Persistence of High Explosives from Low-order Detonations within a Salt Marsh Impact Area

**Abstract**

The accumulation or persistence of energetic compounds resulting from live-fire training with tracers and mortars has been a concern in the U.S. military since 1983. Several studies have shown that high explosive ordnance dissolutions of mortar and artillery propellants normally leave very little energetic residue in the impact area. Occasionally, a malfunction will produce either unexploded or partially low-order ordnance remnants that consists of pieces of the projectile body and chunks of the HE (high explosive) filler that may be scattered up to tens of meters from the impact point.

Within an Alaskan salt marsh impact area, we studied the spatial distribution and persistence of the high explosives TNT (2,4,6-
trinitrotoluene), RDX (1,3,5-trinitroimidazolone), and HMX (1,3,5-
trinitroimidazole) that were deposited from low order detonations of 100-m mortar projectiles. The scatter areas of the solid pieces of high explosives were measured and the number of macroscopic pieces determined for three low order detonations. The macroscopic pieces of residues varied by several orders of magnitude. The multi-increment sediment samples collected within the scatter area for three consecutive summers. Distributional heterogeneity was examined at several scales by analysis of discrete sediment samples collected at 0.1-m, 1-m, 3-m, 5-m, 10-m, and 30-m intervals.

The HE chunks have diminished in size by dissolution and disaggregation. Only the largest chunks were still present 1.5 years after deposition. HE concentrations in discrete sample of surface sediment varied by several orders of magnitude. The multi-increment sediment sample data showed that the concentrations of all three analytes declined when the macroscopic HE chunks were removed and no new input occurred. Rate of decline was the least for HMX and the greatest for TNT. The water-saturated, anoxic conditions of the salt marsh are likely to result in biotransformation following the dissolution of the solid high explosives.

**Physical Changes of Solid Residue from Two Low-order Detonations**

**Study Site:** Estuary salt marsh impact area in Alaska. Live-fire exercise in March 2006 when the impact area was ice-covered. Solid Composition B (60/40 RDX/TNT) residues from low-order detonations in May 2005. The Comp B residue originated from clusters of millimeter-sized particles to individual chunks that were 3 cm in their longest dimension. A subset of 14 discrete points with HE residue were photographed at two low-order detonation sites.

**Low-order detonation crater**

Scatter area of solid high explosives filler (storage flag mark each discrete point with HE residue)

**Temporal Physical Changes of Comp B Residue in a Salt Marsh Impact Area**

<table>
<thead>
<tr>
<th>Date</th>
<th>Concentration (µg/g)</th>
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<tbody>
<tr>
<td>24 May 2006</td>
<td>3,900</td>
</tr>
<tr>
<td>23 August 2006</td>
<td>3,200</td>
</tr>
<tr>
<td>22 May 2007</td>
<td>3,600</td>
</tr>
<tr>
<td>24 August 2007</td>
<td>3,400</td>
</tr>
</tbody>
</table>

**Disaggregation and Dissolution**

- The dynamics of the salt marsh environment include periodic tidal inundation and fluctuating redox potentials. Climatic factors include seasonal freeze/thaw cycles and variable amounts and forms of precipitation. There is also ice cover in the winter, and bioparticulation by animals and plants in the summer. These factors contribute to mechanical and chemical transformation of solid HE residue.
- The persistence of the HE chunks in the salt marsh environment is much less (by orders of magnitude) than would be predicted by dissolution of HE chunks by rainfall in an upland environment (Lever et al. 2005). Dissaggregation is an important process to consider because it greatly increases the residue surface area.

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**Persistence of Comp B Residues in Sediment after Removal of HE Chunks**

Live-fire exercise in February 2005. A total of 160 projectiles were fired from 120-mm mortars, of which 126 projectiles did not detonate and four projectiles produced low-order detonations. Site May 2005, one low-order detonation crater was located. Eighteen chunks of Comp B were found. The chunks were 2 to 4 cm in their longest dimension and were concentrated between 13.5 and 16.5 m east of the crater. The collective scatter area of the solid residue was 120 m.

To monitor the persistence of the Comp B residue remaining in the sediment, a 30-m x 30-m area that included the crater and chunk scatter was established in September 2005, and replicate multi-increment samples were collected each summer. After a series of flooding tides and 180 mm of rainfall, the red stain was gone. Most of the chunks were intact but had surface roughening and appeared friable.

- The mass of residues continued to decline.
- After 2 years, the red stain was gone. Most of the chunks were intact but had surface roughening and appeared friable.
- The Mass of residues continued to decline.
- Visual examination of the impact crater after 2 years indicated that the residue surface area was reduced by a factor of 2.

**Range of Concentration in 100 Discrete Samples**

- Concentration range: 0.02 to 6,600 µg/g.
- Median concentration: 2.3 µg/g.
- Mean concentration: 4.0 µg/g.
- Standard deviation: 2.4 µg/g.
- Coefficient of variation: 61%.

**Areas with particular explosive residues are extremely difficult to characterize by sampling.**

**Variability between discrete samples is enormous, even within the impact crater.**

**Multi-increment samples suggest that HMX is the most persistent analyte and TNT the least persistent analyte in the water-saturated, periodically anoxic conditions of the salt marsh sediment.**