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Outdoor dissolution of detonation residues of three insensitive munitions (IM) formulations

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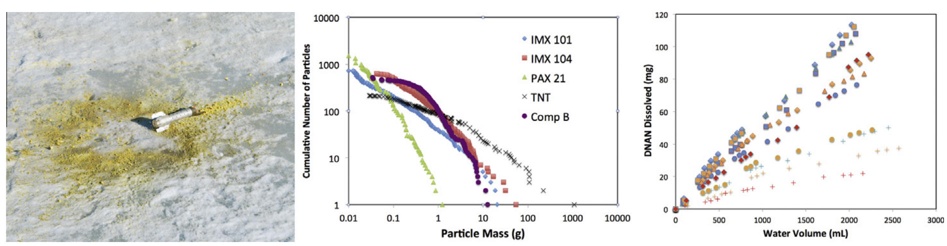
HIGHLIGHTS

- Detonation residues of IMX 101, IMX 104, and PAX 21 differ in size.
- Size distributions are likely controlled by the initial explosive mass in the rounds.
- These formulations break more easily than do conventional explosives.
- Centimeter-sized DNAN pieces have quasi-linear dissolution rates.

GRAPHICAL ABSTRACT

(a) Image of a low order detonation, (b) size distributions of particles scattered by IM rounds compared with those for TNT and Comp B rounds and (c) quasi-linear dissolution of DNAN as a function of water volume used to estimate particle life spans.



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ABSTRACT

We seek to understand the environmental fate of three new insensitive munitions, explosive formulations developed to reduce the incidence of unintended detonations. To this end, we measured the size distribution of residues from low order detonations of IMX 101, IMX 104, and PAX 21-filled munitions and are studying how these three formulations weather and dissolve outdoors. The largest pieces collected from the detonations were centimeter-sized and we studied 12 of these in the outdoors test. We found that the particles break easily and that the dissolution of 2,4-dinitroanisole (DNAN) is quasi-linear as a function of water volume. DNAN is the matrix and the least soluble major constituent of the three formulations. We used DNAN's linear dissolution rate to estimate the life span of the pieces. Particles ranging in mass from 0.3 to 3.5 g will completely dissolve in 3–21 years given 100 cm y^{-1} precipitation rates.

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1. Introduction

Explosive compounds that are less sensitive to shock and high temperatures are being tested as replacements for trinitrotoluene (TNT) and 1,3,5-hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX). Two of these compounds, 2,4-dinitroanisole (DNAN) and 3-nitro-1,2,4-triazol-5-one (NTO) have good detonation characteristics and are the main ingredients in the insensitive explosive formulations studied here, IMX 101, IMX 104, and PAX 21. DNAN, like TNT, melts at less than 100 °C and can be melt cast. This process mixes crystals of energetic compounds, such as NTO, nitroguanidine (NQ), ammonium perchlorate (AP), and RDX into molten DNAN, the matrix or binder, (Pelletier et al., 2010; Rutkowski et al., 2010) to produce the insensitive explosives investigated here (Table 1).

The insensitive explosive formulations studied here differ from conventional explosives in several ways: (1) they have three or

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Table 1
Properties of DNAN, NTO and other compounds found in IM formulations and the approximate percent composition of the formulations.

	Solubility [a] (mg L^{-1})	Density (g cm^{-3})	Mol. formula	Reference
DNAN	276	1.34	$C_7H_6N_2O_5$	Boddu et al. (2008)
NTO	16642	1.05	$C_2H_2N_4O_3$	Spear et al. (1989)
TNT	128	1.65	$C_7H_5N_3O_6$	Park et al. (2004)
RDX	56	1.82	$C_3H_6N_6O_6$	Monteil-Rivera et al. (2004)
HMX	4.5	1.81	$C_4H_8N_8O_8$	Monteil-Rivera et al. (2004)
NQ	3800	1.55	$CH_4N_4O_2$	Haag et al. (1990)
AP	217000	1.95	NH_4ClO_4	Motzer (2001)

	DNAN	NTO	NQ	RDX + HMX	AP
Percent of each compound in the formulations					
IMX 101	43	20	37	–	–
IMX 104	32	53	–	15	–
PAX 21	34	–	–	36	30

[a] At 25 °C.

more major energetic components; (2) these components have different water solubilities and crystal sizes; and (3) the matrix (DNAN or DNAN + RDX) is the least water-soluble component (Boddu et al., 2008). The high aqueous solubility of NTO (Spear et al., 1989), NQ (Haag et al., 1990) and AP (Motzer, 2001) increases the likelihood that they could reach groundwater and be transported off the training range (Table 1). If toxic, the presence of these compounds in groundwater can trigger regulatory action and stop military training at the range.

Toxicology data for DNAN show that it is more toxic to mammals than TNT (Davies and Provatas, 2006), and is toxic to bacteria and earthworms (Dodard et al., 2013). Although NTO has low mammalian toxicity (London and Smith, 1985) both NTO and DNAN can form toxic transformation products (Le Campion et al., 1999; Davies and Provatas, 2006). AP is known to interfere with iodine uptake and so affects thyroid function (Motzer, 2001; Crane et al., 2005).

For this research, we measured the sizes of particles resulting from low order detonations (LO) of three IM formulations. LO detonations scatter some fraction of their explosive fill onto the soil and, based on information on the fraction of fired rounds that release explosives into the environment, are estimated to be the largest contributor of explosives onto ranges today (Taylor et al., 2004a). The size distribution of scattered explosive particles is needed to determine their rate of dissolution given yearly precipitation. Using IM chunks collected in the field we measured their outdoor dissolution and photographed the particles to document how they weathered. Using micro computed tomography, we also imaged a chunk of each formulation, both before and near the end of the experiment, to document the effects of dissolution.

2. Materials and methods

All particles came from low order (LO) detonated rounds and were collected in the field. We measured the IMX 101 masses from three 105-mm rounds detonated as part of insensitivity tests by National Technical Systems. All other detonations were on ice surfaces at Eagle River Flats, a training range in Alaska. Here, we collected particles scattered from LO detonations of a 155-mm practice round containing IMX 101, from four of 81-mm mortar rounds filled with IMX 104 (Walsh et al., 2014) and from five 60-

Fig. 1. (a) Set up for low order detonations of a 60-mm mortar; (b) the low order detonation; (c) collecting the pieces and (d) photograph of a subset of the massed pieces collected.