Chemosphere 194 (2018) 622–627

Contents lists available at ScienceDirect

Chemosphere

journal homepage: www.elsevier.com/locate/chemosphere

Improving post-detonation energetics residues estimations for the Life Cycle Environmental Assessment process for munitions

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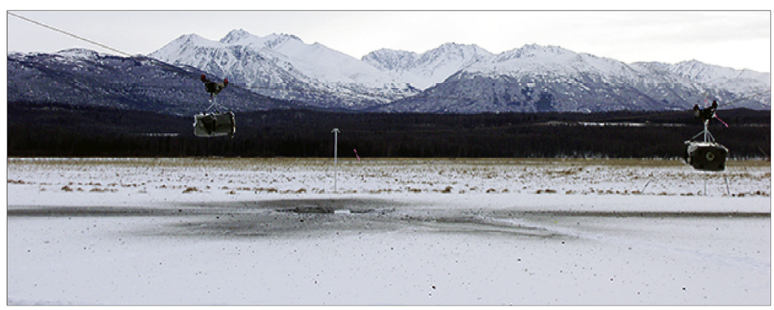
HIGHLIGHTS

- Life Cycle Environmental Assessments report no significant post-detonation residue.
- Field testing of munitions indicates gram quantities or more of detonation residues.
- Detonation tests were conducted to compare aerial residues with residues deposition.
- Aerial residues data account for <10% of total post-detonation energetics residues.
- Live-fire detonation residues deposition data is needed for accurate assessments.

GRAPHICAL ABSTRACT



Air sampling instruments (Flyers) suspended above detonation residues on snow

ARTICLE INFO

Article history:
Received 19 July 2017
Received in revised form
14 November 2017
Accepted 15 November 2017
Available online 15 November 2017

Handling Editor: Keith Maruya

Keywords:
Life Cycle Environmental Assessment
Munitions
Energetics
Detonation residues
Combustion products
Emission factors

ABSTRACT

The Life Cycle Environmental Assessment (LCEA) process for military munitions tracks possible environmental impacts incurred during all phases of the life of a munition. The greatest energetics-based emphasis in the current LCEA process is on manufacturing. A review of recent LCEAs indicates that energetics deposition on ranges from detonations and disposal during training is only peripherally examined through assessment of combustion products derived from closed-chamber testing or models. These assessments rarely report any measurable energetic residues. Field-testing of munitions for energetics residues deposition has demonstrated that over 30% of some energetic compounds remain after detonation, which conflicts with the LCEA findings. A study was conducted in the open environment to determine levels of energetics residue deposition and if combustion product results can be correlated with empirical deposition results. Energetics residues deposition, post-detonation combustion products, and fine aerosolized energetics particles following open-air detonation of blocks of Composition C4 (510 g RDX/block) were quantified. The deposited residues amounted to 3.6 mg of energetic per block of C4, or less than 0.001% of the original energetics. Aerial emissions of energetics were about 7% of the amount of deposited energetics. This research indicates that aerial combustion products analysis can provide a valuable supplement to energetics deposition data in the LCEA process but is insufficient alone

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https://doi.org/10.1016/j.chemosphere.2017.11.072
0045-6535/Published by Elsevier Ltd.

to account for total residual energetics. This study demonstrates a need for the environmental testing of munitions to quantify energetics residues from live-fire training.

Considering Energetics Residues in the Life Cycle Environmental Assessment Process for Munitions.

1. Introduction

Munitions developed in the United States must go through a process known as the life cycle environmental assessment (LCEA) as part of the certification process for use. The LCEA process is detailed in DoD Instruction (DoDI) 5000.02 and includes a section on environment, safety, and occupational health (ESOH) (US DoD, 2015). Section 16 of Enclosure 3 of DoDI 5000.02 states that "The Program Manager will integrate ESOH risk management into the overall systems engineering process for all engineering activities throughout the system's life cycle" to manage, reduce, or eliminate ESOH risks associated with the materiel under development. Regulatory impetus is derived from the National Environmental Policy Act (NEPA) of 1969 (as amended) (US Executive Office, 1969). The NEPA requires analyses to determine whether a Finding of No Significant Impact (FoNSI) or a Notice of Intent (NOI) to file an Environmental Impact Statement (EIS) is to be assigned to the item being examined. The resulting document is known as the Life-Cycle Environmental Assessment. In addition, Executive Order 12144—Environmental Effects Abroad of Major Federal Actions further strengthens the guidance as set forth in the NEPA act of 1969 (US Executive Office, 1979). Reportage of results occurs through a Programmatic ESOH evaluation (PESHE) that documents "data generated by ESOH analyses conducted in support of program execution." The PESHE includes "identification of ESOH risks and their status; and, identification of hazardous materials, wastes, and pollutants (discharges/emissions/noise) associated with the system and its support as well as the plans for minimization and/or safe disposal."

The LCEA process evaluates possible contamination generated during the use of munitions in training, disposal, demilitarization, and war. For this paper, we focused on detonations of munitions on training ranges, considering only high-order detonations from properly functioning munitions. We did not consider improperly functioning munitions (low-order, partial-detonations, and duds) as those types of events are extremely variable. For the determination of high-order detonation residues, combustion model predictions or actual sampling results are used. For the latter, testing typically occurs in enclosed blast chambers where post-detonation combustion products are measured. Energetics residues deposition is estimated based on the analysis of the combustion products collected by gas-collection samplers, gas sensors, and instrumentation. Samples are analyzed for over 250 analytes, including explosive compounds (Krupacs, 2004). However, the extent of deposition on the walls, shot to shot carryover, and ground residue of the target analytes remains uncertain. Five LCEAs were reviewed for this paper, four from the US (Krupacs, 2004, 2014; Antreassian et al., 1992; Boyce, 2009) and one from Sweden (Hägvall et al., 2004). Two of the five estimates relied on the sampling of combustion gasses, while the remaining three modeled the combustion products rather than rely on blast chamber data (Krupacs, 2004, 2014; Boyce, 2009; Hägvall et al., 2004). Only one of the five LCEAs reviewed (PAX-21 high-explosive mortar rounds) also examined post detonation residues. None of the LCEAs reported significant environmental impacts from detonations.

Field-testing of the PAX-21 mortar rounds was undertaken as part of the Strategic Environmental Research and Development Program (SERDP) project ER-2219 to determine if measurable detonation residues were deposited following training with these rounds (SERDP Project ER-2219, 2016). Seven PAX-21 60-mm mortar rounds were drawn from inventory and command detonated in the open environment in 2012. Results indicated that, on average, 14 g of perchlorate (ClO_4) residue resulted from high-order detonations, 15% of the original perchlorate mass (Walsh et al., 2013). A subsequent re-evaluation of residues data from the original 60-mm PAX-21 mortar round LCEA revealed a similar mass of perchlorate (13 g) resulting from the detonation of two rounds during the enclosed chamber tests (Krupacs, 2004). An addendum was issued by Picatinny Arsenal shortly after the release of these findings, reclassifying the rounds because of "the residual risk of perchlorate contamination" (Boyce, 2012).

Field deposition residues data differ significantly from the impact findings of current LCEAs. Past LCEA data and model results indicate less than 0.01 mg energetics residues following detonation, whether for 60-mm or 155-mm munitions, with over 99.99% of all energetics consumed (Krupacs, 2004, 2014; Antreassian et al., 1992; Boyce, 2009; Hägvall et al., 2004). Field data indicate much higher mass deposition, up to tens of grams in some cases, with consumption rates of less than 60% in one case (Walsh et al., 2013, 2011, 2014). A more definitive analysis of air emission detonation combustion products with residues deposition data was needed to determine if the LCEA process adequately estimates energetics residues from detonations or if modifications to the process should be considered. To do this, we detonated a series of Composition C4 demolitions blocks in the field and compared residues estimates derived from gaseous emissions with residues deposited on the ground surrounding the detonation.

2. Materials and methods

Tests analyzing airborne residues and combustion products to residues deposited on a snow surface were conducted in Anchorage, Alaska, in February 2015. The test location was the Eagle River Flats impact area (ERF) on Joint Base Elmendorf Richardson (JBER)— Richardson Training Area. At the time of the tests, the Flats were covered with ice that varied in thickness up to 60 cm. There was 2–5 cm of snow cover at the test site. Meteorological conditions for testing were as follows: Mean temperature −1 °C, no precipitation, overcast sky, and winds variable 0–4 m/s, averaging 2 m/s. Wind direction was erratic, unusual for the site. Testing was conducted with blocks of Composition C4 explosive (C4) consisting of 510 g of hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) (up to 10% Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) as a manufacturing byproduct) and 57 g of plasticizer. For the test, a total of five co-located detonations of two blocks of C4 each were executed over a 2 h period. Gaseous emissions and suspended particles were sampled during and immediately after the detonations. Surface residues were sampled upon completion of the five detonations. All results are based on estimates derived from the gas and residues accumulation from all five detonations.

Two sampling methods were used to estimate the detonation