2009 Insensitive Munitions and Energetic Materials Technology Symposium

Qualification Testing of the Insensitive TNT Replacement Explosive IMX-101

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Acknowledgments

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Introduction

• PM CAS Program Objectives:
  – Implementation of an EIDS* and IM Solution in 155mm Artillery Ammunition within 3 years
    • Reduce hazard classification from 1.1 to 1.6
    • Implement system IM solution while maintaining system performance
  – Explosive Technology Transition
    – Provide an insensitive replacement for TNT
    – Provide a fully characterized, IM compliant, and ready for full qualification explosive
    – Provide an EIDS explosive solution

*Extremely Insensitive Detonating Substance
• **System IM Objectives**
  – Demonstrate Type III response for Sympathetic Detonation (SD) without barriers at the 155mm diameter
  – Demonstrate Type V response for Fast Cookoff (FCO) of an artillery round
  – Demonstrate Type III/V response for Shaped Charge Jet (SCJ) at TNT energy
  – Maintain system performance (e.g., Fragmentation and blast overpressure)
  – Maintain acceptable production and life cycle costs (affordable and producible within industrial base)
  – Characterize Slow Cookoff (SCO), Bullet Impact (BI), and Fragment Impact (FI)
Explosive Formulations

<table>
<thead>
<tr>
<th></th>
<th>IMX-101</th>
<th>IMX-102</th>
<th>IMX-103</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,4-Dinitroanisole (DNAN)</td>
<td>40</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>* Proprietary *</td>
<td>40</td>
<td>--</td>
<td>45</td>
</tr>
<tr>
<td>3-Nitro-1,2,4-triazol-5-one (NTO)</td>
<td>20</td>
<td>50</td>
<td>--</td>
</tr>
<tr>
<td>Trinitrotoluene (TNT)</td>
<td>--</td>
<td>35</td>
<td>--</td>
</tr>
<tr>
<td>Wax</td>
<td>--</td>
<td>15</td>
<td>--</td>
</tr>
<tr>
<td>DEMN (Nitrate Salt Eutectic)</td>
<td>--</td>
<td>--</td>
<td>50</td>
</tr>
<tr>
<td>RDX</td>
<td>--</td>
<td>--</td>
<td>5</td>
</tr>
</tbody>
</table>

- Formulated from common and inexpensive ingredients
- Detonation Energy equivalent to TNT
- Low Hazard Sensitivity
- Melt pour processing similar to TNT
### Engineering IM Tests

#### Fragment Impact

- **SCO**
- **SCJI (50mm/81mm)**

#### IM Test Results:

<table>
<thead>
<tr>
<th>IM Test:</th>
<th>FCO</th>
<th>SCO</th>
<th>BI</th>
<th>FI</th>
<th>SD</th>
<th>SCJI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passing Criteria</td>
<td>V</td>
<td>V</td>
<td>V</td>
<td>V</td>
<td>III</td>
<td>III</td>
</tr>
<tr>
<td>155mm Baseline (TNT)</td>
<td>FAIL</td>
<td>FAIL</td>
<td>FAIL</td>
<td>FAIL</td>
<td>FAIL</td>
<td>FAIL</td>
</tr>
<tr>
<td>IMX - 101</td>
<td>PASS</td>
<td>PASS</td>
<td>PASS</td>
<td>PASS</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>IMX - 102</td>
<td>PASS</td>
<td>PASS</td>
<td>PASS</td>
<td>PASS</td>
<td>PASS</td>
<td>PASS</td>
</tr>
<tr>
<td>IMX - 103</td>
<td>PASS</td>
<td>PASS</td>
<td>FAIL</td>
<td>PASS</td>
<td>PASS</td>
<td>FAIL</td>
</tr>
</tbody>
</table>

- Past program to replace TNT for artillery projectiles produced IMX-101, IMX-102, and IMX-103
- Selected IMX-101
**Explosive Producibility**

- **Producibility**
  - Over 5,000 kg IMX-101 generated in production scale batches at BAE-Holston
    - One batch chosen for qualification (007)
  - Artillery round load studies at ARDEC
    - Optimized artillery round loading configuration and temperature profiles
    - Produced All Up Rounds for gun launch
    - Evaluated round QA procedures
      - Refine X-ray methods and data interpretation
Energetic Materials Qualification Process

• Purpose
  – Only qualified explosives will be used in munitions and devices for operational and training purposes

• Comprehensive assessment of the Energetic Material
  – Safe and Suitable for the intended use

• Assessment Includes
  – Small Scale Impact, Friction, ESD, Thermal properties
  – Ignition properties
  – Critical Temperature
  – Shock Sensitivity
  – Mechanical Properties
  – Sensitivity with age
  – Toxicity
  – Performance
  – Compatibility
  – System Sensitivity (e.g., Set Back From Gun Launch)
<table>
<thead>
<tr>
<th>TEST RANGE OR LIMIT</th>
<th>ERL/Bruceton Impact (cm)</th>
<th>BAM Friction (N)</th>
<th>ElectroStatic Discharge (ESD, J)</th>
<th>DSC (Exotherm peak; °C)</th>
<th>Vacuum Thermal Stability (ml/g, 100 °C/48 h)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2.5 kg drop weight</td>
<td>80 N (Min.)</td>
<td>0.25 J</td>
<td>10 °C/min, 500 °C max</td>
<td>≤ 2 ml/g of gas evolved</td>
</tr>
<tr>
<td>IMX-101</td>
<td>&gt; 100</td>
<td>240</td>
<td>No Go</td>
<td>223</td>
<td>0.34</td>
</tr>
<tr>
<td>TNT</td>
<td>88</td>
<td>216</td>
<td>No Go</td>
<td>300</td>
<td>0.10</td>
</tr>
<tr>
<td>RDX</td>
<td>27</td>
<td>168</td>
<td>Go</td>
<td>241</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Critical Temperature

• Self Heating = Thermal decomposition of material produces heat faster than it can be dissipated to surroundings

• Critical Temperature = Lowest constant temperature at which a material can self heat catastrophically
  • No Scaling – same crit temp at 1-liter and 12-liter
  • Acceptable processing safety margin

Henkin
40 mg
Sealed Cell

20 g Tests

ARL 1-liter

AFRL 1-liter

Cook Off Tests for IMX-101

Tc (deg C)

Sample Size (g)

Nonviolent Ejection

170 °C

No Scaling – same crit temp at 1-liter and 12-liter

Self Heating = Thermal decomposition of material produces heat faster than it can be dissipated to surroundings

Critical Temperature = Lowest constant temperature at which a material can self heat catastrophically

Acceptable processing safety margin
### Shock Sensitivity

- Expanded Large Scale Gap Test (ELSGT)

  - 50% Gap Thickness

#### Data Table

<table>
<thead>
<tr>
<th>Test Number</th>
<th>Density (g/cc)</th>
<th>Gap (Cards)</th>
<th>Pressure (kbar)</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.63</td>
<td>100</td>
<td>76</td>
<td>Go</td>
</tr>
<tr>
<td>2</td>
<td>1.64</td>
<td>200</td>
<td>51</td>
<td>No Go</td>
</tr>
<tr>
<td>3</td>
<td>1.64</td>
<td>149</td>
<td>61</td>
<td>Go</td>
</tr>
<tr>
<td>4</td>
<td>1.64</td>
<td>176</td>
<td>56</td>
<td>No Go</td>
</tr>
<tr>
<td>5</td>
<td>1.64</td>
<td>163</td>
<td>59</td>
<td>No Go</td>
</tr>
<tr>
<td>6</td>
<td>1.64</td>
<td>156</td>
<td>59</td>
<td>Go</td>
</tr>
<tr>
<td>7</td>
<td>1.64</td>
<td>159</td>
<td>59</td>
<td>Go</td>
</tr>
<tr>
<td>8</td>
<td>1.65</td>
<td>161</td>
<td>59</td>
<td>Go</td>
</tr>
<tr>
<td>9</td>
<td>1.64</td>
<td>162</td>
<td>59</td>
<td>No Go</td>
</tr>
<tr>
<td>10</td>
<td>1.64</td>
<td>157</td>
<td>59</td>
<td>No Go</td>
</tr>
<tr>
<td>11</td>
<td>1.64</td>
<td>152</td>
<td>60</td>
<td>Go</td>
</tr>
<tr>
<td>12</td>
<td>1.64</td>
<td>155</td>
<td>60</td>
<td>Go</td>
</tr>
<tr>
<td>TNT</td>
<td>1.59</td>
<td>438</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Comp B</td>
<td>1.69</td>
<td>489</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

#### Diagram:

- Detonator
- Pentolite Donor
- PMMA Gap
- Sample

3"x11"
Detonation Velocity

• Detonation Velocity from ELSGT Samples

- IMX-101
  - Detonation Velocity (km/s): 6.9
  - Density (g/cc): 1.64

- IMX-101
  - Detonation Velocity (km/s): 6.9
  - Density (g/cc): 1.64

- TNT
  - Detonation Velocity (km/s): 6.9
  - Density (g/cc): 1.64
Extremely Insensitive Detonating Substance (EIDS)

- Usual Hazard Classification for Explosives is 1.1 (Mass Explosion)
  - Large quantity-distance criteria imposed for bulk storage of ammunition
    - Separation distance for 4500 kg explosive was 381 m

- Hazard Classification of 1.6 (No Mass Explosion)
  - Separation distance for 4500 kg explosive is 52 m
    - Decrease logistics burden

- System IM objectives become more achievable with less sensitive explosive
UN Series 7 Tests

- EIDS Cap – Sensitivity to shock from standard detonator
- EIDS Gap – Sensitivity to a calibrated shock
- Susan Impact – Sensitivity to high velocity impact while confined
- EIDS Bullet Impact – 50 cal and two sample orientations
- EIDS External Fire – 30 minute bonfire
- EIDS Slow Cookoff – Increase temperature 3.3 °C/hr
EIDS Characterization

- **EIDS Results - Cap**

  No Witness Plate Penetration in 3 Trials

  **PASS**

  Figure 5-20. EIDS Cap Sensitivity Test configuration (UN Test 7(a)) – Cardboard Tube
EIDS Characterization

- EIDS Results - Gap

**Detonator (Figure 5-4)**
- **Detonator Holder**
  - Wood Block 3.75 in (95 mm)
  - Diameter Drilled to Hold Detonator

**Pentolite Donor**
- 3.75 in (95 mm) diameter
- (50/50 TNT/PETN)
- 40.5 ± 13 grains/in\(^2\) \(1.6 ± 0.05\) g/cc

**PMMA (polymethylmethacrylate)**
- Gap
  - 3.75 in (95 mm) diameter

**Substance**
- DOM Seamless Steel Tube
  - 3.75 in (95 mm) OD
  - 2.875 in (73 mm) ID
  - Tensile Strength = 60ksi (420MPa)
  - Elongation (%) = 22 (± 20% variation)
  - Brinell Hardness = 125 (± 20% variation)

**Mild Steel Witness Plate**
- 8 in x 8 in x 0.875 in
  - (200 mm x 200 mm x 20 mm)
  - Tensile Strength = 80ksi (580MPa)
  - Elongation (%) = 21 (± 20% variation)
  - Brinell Hardness = 160 (± 20% variation)

No Witness Plate Penetration in 3 Trials

PASS

Figure 5-22. EIDS Gap Test configuration (UN Test 7(b))
EIDS Characterization

- EIDS Results - Susan

Launch Velocities were 340 to 365 m/s
- EIDS = < 3.9 psi blast overpressure in at least 5 trials
- The average overpressure for six IMX-101 tests was 0.4 psi

PASS
EIDS Characterization

- EIDS Results – Slow Cookoff

Threaded Domed End
Cap with raised or no lettering
(Torque 150 ft-lbf (204 Nm))
ASTM A 197M-87

Seamless Steel Pipe
ASTM A53 Grade A

2.1 in
(53 mm)

(1.8 ± 0.18 in)
(45 ± 45 mm)

0.16 ± 0.016 in
(4 ± 0.4 mm)

(7.875 in)
(200 mm)

Figure 5-25. Standard Steel Pipe EIDS Test Item
Thermally Controlled Oven with Venting

Test Item (see Figure 5-26)

Support Stand

Figure 5-28. EIDS Slow Cookoff Test Configuration (UN Test 7(f))

Fail

TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.
Summary

- IMX-101 was fully characterized for safety and suitability in its intended use
  - Hazard testing demonstrated that IMX-101 was less sensitive than TNT
  - Critical temperature assessment indicated that IMX-101 was safe to process under typical melt pour processing conditions
  - The shock sensitivity of IMX-101 was far less than TNT
  - The IMX-101 detonation velocity was identical to TNT
  - EIDS testing indicated that IMX-101 is not a candidate for 1.6 Substance hazard classification due to a failing result from SCO testing
- The aging study will be completed this fall
- System IM testing is set to be conducted this summer
M795 IM
Yuma Proving Grounds
MACS SH
24 Sep 09