Towards Greener Munitions with less Environmental Impacts: The RIGHTTRAC Project

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Human and Environmental Toxicology of Munitions-Related Compounds – from Cradle to Grave, April 2011, Amsterdam, The Netherlands

Defence R&D Canada - Valcartier
SL 2011-543
April 2011
Acknowledgements

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Overview

• Issues in Range and Training Areas (RTAs)
• Revolutionary Insensitive, Green and Healthier Training Technology with Reduced Adverse Contamination (RIGHTTRAC) Concept
  – Fuzing System
  – Explosive Charge
  – Gun Propellant System
  – Environmental Properties
  – IM Properties
  – Life-cycle costing
• Conclusions
**Issues/Problematic**

**Impact Areas**
- **RDX** (Most used explosive)
  - The most mobile through the soil profile
  - Migrates to groundwater and contaminates surrounding areas
- **Toxic heavy metals** (fuze, shell, propellant…)
- **Sources**: Low-order detonations
  - Blow-in-place of UXO
  - Corrosion or rupture of UXOs

**Firing Positions**
- Significant amounts of propellants were detected
- Some of the constituents are **toxic** for the environment and **carcinogenic** for the users. (eg. 2,4-DNT, NG, phthalate derivatives, ethyl centralite, heavy metals, etc.)
- **Sources**: Incomplete combustion of propellants
  - Open burning of excess propellant
RIGHTTRAC Concept

Green/IM propellant

More reliable fuzing systems with self destruct mechanism

Green/IM explosive

Objectives: To demonstrate that Green / IM munitions have better properties than current munitions with the benefit of decreasing the environmental pressure, health hazards, and achieving IM munitions for use in operations.

Technologies:
- Replace toxic and/or environmentally-damageable components of explosive and gun propellant by green, insensitive and recyclable compounds;
- Reduce the dud rate by including a self-destruct mechanism in a fuze;
- Technology transferable to other calibers.
Fuzing System

• Development of a self-destruct capability to current artillery fuzing system in case of a failure of the primary fuze:
  – Operator handling
  – Soft impacts
  – Age-related failures

• Implementation in the existing C32A1 multi-options fuze artilley (MOFA) and/or the point detonating mechanical (PDM) 739.

• Reduce the actual live fire dud rate from approximately 5% overall to less than 1%;
Explosive Charge – Booster (WBS 5.2.1)

✓ Preselection:
  • PBXN-5 (95% HMX, 5% Viton)
  • PBXW-14 (60% TATB, 35% HMX, 5% PTFE or Viton A)
  • PBXN-9 (92% HMX, 2% HyTemp, 6% DOA)
  • A5 (99% RDX) (current)

Selection (July 10)
  • Data on S3 (MSIAC\textsuperscript{1})
  • Environmental properties (literature)

✓ Tests were done to verify if A5 would work with reduced booster size – Successful
✓ Simulation of booster in center and near-center axis
  ✓ Results support all tests
✓ PBXN-5 was selected

\textsuperscript{1} Munitions Safety Information Analysis Center
Main Explosive Charge Preselection (WBS 5.2.2)

✓ GIM (9% ETPE, 51% HMX and 39% TNT)
  • Green compliance = High; IM compliance = High

✓ CX-85 (10% HTPB, 5,5% DOA, 84% HMX)
  • Green compliance = High; IM compliance = High
  • NTO rejected
    • Green compliance = Low; IM compliance = High
    • High solubility (49 g/L)
    • Ecotoxicity on NTO precursors (BAE)
    • No data on environmental fate of degradation products or carcinogenicity
  • DNAN rejected
    • Green compliance = Very Low; IM compliance = High
    • High toxicity

<table>
<thead>
<tr>
<th>Compound</th>
<th>Solubility</th>
<th>LD$_{50}$ (rat)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RDX</td>
<td>40-60</td>
<td>100</td>
</tr>
<tr>
<td>HMX</td>
<td>6</td>
<td>6000</td>
</tr>
<tr>
<td>TNT</td>
<td>130</td>
<td>794-1320</td>
</tr>
<tr>
<td>DNAN</td>
<td>276</td>
<td>199</td>
</tr>
<tr>
<td>NTO</td>
<td>49 000</td>
<td>&gt; 5000</td>
</tr>
<tr>
<td>Comp B</td>
<td></td>
<td>197</td>
</tr>
</tbody>
</table>

Selection March 2011
Main Explosive Charge Performance Measurements

Performance tests (Plate dent tests coupled with Velocity of Detonation measurements)

<table>
<thead>
<tr>
<th></th>
<th>Density (g/cm³)</th>
<th>VoD (m/s)</th>
<th>Relative VoD (% Comp. B)</th>
<th>Detonation Pressure (calc) (GPa)</th>
<th>Relative P_{CJ} (% Comp B)</th>
<th>Plate dent (cm)</th>
<th>Relative perf. (% Comp. B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CX-85</td>
<td>1.61</td>
<td>8159</td>
<td>103</td>
<td>26.8</td>
<td>102</td>
<td>0.71 ± 0.01</td>
<td>90</td>
</tr>
<tr>
<td>GIM</td>
<td>1.67</td>
<td>7726</td>
<td>97</td>
<td>24.9</td>
<td>94</td>
<td>0.76 ± 0.01</td>
<td>96</td>
</tr>
<tr>
<td>Comp. B</td>
<td>1.68</td>
<td>7931</td>
<td>100</td>
<td>26.4</td>
<td>100</td>
<td>0.79 ± 0.01</td>
<td>100</td>
</tr>
</tbody>
</table>

VoD = Velocity of Detonation

- CX-85 under performs in plate dent tests.
- Candidates very close or better than Comp B in VoD and detonation pressure.
- Candidates as good as any other known IM explosive.
RIGHTTRAC – Gun Propellant (WBS 5.4)

- Down-selected 3 candidates
  - “Green” M1 propellant (MM1) (DNT, DBP and DPA free)
  - Modified triple base propellant (TB)
  - Modified HELOVA (HMX-based propellant with ETPE and energetic plasticizer)
- Modified LOVA (HMX-based propellant with NC and CAB)

Selection May 2011
HELOVA showed the best ballistic performance, but the worst mechanical properties (cracking of the grains at low temperature)

HELOVA was replaced by LOVA, based on NC, HMX, ATEC and CAB

Two ingredients were discarded: TEGDN and ETPE

Fine tuning of formulations using a design of experiments was done to optimize the ballistic and mechanical properties for LOVA

Impact: Potential 6 months delay (briefing note)

Downselection of two formulations: Green M1 and LOVA

Tests ongoing at BRI and INRS to verify the solubility kinetics and toxicity of LOVA
Environmental assessment of energetic formulations

- Energetic formulation
  - Leaching
  - Toxicity
  - Dissolution
  - Recycling
  - Air residues

- Soluble ingredients
  - Soil invertebrates
  - Terrestrial plants
  - Soil elutriates
  - Sorption (Kow, Kd)
  - Degradation
  - Photolysis
  - Hydrolysis

- Weathering
- Lab soil columns
Environment - Propellant (WBS 4.2)

- **Air Residues (CRIQ)**
  - Test method for air residues ready
  - Reference formulation (M1 gun propellant) tested in Nicolet in Oct 09
  - Formulations tested in closed vessel
    - Toxicity: TB < HELOVA < green M1
  - Tests on LOVA in closed vessel to come
  - Chosen formulation will be tested in 2012
  - Results will be compared with closed vessels trials
Emission gases

- Combustion gases: CO, CO$_2$, CH$_4$, NH$_3$, SO$_2$
- VOC (Methods TO-15 (Tedlar bags) and TO-17 (Carbotrap)):
  - $>100$ compounds, mainly aromatics
  - Monocyclic aromatics: 80% (benzene)
  - Monocyclic aromatics, nitrogeneous: 10% (benzonitrile)
  - Aliphatic, nitrogeneous: 10%
  - Major compounds:
    - Benzene (300 to 350 ppb)
    - Toluene (150 to 200 ppb)
    - Carbonyle sulfide (40-120 ppb)
    - Methyl isocyanade (70-90 ppb)
    - Ethane dinitrile (10-75 ppb)
Emission gases

- **SVOC:**
  - Bicyclic aromatics: < 5% (main: naphtalene)
  - Monocyclic aromatics, nitrated: <1%
  - Phthalates (< 0.1%)
  - Polycyclic aromatics: < 0.1%

- **Particulate matter**
  - 160-210 mg/m³
  - Mean particle size 0.93 μm
  - Mainly Pb, K, S, Fe and Cu
  - Hg and H₂S at ppm level
Environment - Recycling (WBS 4.3)

1. Recovery of formulations from the munition
   ✓ Straightforward for propellants and GIM
   ✓ PBX: Pilot scale tests with high pressure water jets done
   ➢ Report in final revision since December 2010

2. Separation of components from the formulation
   ➢ Only remaining test is to extract the components from the slurry obtained from PBX recovery

<table>
<thead>
<tr>
<th>Formulation</th>
<th>Individual components</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Name</td>
</tr>
<tr>
<td>Explosives</td>
<td>GIM</td>
</tr>
<tr>
<td></td>
<td>CX-85</td>
</tr>
<tr>
<td>Propellants</td>
<td>TB</td>
</tr>
<tr>
<td></td>
<td>MM1</td>
</tr>
<tr>
<td></td>
<td>HELOVA</td>
</tr>
</tbody>
</table>

LOVA: HMX is expected to be extracted as easily as for HELOVA

**Reuse**: the alternative use of a munition or its components, for example change from operational to training use

**Recycle**: the use in a different item of materials recovered from a munition, e.g. mining or fertilizer industry
Environment Propellant Leaching (WBS 4.1.2)

- Indoor adsorption tests on sand column (20 x 3.7 cm)
- Outdoor dissolution test on fritted disk
- Results:
  - TEGDN leaching rate: MM1 < TB < HELOVA
  - Weight of TEGDN: HELOVA < MM1 < TB
  - The amount of TEGDN released from the Triple base is 4x higher than HELOVA’s.
- Tests on LOVA are planned

Mass of TEGDN lixiviated from the gun propellant formulations during laboratory dissolution tests, column tests and weathering

<table>
<thead>
<tr>
<th>Experiment</th>
<th>SB</th>
<th>TB</th>
<th>HELOVA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2:1</td>
<td>1:2</td>
<td>Uncoated</td>
</tr>
<tr>
<td>Dissolution (mg/L)</td>
<td>1900</td>
<td>2008</td>
<td>3968</td>
</tr>
<tr>
<td>Column tests(^1) (mg)</td>
<td>NA</td>
<td>2050</td>
<td>2820</td>
</tr>
<tr>
<td>Weathering, grains(^2) (mg)</td>
<td>787</td>
<td>747</td>
<td>1422</td>
</tr>
<tr>
<td>Weathering, grinded(^2) (mg)</td>
<td>1268</td>
<td>1355</td>
<td>1131</td>
</tr>
</tbody>
</table>

Ratio of TEGDN lixiviated from the gun propellant formulations during laboratory dissolution tests, column tests and weathering

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</thead>
<tbody>
<tr>
<td></td>
<td>2:1</td>
<td>1:2</td>
<td>Uncoated</td>
</tr>
<tr>
<td>Column tests(^1) (%)</td>
<td>NA</td>
<td>65</td>
<td>87</td>
</tr>
<tr>
<td>Weathering, grains(^2) (%)</td>
<td>26</td>
<td>31</td>
<td>60</td>
</tr>
<tr>
<td>Weathering, grinded(^2) (%)</td>
<td>43</td>
<td>57</td>
<td>50</td>
</tr>
</tbody>
</table>

\(^1\)1.5 simulated years  \(^2\)265 days
Ecotoxicological Study NRC-BRI Propellant Formulations (WBS 4.1.1)

- **Dissolution:** TB > MM1 > HELOVA

- **Ecotoxicity:** MM1 > TB > HELOVA

- Propellant formulations have adverse toxic effects on earthworm survival, earthworm avoidance behavior and ryegrass growth

- TEGDN may be the cause of toxicity in HELOVA and the other propellant formulations (TB and MM1)

- Based on data gathered thus far on formulations, **HELOVA seems to be the most stable formulation in terms of leakage and the less toxic formulation**
Components of interest

HELOVA: HMX (68%), TEGDN (7%)  
TB: NQ (24%), TEGDN (24%)  
MM1: TEGDN (30%), AK (1%)

Sorption

- **HMX ~ AK > TEGDN > NQ**  
  (sand/silt/clay)  
- No sorption in sand

Degradation

- Hydrolysis of HMX, TEGDN and AK was insignificant  
- Degradation was insignificant in non sterile sand  
- Slow degradation of TEGDN in sand/silt/clay  
- Photolysis was the fastest degradation process and kinetics followed the order: **NQ > HMX > TEGDN > AK**  
- Photolysis of solid formulations and identification of photoproducts is ongoing
Cost-Efficiency Analysis (CEA)

Aim of Study
- The study uses a CEA to estimate the green munitions' incremental economic costs

Methodology
- Based on cost differences between green and conventional munitions

Relevant cost categories
Simulated data were used for:
- Liability - Demilitarization (e.g. Disposal)
- Remediation - Initial investment (e.g., PBX plant)
- Conception
- Manufacturing cost of each unit (shell, propelling charge, fuze, etc.)

Degree of completion
- Proceedings produced using a hypothetical military installation
- Still gathering data for production costs and munitions consumption
- Report will be completed in 2011 for a Canadian installation

Future Work
- The retrofit costs and the new build costs of the self-destruct fuze
- The end-to-end (i.e. Whole Life Cost) data for this capability
- The same analysis may be done for the Propellant and Explosive Green/IM, once possible, in order to identify the cost drivers per unit cost to bring this capability into service.
# Insensitive Munitions – Small-Scale Testing

(WBS 5.2.2.7 and 5.4.3)

<table>
<thead>
<tr>
<th>Composition</th>
<th>Bullet Impact</th>
<th>Shaped Charge Jet</th>
<th>Sympathetic Detonation</th>
<th>Slow Cook-off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comp B</td>
<td>I or II</td>
<td>I</td>
<td>III</td>
<td>NA</td>
</tr>
<tr>
<td>GIM</td>
<td>V</td>
<td>I</td>
<td>III</td>
<td>NA</td>
</tr>
<tr>
<td>PBX</td>
<td>V</td>
<td>I</td>
<td>NR</td>
<td>NA</td>
</tr>
<tr>
<td>M1</td>
<td>IV</td>
<td>II</td>
<td>NA</td>
<td>IV-V</td>
</tr>
<tr>
<td>MM1</td>
<td>V</td>
<td>II</td>
<td>NA</td>
<td>IV-V</td>
</tr>
<tr>
<td>TB</td>
<td>V</td>
<td>II</td>
<td>NA</td>
<td>IV-V</td>
</tr>
<tr>
<td>HELOVA</td>
<td>V</td>
<td>II</td>
<td>NA</td>
<td>IV-V</td>
</tr>
</tbody>
</table>

NR: No reaction  
NA: Not available

- **Preliminary Variable Confinement Cook-Off**
  - Best results for PBX

- **Hot Fragment Conductive Ignition (for propellant)**
  - Best results for HELOVA

- **Fragment Impact**
  - Fragment launcher under development
  - Launcher was used to launch 10-g projectile over 6 km/s
  - Need to adapt launcher for 18.6-g projectile and 2.5 km/s
IM Sub-Scale Testing: Reaction to blow-in-place with C4 (WBS 5.2.2.7)

- As the main charge explosives (GIM and CX-85) have IM properties, their reaction to blow-in-place procedure has to be studied.
- Simulation of a UXO detonation with C4.
- Unburned residues were sampled and analyzed.
- Conclusion: all IM explosives lead to a high-order detonation, with traces of unburned explosives spread.
Selection Criteria

2 Explosives
3 Gun propellants

- DRDC GD
  - Technical Feasibility (20%)

- DRDC
  - Insensitive Munitions (25%)
    - DRDC BRI INRS CRIQ
    - Environmental Properties (30%)
      - Environmental fate, bioavailability, air emissions, recyclability

- DRDC GD
  - Life Cycle Cost (15%)

- DRDC GD
  - Performance (10%)
    - Must be at least as good as in-service ammunition
Conclusions

- RIGHTTRAC aims to demonstrate a greener and less vulnerable 105-mm round that will ease the environmental pressure on the Canadian Forces RTAs.

- We are working on:
  - The fuze (to reach a near-zero dud rate)
  - The gun propellant (to incorporate less toxic ingredients that will also increase IM)
  - The explosive (to replace RDX – move to HMX, and add a binder that will reduce the bioavailability and increase IM)

- Each main deliverable can be used alone or with another one.
- Each main deliverable can be used in another calibre.
- Life-cycle cost of current ammo vs green ammo.
- International collaboration welcome.
KTA 4-42: Development of a framework to assess the environmental impacts of green munitions constituents and of new energetic formulations

Objectives

- Framework to evaluate the environmental and health impacts of munitions constituents and formulations.
- User community: site managers, environmental professionals, munitions developers
- Will help perform appropriate risks assessments necessary to ensure the use of military RTAs as sustainable resources.
- Participants:
  - AU (DSTO)
  - UK (DSTL)
  - CA (DRDC, BRI, INRS)
  - US (USAPHC, ECBC)
Definition of green munitions

• No official definition of green munition in TTCP countries
• No such thing as a green munition!
• Greener munitions:
  – Munitions that are designed to minimize their adverse environmental and occupational health impacts over their whole life cycle, while still retaining the necessary functionality and characteristics associated with their intended purpose

• International collaboration welcome
Objective/Objectif:
- Decrease environmental contamination
- Decrease health hazards
- Improve munitions performance
- Réduire la contamination environnementale
- Réduire les risques pour la santé
- Améliorer les performances de la munition

More reliable fuzing system with self-destruct mechanism
Decrease of dud rate
Fusée plus fiable avec mécanisme d’auto-destruction
Réduction du taux de raté

Green insensitive gun propellant
Poudre propulsive écologique à vulnérabilité réduite

Green insensitive explosive
Explosif écologique à vulnérabilité réduite
DEFENCE & DÉFENSE