRPb - ammunition with copper and nylon composite bullet (projectile) and a lead primer (TNR-Pb - lead trinitroresorcinate);

#4) Frang-DDNP - ammunition with copper and nylon composite bullet (projectile) and a non-lead primer (DDNP – diazodinitrophenol).

Table 1 shows the materials and components used in the production of the mentioned 9 mm ammunitions. Table 2 presents the energy and water requirement for the manufacture and assembling of the ammunitions, which is similar for the four types.

Assessment of the emissions associated with ammunition firing is performed following Rotariu et al. (2015), in which is provided information in more detail regarding the emission collection and analysis. A 9 mm lab weapon having the barrel tightly inserted in polyethylene recipients (HDPE 60 L drums for the collection of solid residues and LDPE bags sheeted on wood frames – 250 to 500 L – for the collection of gaseous products and metallic fumes) is fired ten times for each type of ammunition. The metal content (Pb, Cu, Zn and Sb) in the residues and fumes are analysed using Atomic Absorption Spectrometry (AAS) and Scanning Electron Microscopy - Energy-dispersive X-ray spectroscopy (SEM-EDX). The gaseous emissions (CO_2, CO, HCN, NO, NO_2, NH_3, CH_4) are detected using freshly calibrated electrochemical sensors inserted in the recipients and two MiniWarn data acquisition systems (Draeger, Germany). The data is processed using the *Gas Vision 5.8.2* software.

Table 3 presents the emissions associated with the firing of the ammunition, in which the higher values are highlight in bold for each emitted gas or metal. CO, NO and NO_2 emissions are similar for all the four ammunitions, whilst ammunitions #1 and #2 have higher emissions for NH_3, HCN, CH_4, Pb and Sb. The ammunitions with a composite projectile (#3 and #4) present higher emissions for Cu. The lead free ammunition (copper and nylon composite and non-lead primer) is the