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Explosives Residues Resulting from the Detonation of Common Military Munitions: 2002–2006

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Cold Regions Research
and Engineering Laboratory

COVER: Detonation of an M933 120-mm mortar round on Eagle River Flats, Alaska, 17 February 2005. (Photo by M.R. Walsh)

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ABSTRACT

Detonation of military munitions from live-fire and blow-in-place operations results in the deposition of explosives residues on training ranges. Residue accumulation may cause range availability restrictions and adversely affect training. As part of the Strategic Environmental Research and Development Program and through support from the U. S. Army Garrison, Alaska, methodologies were developed for the sampling and analysis of residues. Several munitions were detonated and their residues examined to obtain an estimation of deposition rates for some common military munitions. This paper summarizes and compares tests conducted from 2002 through 2006 on mortar and howitzer rounds. Tests were conducted on snow-covered ice, thereby allowing residue quantification on a per-round basis. Explosives constituents investigated included trinitrotoluene (TNT), cyclotrimethlene-trinitramine (RDX), and cyclotetramethylene-tetranitramine (HMX). Analysis of test results indicates live-fire detonations are very efficient, resulting in about 3×10^{-4}% of the original explosive load in the residues. Blow-in-place detonations, when high order, average an order of magnitude more explosive residue, 3×10^{-3}%. Rounds undergoing low-order detonation will be the most significant short-term source of explosives in the range. Corroded or ruptured dudded rounds are a greater long-term source. These estimates can be used as baseline input for range sustainability and maintenance planning.

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PREFACE

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1 INTRODUCTION

Live-fire training is essential to the preparedness of our armed forces. To conduct live-fire exercises, well-maintained impact ranges are critical. These ranges can no longer be treated as fire-and-forget facilities. Lawsuits at both the Massachusetts Military Reservation (USEPA 2000, Clausen et al. 2004) and Eagle River Flats in Alaska (USAEC 2005) have resulted from the environmental impacts of training activities. These lawsuits and the potential of others to restrict or eliminate training activities have triggered a need to quantify the impact that the detonation of munitions, both live-fire and blow-in-place, have on ranges.

Much of the original work on characterizing residues on active military ranges was done with soils (Walsh et al. 1997; Jenkins et al. 1998, 2006; Thiboutot et al. 1998, 2004; Radtke et al. 2002). The heterogeneous particulate nature of the residues made sampling and analysis difficult, with several studies required to develop methods to overcome these problems (Jenkins et al. 1997, 1999, 2005; Walsh et al. 2000). The results from these studies provided a good indication of the accumulation and distribution of energetic residues in areas sampled, but no data were available for the live-fire detonation of single rounds. Other work has been done on blow-in-place (BIP) detonation of high-explosive rounds both in the United States and Canada (Pennington et al. 2004, 2005) and in Norway, but results have been difficult to interpret because 1) some rounds were detonated without fuzes, 2) the detonation plume could not be accurately demarcated, 3) various donor charges were used, or 4) the same test areas were used for multiple tests, leading to possible cross-contamination.

To circumvent these issues, the U. S. Army Engineer Research and Development Center's Cold Regions Research and Engineering Laboratory (CRREL) has been testing munition detonation on snow-covered ranges since 2000. Work by Collins and Calkins (1995) at the Eagle River Flats impact area on Fort Richardson, Alaska, in 1991 indicated that detonation plumes from live-fired munitions were easily discernable and that collection of residue samples may be relatively straightforward. In 2000, Jenkins (2002) reported a method to estimate the composition and mass of residues deposited from both live-fire and BIP tests with mortar rounds and other munitions using snow-covered ranges. Results using this approach are summarized in Hewitt et al. (2003). Although the residue plume was easily demarcated, soil thrown up from the detonations in some tests made samples processing more difficult than anticipated. A solution to this problem was to test on snow underlain with ice. Tests conducted by Walsh in 2002 and 2004 (Hewitt et al. 2003, Walsh et al. 2005a) at the Eagle River Flats impact range (ERF) entailing the sampling of residues from live-fire and BIP mortar and howitzer projectiles indicated that “clean” plumes containing only detonation residues were achievable. Processing and analysis of the samples were simplified by the absence of soil.

This paper reports the results of several studies of both live-fire and blow-in-place detonations of high-explosive (HE) mortar and artillery projectiles on snow-covered ice in Alaska. Per-round residue quantities are given for the high-explosive constituents for each type of round. A comparison between the two detonation methods and between mortar and artillery rounds will be discussed.

2 METHODS

All tests were conducted on snow-covered ice in active impact areas in Alaska. Prior to detonation, background snow samples were taken in the test area. For live-fire tests, rounds were directed into an area that had not been previously fired on that winter. Detonations were spaced as much as possible to avoid overlap between plumes. Where this failed, multi-impact plumes were sampled and the results divided to get a per-round estimate. For BIP tests, projectiles were spaced 50 m apart along a line in a clean area. For larger rounds, 60-cm ice blocks were placed beneath the projectile to deter blast penetration to ground. Prior to sampling in either case, an unexploded ordnance (UXO) technician or explosive ordnance disposal (EOD) specialist checked the area for UXO.

Sampling Methods

Sampling methods on snow-covered surfaces have been described in detail in previous publications (Jenkins et al. 2002, Walsh et al. 2005a, Hewitt et al. 2003). Following clearance of the area of UXO, the residue plumes were examined and the plume edge demarcated. This was based on a determination of where the soot was no longer consistently visible on the snow surface. The circumference of the plume was walked using a global positioning system to record its outline. Sampling personnel then entered the plume and obtained representative samples. The general method used was to sample random areas within the demarcated detonation plume down to a depth of about 2 cm, depending on snow depth and condition. The original sampling protocol, which we call the discrete sampling method (DSM), required obtaining up to twenty 1-m^2 snow samples, each collected in a separate clean polyethylene bag. Most tests employed the multi-increment sampling method, as it is more expedient, results in better coverage of the plume, allows more quality control samples, and results in fewer samples to be processed. For the multi-increment sampling method, approximately 100 increments are collected in a systematic-random manner with a 10- × 10-cm scoop, depositing the increments into a clean polyethylene bag. Replicate multi-increment samples are collected to test for uncertainty derived from the small total area collected, generally less than 1%.

To verify that the plume is correctly demarcated, multi-increment 10- × 10-cm samples are collected in annular bands of 0–3 and 3–6 m outside the plume (OTP). Replicate OTP samples are randomly taken to test for uncertainty. Inside the plume, duplicate 20- × 20-cm by 40-increment multi-increment samples may be taken, facilitating the acquisition of 10- × 10-cm subsurface samples beneath the sampled point to test for correct depth of sampling. Other quality control procedures conducted include sampling in bands within the plume based on radial distance from the detonation point and perceived soot densities. These procedures test for proximity and density biases and were used primarily with the DSM method.

Analysis Methods

Upon completion of sampling, the snow samples were transported to a nearby lab facility where they were rebagged to avoid contamination from the exterior of the sample bag. The rebagged samples were then double-bagged and placed in clean plastic tubs for melting. Double-bagging and placement in tubs prevents loss of the sample from leakage if the bag is pierced by a sharp piece of fragmented ordnance. Sample temperature was kept below 10°C. Samples from each detonation were processed as a batch, with the samples containing the least visible residues (OTPs and subsurface samples) processed before samples with heavier residues.

The sample processing entailed filtering of the melted snow sample and concentration of the filtrate (Jenkins et al. 2000, 2002). The liquid sample was passed through a glass microfiber filter on a vacuum system. The soot fraction was placed in a jar for storage at 5°C and two 500-mL aliquots were taken of the total filtrate. One of these aliquots was stored with the filters as a backup sample while the other was pulled by a vacuum through a solid-phase extraction filter, separating the analytes from the water. The cartridge was then eluted with 5 mL of acetonitrile (AcN), resulting in a 100:1 concentration. The eluted sample was split into two fractions, a 1.5-mL fraction to be stored at the processing laboratory and a 3.5-mL fraction that was shipped to the analytical laboratory along with the soot fraction. Samples containing evidence of high concentrations of residues were shipped in separate containers to reduce the chances of cross-contamination.

Analysis methods are detailed in Hewitt et al. (2005). The main analytes of concern are RDX, HMX (a manufacturing by-product of RDX), and TNT, the main energetic constituents of the high-explosive munitions tested. Soot extractions were done on a shaker table with AcN (30–100 mL). Extracts from both the soot and filtrate fractions were analyzed using either gas chromatography–electron capture detection (GC-ECD) or reverse-phase high-performance liquid chromatography (RP-HPLC) or both instruments. Detection limits for the RP-HPLC are approximately 30 µg/L for filter extracts and 20 µg/L for the aqueous extracts. Detection limits for the GC-ECD are between 1 and 30 µg/L for the soot extracts and 1 µg/L for the aqueous extracts. Results are reported on a mass basis for these tests rather than surface concentration (µg/m^2) or soil concentration (µg/kg), thereby allowing analysis of residues on a per-round basis.

3 TESTS

Tests were conducted at ERF and Donnelly Training Area Washington Range impact area (DTA). ERF is an estuarine salt marsh that floods during lunar high tides, building up a layer of ice over the mud and vegetation. It is the only large-caliber impact area on Fort Richardson and is an active range during the winter months. Munitions from 60-mm to 120-mm mortar rounds and 105-mm artillery projectiles are fired into ERF. Depending on snow depth, an ice road can be cleared into the impact area to facilitate testing. Donnelly Training Area is a vast training range located on the former Fort Greely near Delta Junction. Washington Impact Range is located along the Delta River floodplain, which is a cobbled area that generally freezes over during winter from overflow of the river. The area used for these tests was a new extension of the range that had not been previously used. Range access was arranged through U. S. Army Garrison, Alaska, Range Control.

Both locations were utilized during the winter months, between January and March. Temperatures ranged from near 0° to –35°C. For all tests, winds were under 3 m/s and skies were generally overcast. Precipitation occurred only during part of one test. These conditions were almost ideal for these tests.

Tests were conducted using one of two methods of detonation: live fire or blow-in-place. Only one detonation method was used during each test. In all tests, only high-order detonations were sampled. Each series of tests was conducted and sampled the same day when possible. For BIP tests, most rounds were detonated within seconds of each other.

Live-Fire Tests

The five munitions tested using live-fire detonations (Hewitt et al. 2005; Walsh et al. 2005b, 2005c, 2006a) are listed in Table 1. A minimum of seven detonations was sampled for each munition. Results indicate that all rounds sampled went high order (>99.99% consumption of energetic materials). The majority of munitions tested contained Composition B (Comp B) explosive filler (60% RDX [9% of which can be HMX], 39% TNT, 1% wax) with one test having TNT as the filler. Where applicable, constituents of interest in the fuze are also added to the explosives load.

Table 1. Live-fire detonation tests.

Munition	Date tested	Test location	Number of rounds	Filler	Mass per round RDX (g)	Mass per round HMX* (g)	Mass per round TNT (g)
60-mm mortar (M888)	Jan 06	ERF	7	Comp B	230	—	140
81-mm mortar (M374)	Mar 02	ERF	14	Comp B	598	—	371
120-mm mortar (M933)	Feb 05	ERF	8	Comp B	1794	0.12	1166
105-mm howitzer (M1)	Mar 02	ERF	13	Comp B	1274	—	812
155-mm howitzer (M107)	Jan 05	DTA	7	TNT	21	—	6622
155-mm howitzer (M107)	Jan 05	DTA	7	Comp B	4212	—	2724

* HMX may constitute up to 9% of total RDX mass as a manufacturing by-product.

Tests with all rounds except the 120-mm mortar rounds were sampled the same day they were fired. The 120s were sampled the following morning because of darkness and the presence of low-order and dudded rounds. For all tests, weather conditions were near ideal. A light snow was falling just prior to the completion of firing the 60-mm projectiles. No other precipitation occurred during testing. All but the 155-mm rounds were fired as part of training exercises, giving us limited influence on the placement and spacing of the rounds. The 155s were fired in support of our research.

BIP Tests

The three munitions tested using BIP detonation (Walsh et al. 2005a, 2006b) are listed in Table 2. A minimum of seven detonations was sampled for each munition. Results indicate that all rounds sampled went high order, although low-order detonations in proximity to at least one round were recorded. The majority of tests was conducted with Comp B with one test having TNT as the filler. All test projectiles but one were fuzed. Where applicable, constituents of interest in the fuze are also added to the explosives load.

Table 2. BIP detonation tests.

Munition	Date tested	Test location	Number of rounds	Filler	Mass per round		
					RDX (g)	HMX* (g)	TNT (g)
81-mm mortar (M374)	Jan 04	ERF	7	Comp B	598	—	371
105-mm howitzer (M1)	Jan 04	ERF	7	Comp B	1274	—	812
155-mm howitzer (M107)	Mar 04	ERF	7	TNT	21	—	6622
155-mm howitzer (M107)	Mar 04	ERF	14	Comp B	4212	—	2724

* HMX may constitute up to 9% of total RDX load as a manufacturing by-product.

With one exception, all tests conducted with horizontal fuzed rounds used one block of C4 explosive as the donor charge. This test, utilizing seven of the 155-mm Comp B projectiles, had three fuzed projectiles set up vertically, three fuzed projectiles set up horizontally with two blocks of C4, and one unfuzed projectile set up horizontally (Walsh et al. 2006b). The 81-mm test was carried out over three consecutive days. The 105-mm test spanned two days. The 155-mm tests were conducted over three consecutive days, with seven projectiles detonated and sampled each day. Climatic conditions over these multi-day tests were stable.

4 RESULTS

A series of 10 tests over four years has been conducted on residues resulting from live-fire and blow-in-place detonations of artillery and mortar rounds on snow-covered ice in Alaska. A total of 84 plumes resulting from the detonation of 91 rounds was sampled. Background samples taken at each site prior to testing contained no detectable explosives, indicating clean snow surfaces.

Table 3 contains the results of the live-fire testing. In cases where plumes contained multiple detonations, only single-detonation plumes were used to derive average areas. Residue results are for all detonations sampled. ND signifies that residue concentrations were below detection limits for the analytical methods. Per-round total residues are given as mass and percentage of the original explosives load, which includes the fuze constituents. To put these numbers in perspective, we define a high-order detonation as one that results in less than 1.0×10^{-2}% of the HE load deposited as residues.

Table 3. Per-round results of live-fire detonation tests.

Munition	Number of rounds	Plume area (m^2)	RDX (mg)	HMX (mg)	TNT (mg)	Total (mg)	Total (%)
60-mm mortar (M888)	7	214	0.076	ND	ND	0.076	2.0×10^{-5}
81-mm mortar (M374)	14	230*	8.3	ND	1.1	9.4	1.0×10^{-3}
120-mm mortar (M933)	8	450*	17.0	1.3	2.8	21.0	7.0×10^{-4}
105-mm howitzer (M1)	13	530*	0.095	ND	0.17	0.27	1.3×10^{-5}
155-mm howitzer (M107—TNT)	7	757	ND	ND	ND	<0.1	$<1.5 \times 10^{-6}$
155-mm howitzer (M107—Comp B)	7	938	0.3	ND	0.009	0.31	4.4×10^{-6}

* Area is the average of single detonation plumes only.

Table 4 contains the results of the BIP testing. The mass of the donor charge (520 g of RDX in each block) and relevant fuze constituents are added to the explosive load for all tests. Detonation residues for single blocks of C4 are given for reference at the bottom of the table. The blocks were initiated with blasting caps in all tests.

Table 4. Per-round results for blow-in-place detonations.

Munition	Number of rounds	Plume area (m^2)	RDX (mg)	HMX (mg)	TNT (mg)	Total (mg)	Total (%)
81-mm mortar (M374)	7	820	130	23	ND	150	1.0×10^{-2}
105-mm howitzer (M1)	7	860	41	8.7	ND	50	1.9×10^{-3}
155-mm howitzer (M107—TNT)	7	1970	5.0	0.21	10	15	2.1×10^{-4}
155-mm howitzer (M107—Comp B)	7	1620	15	1.0	ND	16	2.1×10^{-4}
155-mm howitzer (M107—Comp B[1])	3	650	7.9	4.3	ND	12	1.6×10^{-4}
155-mm howitzer (M107—Comp B[2])	3	1370	19	3.0	ND	22	2.7×10^{-4}
155-mm howitzer (M107—Comp B[3])	1	1010	54	7.4	ND	61	8.1×10^{-4}
C4 Block (M023)	11	138	12	7.4	ND	19	2.6×10^{-3}

[1] Vertical orientation, fuzed, one donor charge

[2] Horizontal orientation, fuzed, two donor charges

[3] Horizontal orientation, non-fuzed, one donor charge

A minimum of two and generally three multi-increment samples were collected within all plumes. The exceptions are the 81-mm and 105-mm live-fire plumes that had only DSM samples taken within the plumes. Subsurface samples obtained from random plumes averaged 5% of values obtained for surface samples in the four cases where these tests were performed. Generally, duplicate subsurface tests were conducted in each of these cases. In one case, there was evidence of particles of filler in the subsurface samples (residue mass >80% of plume result). In this case, these residue values were added to the surface values to calculate the estimated plume residue masses. In the one case (out of 10) where OTP residues amounted to more than 3.5% of the residues within the plume, the residues and sampled area were added to the plume results. Excluding this one case, residues outside the demarcated plume averaged 1.3% of those inside the plume.

Processing and laboratory QC tests also were conducted. Spike recoveries for the analytical instrumentation were within 5% of expected values. Filtered water blanks run through the filtration equipment, the SPE equipment, and the analytical instrumentation all indicated no cross-contamination during the processing of the samples. Splits of filtrates (three per sample) agreed on average to within 5% (Range: 1.9%–6.7%).

5 DISCUSSION

The results of these tests indicate that live-fire and BIP detonations of the tested munitions will not result in appreciable explosives residue mass on a per-round basis. The high-order detonation of projectiles leaves only milligram quantities of explosives residues. However, the cumulative effect of firing tens of thousands of rounds into an area may lead to the accumulation of residues, specifically RDX, that may lead to groundwater contamination concerns. For RDX, drinking water limits have been set at 2 µg/L. There are many variables that will affect whether this limit is exceeded in the presence of residues, but residues quantity and concentration are obvious factors.

Live-fire detonations leave less residues than BIP detonations. The live-fire residues amounted to 3.3×10^{-4}% of the explosives load for all rounds tested and 2.5×10^{-4}% for rounds that also were blown in place. For BIP rounds, the average was 3.1×10^{-3}%, an order of magnitude greater than for live-fire detonations. Comparing mortar rounds to artillery rounds, mortar rounds are less efficient during live fire detonations by two orders of magnitude, 6×10^{-4}% versus 6×10^{-6}%. For BIP detonations, our data are incomplete, but preliminary results indicate one order of magnitude difference, 1×10^{-2}% for mortar rounds versus 2×10^{-3}% for artillery rounds. This gap may close when the larger (120-mm) mortar round is tested.

The implications of these results on range management and sustainability have to be taken into context with the number of rounds fired into an impact area and the estimated dud and low-order rates for these munitions. In a report of findings by Dauphin and Doyle (2000), dud rates for high-explosive munitions average 3.37% and low-order detonations average 0.09%. Artillery rounds tend to have higher overall dud and low-order rates (4.68% and 0.16%) than mortar rounds (2.91% and 0.08%). Unexploded ordnance blown in place in the field that go high order, as in our tests, are not a significant source of residues at these dud rates. The low-order rounds, detonated dudded rounds that go low order, and unaddressed duds, however, are immediate and legacy concentrated sources for high amounts of explosives on ranges. Our experience in the field indicates that Dauphin and Doyle’s figures may be low, as we have witnessed dud rates up to 25% and low-order detonation rates of at least 5% for mortars during military training exercises.

As an example, we will look at 81-mm mortar rounds. Using Dauphin and Doyle’s figures, for every 10,000 rounds fired, 205 rounds will fail to detonate and two will go low order. Explosives residues from the 9,793 functioning rounds will total about 94 g spread out over the area encompassed by the various target areas. The two low-order rounds will result in about 950 g of explosives near one or two targets on the range, assuming 50% consumption of the original explosive mass in the projectile. If detonated in place, the dudded rounds will result in approximately 31 g of residues distributed among the various target areas. If left unaddressed on the range, over 200 kg of explosives will eventually enter the ecosystem, either through corrosion of the body or breaching of the projectile by nearby detonations. If low-order and dud rates are as high as witnessed during training exercises, the deposition mass of these energetic residues will be significantly higher. It is obvious that to sustain range activities in an environmentally responsible manner, dudded rounds must be tracked and addressed and low-order rounds should be cleaned up if possible.

6 SUMMARY

Live-fire high-order detonations of standard U. S. Army mortar and artillery munitions will leave very little residue on impact ranges and should not be a sustainment issue, even when fired into ranges in large quantities. Low-order detonations may be an issue if low-order rates are higher than those stated in the literature. Cleanup of low-order explosives debris, including collecting and disposing of the larger chunks of explosives, should be considered where practical. Dudded rounds need to be tracked and addressed to avoid future environmental problems. Proper BIP detonation of dudded rounds will result in much lower concentrations of explosives residues and ensure sustained use of vital training ranges.

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APPENDIX A: DATA TABLES

The following tables contain data for individual tests as well as an expansion of the results depicted in Tables 3 and 4 in the body of this paper.

81-mm BIP / Comp B / Protocol tests			
	RDX (mg)	**HMX (mg)**	**TNT (mg)**
1	15	8.6	ND
2	4.7	4.3	ND
3	13	1.6	ND
4	540	57	ND
5	34	7.3	ND
6	270	62	ND
7	65	23	ND
Range	4.7–540	1.6–62	—
Median	34	8.6	ND
Mean	135	23	ND

105-mm BIP / Comp B / Protocol tests			
	RDX (mg)	**HMX (mg)**	**TNT (mg)**
1	15	3.9	ND
2	16	4.8	ND
3	24	7.8	ND
4	14	6.1	ND
5	173	19	ND
6	25	12	ND
7	17	7.3	ND
Range	14–170	3.9–19	—
Median	17	7.3	ND
Mean	41	8.7	ND

155-mm BIP / Comp B / Baseline tests			
	RDX (mg)	**HMX (mg)**	**TNT (mg)**
1	15.4	2.6	ND
2	4.4	ND	ND
3	5.8	0.93	ND
4	28.6	1.7	ND
5	21.5	0.18	ND
6	1.9	ND	ND
7	23.7	0.6	ND
Range	1.9–28.6	ND–2.6	—
Median	15.4	0.93	ND
Mean	14.5	0.86	ND

155-mm BIP / Comp B / Alternatives tests			
	RDX (mg)	**HMX (mg)**	**TNT (mg)**
Vertical			
8	1.5	0.85	ND
9	20	9.5	ND
10	2.1	2.5	ND
Range	1.5–20	0.85–9.5	—
Median	2.1	2.5	ND
Mean	7.9	4.3	ND
2-donor			
11	17	6.7	ND
12	23	1.4	ND
13	16	0.88	ND
Range	16–23	0.88–6.7	—
Median	17	1.4	ND
Mean	19	3.0	ND
No fuze			
14	54	7.4	ND

155-mm BIP / TNT			
	RDX (mg)	**HMX (mg)**	**TNT (mg)**
1	6.0	ND	9.9
2	6.9	1.5	18
3	5.9	ND	12
4	ND	ND	15
5	ND	ND	7.7
6	4.3	ND	3.5
7	12	ND	6.3
Range	ND–12	ND–1.5	3.5—18
Median	5.9	ND	9.9
Mean	5.0	0.21	10

81-mm Live-fire			
	RDX (mg)	**HMX (mg)**	**TNT (mg)**
1 (Single)	5.4	ND	2.2
2 (13 detonations)	8.5	ND	1
Range	5.4–8.5	—	1.0–2.3
(As 2) Median	—	ND	—
Mean	7.0	ND	1.6
(As 14) Median	8.5	ND	1.0
Mean	8.3	ND	1.1

105-mm Live-fire / Comp B / Single detonation plumes			
	RDX (mg)	**HMX (mg)**	**TNT (mg)**
1 (S1)	0.084	ND	0.13
2 (S4)	0.17	ND	0.21
3 (S9)	0.025	ND	0.043
5 (S10)	0.056	ND	0.13
6 (S11)	0.26	ND	0.031
7 (S12)	0.1	ND	0.16
8 (S13)	0.038	ND	0.21
Range	0.025–0.26	—	0.031–0.21
Median	0.084	ND	0.13
Mean	0.10	ND	0.13
9 (S2-Dbl-ea.)	0.085	ND	0.14
10 (S7-Quad)	0.082	ND	0.25
Range (All)	0.025–0.26	ND	0.031–0.25
Median (All)	0.082	ND	0.16
Mean (All)	0.095	ND	0.17

60-mm Live-fire / Comp B			
	RDX (mg)	**HMX (mg)**	**TNT (mg)**
1	0.090	ND	ND
2	0.048	ND	ND
3	0.19	ND	ND
4	0.043	ND	ND
5	0.06	ND	ND
6 (Dbl-ea.)	0.050	ND	ND
	0.050	ND	ND
Range	0.043–0.19	—	—
Median	0.050	ND	ND
Mean	0.076	ND	ND
Standard deviation	0.05		
% RSD	69%		

120-mm Live-fire			
	RDX (mg)	**HMX (mg)**	**TNT (mg)**
1	8.8	0.93	1.1
2	29	1.4	2.1
3	35	2.3	6.9
5	11	0.069	0.56
6	8.5	0.46	0.24
7	0.75	0	0.15
8	28	3.8	8.3
Range	0.75–35	ND–3.8	0.15–8.3
Median	11	0.93	1.1
Mean	17	1.3	2.8

155-mm Live-fire / Comp B			
	RDX (mg)	**HMX (mg)**	**TNT (mg)**
1	0.18	ND	ND
2	0.85	ND	ND
3	0.12	ND	ND
4	0.28	ND	ND
5	0.11	ND	ND
6	0.34	ND	0.06
7	0.24	ND	ND
Range	0.11–0.85	—	ND–0.06
Median	0.24	—	—
Mean	0.30	—	—

Expanded Table 3. Results of live-fire detonation tests (per-round basis).

Munition	Number of rounds	Plume area (m^2)	Mean RDX (mg)	Median RDX (mg)	Range RDX (mg)	RDX[†] deposited (%)	Mean HMX (mg)	Median HMX (mg)	Range HMX (mg)	Mean TNT (mg)	Median TNT (mg)	Range TNT (mg)	Total of means (mg)	Total load residues (%)	% of residues as RDX
60-mm mortar (M888)	7	214	0.076	0.050	0.043–0.19	8.2E-05	ND	ND	—	ND	ND	—	0.076	2.0×10^{-5}	100
81-mm mortar (M374)	14	230*	8.3	8.5	5.4–8.5	2.3E-03	ND	ND	—	1.1	1.0	1.0–2.2	9.4	1.0×10^{-3}	88
120-mm mortar (M933)	8	450*	17	11	0.75–35	1.7E-03	1.3	0.93	ND–3.8	2.8	1.1	0.15–8.3	21	7.0×10^{-4}	73
105-mm howitzer (M1)	13	530*	0.095	0.082	0.025–0.26	1.2E-05	ND	ND	—	0.17	0.16	0.031–0.25	0.27	1.3×10^{-5}	38
155-mm howitzer (M107-TNT)	7	757	ND	ND	—	—	ND	ND	—	ND	ND	—	0	0	—
155-mm howitzer (M107-Comp B)	7	938	0.3	0.24	0.11–0.85	1.2E-05	ND	ND	—	0.009	ND	ND–0.060	0.31	4.4×10^{-6}	97

* Area is the average of single detonation plumes only.

[†] Assumes no HMX in Comp B if no HMX in residues. Pro-rated otherwise.

Expanded Table 4. Results for blow-in-place detonations (per-round basis).

Munition	Number of rounds	Plume area (m^2)	Mean RDX (mg)	Median RDX (mg)	Range RDX (mg)	RDX[†] deposited (%)	Mean HMX (mg)	Median HMX (mg)	Range HMX (mg)	Mean TNT (mg)	Median TNT (mg)	Range TNT (mg)	Total of means (mg)	Total load residues (%)	% of residues as RDX
81-mm mortar (M374)	7	820	130	34	4.7–540	2.3E-02	23	8.6	1.6–62	ND	ND	—	150	1.0×10^{-2}	85
105-mm howitzer (M1)	7	860	41	17	14–170	4.5E-03	8.7	7.3	3.9–19	ND	ND	—	50	1.9×10^{-3}	82
155-mm howitzer (M107-TNT)	7	1970	5.0	5.9	ND–12	1.6E-03	0.21	ND	ND–1.5	10	9.9	3.5–18	15	2.1×10^{-4}	33
155-mm howitzer (M107-Comp B)	7	1620	15	15	1.9–29	5.7E-04	1.0	1.0	ND–2.6	ND	ND	—	16	2.1×10^{-4}	94
155-mm howitzer (M107-Comp B[1])	3	650	7.9	2.1	1.5–20	3.3E-04	4.3	2.5	0.85–9.5	ND	ND	—	12	1.6×10^{-4}	65
155-mm howitzer (M107-Comp B[2])	3	1370	19	17	16–23	7.1E-04	3.0	1.4	0.88–6.7	ND	ND	—	22	2.7×10^{-4}	86
155-mm howitzer (M107-Comp B[3])	1	1010	54	—	—	2.2E-03	7.4	—	—	ND	ND	—	61	8.1×10^{-4}	88
C4 block (M023)	11	138	12	4.8	4.5–61	5.3E-03	7.4	4.3	2.6–26	ND	ND	—	19	2.6×10^{-3}	62

[1] Vertical orientation, fuzed, one donor charge

[2] Horizontal orientation, fuzed, two donor charges

[3] Horizontal orientation, non-fuzed, one donor charge

[†] Assumes no HMX in Comp B if no HMX in residues. Pro-rated otherwise.

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14. ABSTRACT

Detonation of military munitions from live-fire and blow-in-place operations results in the deposition of explosives residues on training ranges. Residue accumulation may cause range availability restrictions and adversely affect training. As part of the Strategic Environmental Research and Development Program and through support from the U. S. Army Garrison, Alaska, methodologies were developed for the sampling and analysis of residues. Several munitions were detonated and their residues examined to obtain an estimation of deposition rates for some common military munitions. This paper summarizes and compares tests conducted from 2002 through 2006 on mortar and howitzer rounds. Tests were conducted on snow-covered ice, thereby allowing residue quantification on a per-round basis. Explosives constituents investigated included trinitrotoluene (TNT), cyclotrimethlene-trinitramine (RDX), and cyclotetramethylene-tetranitramine (HMX). Analysis of test results indicates live-fire detonations are very efficient, resulting in about 3×10^{-4}% of the original explosive load in the residues. Blow-in-place detonations, when high order, average an order of magnitude more explosive residue, 3×10^{-3}%. Rounds undergoing low-order detonation will be the most significant short-term source of explosives in the range. Corroded or ruptured dudded rounds are a greater long-term source. These estimates can be used as baseline input for range sustainability and maintenance planning.

15. SUBJECT TERMS

Blow-in-place	Energetics	Ice	Low-order detonation
Donor charge placement	High explosives	Impact ranges	Residues
	High-order detonation	Live fire	Snow

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