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Cold Regions Research and Engineering Laboratory

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Residues from Live Fire Detonations of 155-mm Howitzer Rounds

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ABSTRACT: We quantified the explosives residues deposited by live fire of military munitions to estimate the load of unreacted energetics to soils. This value is needed to estimate potential explosives migration to groundwater. We sampled the impact and firing point residues of seven Composition B filled and seven TNT filled 155-mm howitzer projectiles (one of the five most commonly used rounds in the U.S. arsenal, and live fire residues had not been collected for them). The tests were conducted on an ice- and snow-covered range, which allowed us to sample the residues on an explosives-free surface and to visually demarcate the extent of the residue plume. We used a sampling protocol where 100 snow sample increments of 0.01 m^2 were taken from the entire area of the demarcated plume and combined into one sample. Three replicate samples were taken from within each plume. Samples were also taken outside the visible plume to ensure that sample demarcation was correct. These live-fire detonations were extremely clean. For the Composition B (Comp B) rounds, the mass of RDX and TNT deposited ranged from below detection to 1 mg and 190 µg, respectively, for an individual round. Only 10^{-7} to 10^{-5} % of the high explosives in the original 6.9-kg Comp B round was recovered. For the TNT-filled rounds, no TNT or TNT breakdown products were recovered. Our findings are consistent with other research: live-fire, high-order detonations deposit very little explosive compounds and are not likely to be a threat to groundwater.

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PREFACE

This report was prepared by Michael R. Walsh, Engineering Resources Branch, Dr. Susan Taylor, Environmental Sciences Branch, Marianne E. Walsh, Environmental Sciences Branch, Susan Bigl, Geophysical Sciences Branch, Kevin Bjella, Environmental Sciences Branch, Dr. Thomas Douglas, Environmental Sciences Branch, Arthur Gelvin, Engineering Resources Branch, Dennis Lambert, Engineering Resources Branch, Nancy Perron, Snow and Ice Branch, and Stephanie Saari, Engineering Resources Branch, Cold Regions Research and Engineering Laboratory, U.S. Army Engineer Research and Development Center.

Fieldwork on impact ranges requires the cooperation and help of a great many people. We thank MAJ James Johnson, CPT David Hart and his crew from the 4-11th Field Artillery who fired the rounds, George Alexion and Mike North, range control officers at Fort Greely, and Jeff Lipscomb of CRTC for their support with range access. We thank Jim Hug of Bering Sea Eccotech for keeping us safe on the range. We acknowledge and thank the Army Environmental Center, Dr. Bonnie Packer project manager, for funding the bulk of this work. We also thank Charles M. Collins of ERDC-CRREL who funded the firing point sampling with moneys from the U.S. Army Alaska Soil and Water Fund.

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1 INTRODUCTION

Firing ranges provide soldiers the opportunity to train using a variety of munitions. However, live fire training will result in unexploded ordnance (UXO), low-order detonations (where a significant fraction of the explosive remains undetonated), and high explosive (HE) residues from munitions that detonated as intended (high-order detonation). All of these sources may contaminate the soil and the groundwater, thereby threatening human health and the environment.

Hundreds of thousands of rounds are fired into military impact ranges each year (Foster 1998). The majority of the rounds tested to date detonated as designed and deposited very little HE (Hewitt et al. 2003, Taylor et al. 2004a). Nevertheless, it is important to know the quantity and variability of the HE not consumed in the detonation process for specific munitions as small quantities from many rounds can add up to large quantities of explosives. This is a difficult task because the residues are mixed with soil and these can contain HE from previous detonations. Additionally, when impacted into soil, the area over which the residue was deposited cannot be determined—a key element in estimating the mass of HE deposited.

Jenkins et al. (2000) circumvented these difficulties by collecting and analyzing live fire detonation residues from snow-covered surfaces. The frozen ground minimized soil contamination, and the snow provided a clean sampling background that decreased the chances of cross-contamination from prior range activities. The snow also made the dark detonation residue highly visible, allowing the residue plume to be mapped and measured. This assumes that all of the deposited HE is within the demarcated plume area.

We sampled the residue from seven Composition-B-filled and seven TNT-filled 155-mm howitzer projectiles fired onto Washington Impact Range, Don-

nelly Training Area, Alaska, in January 2005. Composition B (Comp B) is an approximately 60 to 40 mixture of military-grade RDX and TNT and usually contains some HMX, a manufacturing impurity in RDX. We selected 155-mm rounds for testing because they are one of the top five most commonly used rounds in the U.S. arsenal (Papadopoulos 2003), they contain a large mass of HE, and live-fire detonation residues had not been collected for them. Previous studies (Taylor et al. 2004b, Walsh et al. 2005) sampled residues from blow-in-place (BIP) detonations of 155-mm rounds. However, comparison of BIP with live fire detonations for 60-, 81-, and 105-mm rounds indicate that the BIP detonations, even if they are high order, deposit more HE than live-fire rounds (Hewitt et al. 2003). We collected the residues deposited both at the impact points, where the round detonated, and at the firing point to estimate the HE loads and the propellant loads, respectively.

2 FIELD TESTS

Field Site

The live fire tests were conducted on Washington Impact Range, Donnelly Training Area, Alaska. The rounds were fired by the 4-11th Field Artillery from the Bondsteel firing point (UTMWGS84-N7080250, E552813) into an impact area, approximately 8 km away (N7071800 to 2400, E550500 to1100), on the Delta River floodplain (Fig. 1). The gunners used an M-198 Howitzer and a full bag of M3A1 single-based propellant to fire the projectiles the desired distance. Ideally, the rounds are fired into an area underlain with ice and covered with clean snow, and the impact points are separated enough that the residue plumes do not overlap. As strong winds disperse the residues, making the visual demarcation of the plumes difficult, windless conditions are desirable. Low temperature (less than 0°C) and overcast skies help prevent the residues from melting into the snowpack. Because of the cold and the need to collect many samples, it is best if the impact points are easily accessible.

Our impact area generally met these criteria on the days we sampled. The Delta River is a large anastomosing river with a cobble and gravel flood plain characterized, in winter, by intermixed ice and cobble bars. Although the ice cover was not continuous, most of the detonations we sampled occurred on ice and did not break through into the underlying gravel. For the few cases where breakthrough occurred, we did not collect from the small soil-rich areas but did include them as part of the plume. The accuracy of a fired 155-mm projectile is about 50 m, so the rounds could not be spaced systematically. Nevertheless, of the 30 Comp B and 30 TNT rounds fired, seven of each appeared to have non-overlapping plumes, which we sampled. During the two days when the rounds were fired and sampled, 26 and 27 January 2005, winds on the Delta River were light, less than 1 m/s, causing minimal dispersion of the residues, and temperatures were in the –5 to –10°C range.

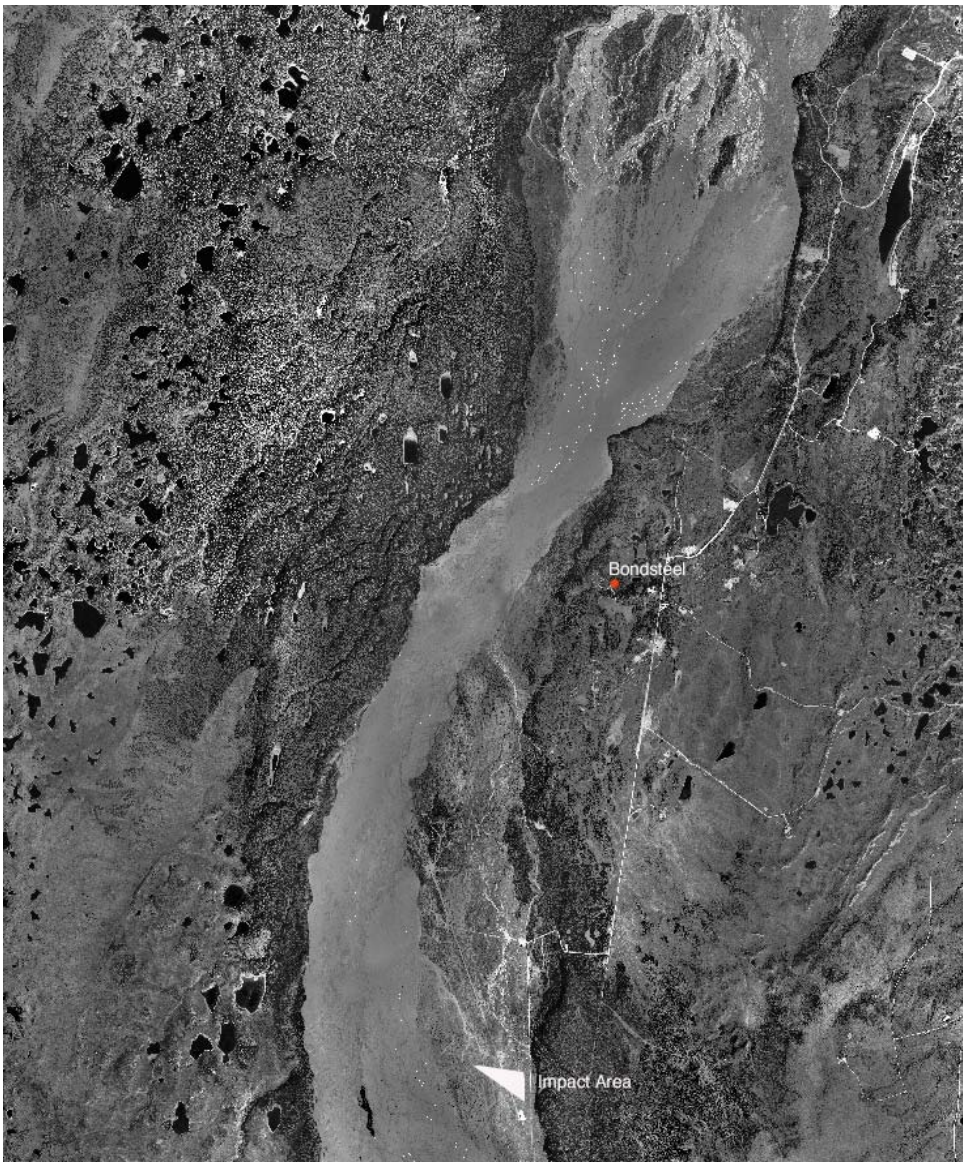


Figure 1. Washington Impact Range, Donnelly Training Area, Alaska, showing the Bondsteel firing point and the impact area, about 8 km distant, on the Delta River floodplain.

Sampling Method

Jenkins et al. (2000) used seven to ten 1-m^2 snow samples to quantify the residues from live fire and blow-in-place detonations (discrete sampling method). This sampling method is time consuming and labor-intensive both in terms of

processing and laboratory analysis. The method is also prone to a sampling bias because people collecting the samples tend to take more samples closer to the crater and in areas where more residues were deposited and the snow is darker.

We, therefore, used an alternative sampling method. We collected approximately 100 snow samples, of 0.01 m^2, from the entire plume and treated them as a single sample (multi-increment sampling method). Although less total surface area is sampled, the large number of smaller increments provides a more widespread coverage of the plume, reducing the tendency towards sampling bias and better estimating the average concentration of the HE in the plume (Jenkins et al. 2005, Walsh et al. 2005). Replicate samples collected from each plume allowed us to test for uncertainty.

To estimate the mass of energetic residues, we need to know the area over which HE is deposited and the average concentration for that area. A critical assumption is that the plume represents the major area of deposition. The plume is composed of soot from the detonation and its depositional pattern can be affected by wind. However, because there is no other way to estimate the area of deposition, we assume that most HE residue is deposited within the plume and tested this assumption by taking two multi-increment samples outside the plume. These samples were taken from concentric rings outside of the plume (OTP). The objectives of OTP sampling are to ensure that the plume was adequately outlined and to determine how much, if any, of the HE is outside of the plume. Samples were obtained for annuli 0 to 3 m and 3 to 6 m from the plume edge.

For all of these samples, we used Teflon-lined aluminum scoops that sampled a 10- by 10- by 1-cm deep volume of snow. All the snow samples were placed in clean, labeled polyethylene bags. Specifics of the firing point and impact point samples are given below.

Firing Point Samples

The 155-mm howitzer was set up in a clean, snow-covered area. For our tests, all rounds were fired from one gun (foreground Fig. 2; Gun 1 Fig. 3). A 50-increment background sample was collected prior to firing the Howitzer. The Comp B and the TNT rounds used the same propellant containing 2.8 kg (6.15 lb) of single based propellant (green bag M3A1).

Figure 2. 155-mm howitzer.

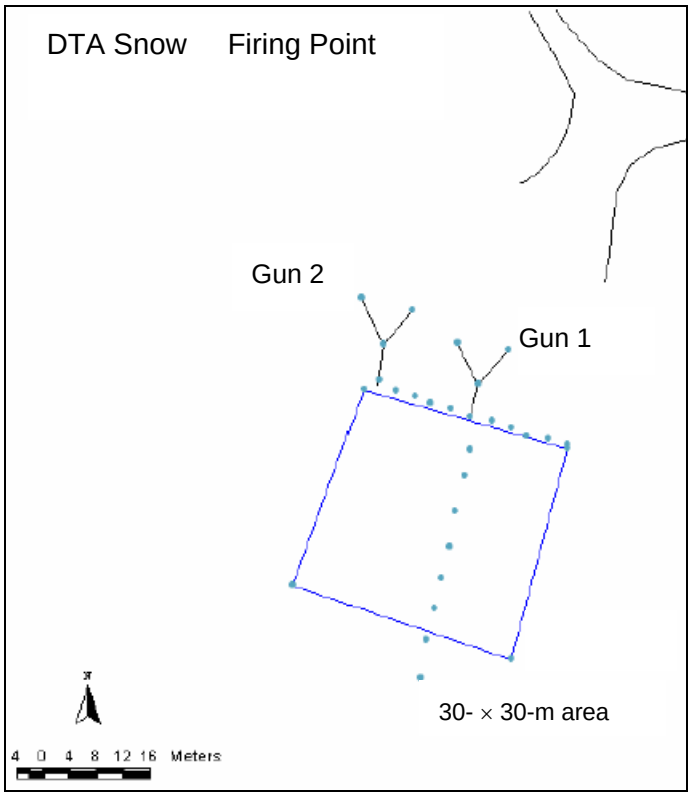


Figure 3. Location of the trays and the snow area sampled for propellant residues. The position of the two howitzer guns is also shown. Only gun 1 was fired.

For the Comp B tests, we placed eight 0.3-m^2 aluminum trays at 5-m intervals out to 40 m along the line of fire and five trays at 3-m intervals out to 15 m perpendicular to the line of fire on either side of the muzzle brake. Figure 3 shows the layout of the trays. In addition, three multi-increment snow samples were taken along the line of fire and included an area 2 m on either side of the trays. Three multi- increment samples were similarly collected perpendicular to the line of fire. The trays were collected and the multi-increment snow samples taken after 30 Comp B rounds had been fired on 26 January.

The gun was not moved and the same gun was used the following day to fire 30 TNT rounds. In this case we did not set out trays because the same propellant was used to fire the Comp B and TNT rounds. After the 30 TNT projectiles had been fired, we collected three multi-increment snow samples from a 30- by 30-m area in front of the gun (Fig. 3), giving us data for a 60-round test. No plume or soot pattern was visible at the firing point, so we selected the areas to be sampled based on where we thought the propellant residues would be deposited.

Impact Point Samples

A 50-increment snow sample of the impact area was collected before firing and served as our background sample. On the two test days, after all 30 rounds had been fired, the impact area was checked by our UXO technician for exposed UXO. We selected 7 of the 30 plumes based on whether or not the projectile had hit a snow and ice area or a gravel bar (the former desirable) and if the resulting plume was visually distinct from any adjacent plumes. The plume perimeters and the locations of the seven selected craters were then mapped with a global positioning system (Fig. 4). Three multi-increment samples of approximately 100 increments were collected inside each demarcated plume. For quality assurance, two multi-increment samples were collected outside the plume, one at 0 to 3 m and the other at 3 to 6 m around the entire plume edge. Each 155-mm howitzer round contains 6.9 kg of Comp B or 6.3 kg of TNT. A typical detonation crater and plume are shown in Figure 5.

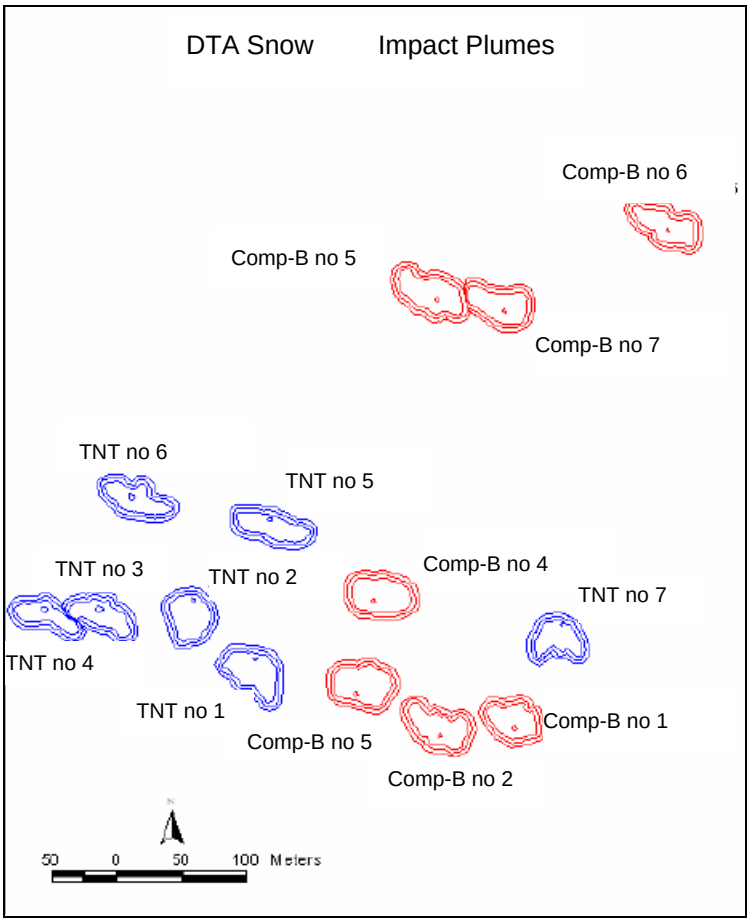


Figure 4. GPS map of impact plumes and OTP areas for all rounds.

Figure 5. Detonation crater and plume formed by Comp B-filled round 7.

Sample Processing and Analysis

The residue on each firing point tray sample was moved to a corner of the tray and then transferred to a piece of aluminum foil. These samples were weighed in the lab and their contents optically examined for propellant residues.

The multi-increment snow samples from both the firing and impact points were kept frozen and transported to Ft. Wainwright for processing. Here, the snow samples were thawed and the water filtered from the soot fraction. Any energetic compounds in the water were concentrated 100:1 using solid-phase extraction following the procedures outlined by Walsh and Ranney (1998). The soot was air-dried and then extracted using acetonitrile. Each sample was shaken with solvent for 18 hours. The energetic concentrations were then determined for the water and the soot fraction using a Reverse-Phase High-Pressure Liquid Chromatograph/Ultra-Violet detector (RP-HPLC-UV) for the firing point samples and a Gas Chromatograph-Electron Capture Detector (GC-ECD) for the impact point samples. To calculate the mass of unreacted energetics deposited on the snow, we multiplied the average concentration of each plume (mass/unit area basis) by the measured area of the plume (Jenkins et al. 2002, Hewitt et al. 2003).

3 RESULTS

Firing Point Samples

Table 1 shows the results for the firing point samples. Not shown is the background sample, which had no detectable energetics. The multi-increment snow samples, taken after firing 30 Comp B rounds, contained 2.4 to 7.8 mg of 2,4-DNT for a swath 40- × 4-m along the line of fire. For the area 30- × 4-m perpendicular to the gun's muzzle brake, 5.7 to 13 mg of 2,4-DNT were recovered. Three 100-increment snow samples were taken of a 30- × 30-m area in front of the gun after all 60 rounds had been fired. These values range from 19 to 110 mg. Reproducibility among the triplicate samples is within a factor of six and the mass of 2,4-DNT per m^2 of snow also varied by a factor of six (Table 1). The variability is likely attributable to the presence or absence of pieces of the unburned propellant.

Table 1. Firing point residues from base propellants use to fire 155-mm howitzers.

Rep	No. of Rounds	Sample location	No. of increments	Sampled snow surface area (m^2)	2,4-DNT mass in snow melt (µg)	2,4-DNT mass in soot (µg)	Mass per m^2 (µg)	Decision unit area (m^2)	Estimated total mass deposited (mg)
1	30	Parallel to gun	91	0.91	8.7	5.1	15	160	2.4
2	30	Parallel to gun	91	0.91	8.1	8.8	19	160	3.0
3	30	Parallel to gun	85	0.85	29	12	49	160	7.8
1	30	Perpendicular	100	1	72	35	110	120	13
2	30	Perpendicular	100	1	13	35	47	120	5.7
3	30	Perpendicular	100	1	20	9	29	120	3.5
1	60	30- x 30-m area	107	1.07	100	28	120	900	110
2	60	30- x 30-m area	99	0.99	14	6.4	21	900	19
3	60	30- x 30-m area	100	1	62	34	96	900	86

For the multi-increment samples taken in the directions parallel and perpendicular to the gun barrel, the per-round deposition rates for 30 rounds are approximately 0.15 and 0.25 mg for the areas sampled. On a per-round basis, the deposition rate in the 30- × 30-m area directly in front of the gun for 60 rounds was on the order of 1.2 mg. These data are rough estimates of energetics deposited from firing the rounds, as we could not delineate the area over which propellants were deposited.

Table 2. Weight of material deposited on 0.3-m^2 aluminum trays set out to collect propellant residues. Directions are based on looking along the gun in the direction of fire.

Tray position	Wt (mg)
5 m in front of gun	835
10 m	1311
15 m	223
20 m	—
25 m	—
30 m	1.1
35 m	—
40 m	—
3 m to right of gun	609
6 m	493
9 m	467
12 m	367
15 m	199
3 m to left of gun	77
6 m	66
9 m	18
12 m	10
15 m	4

Table 2 lists the mass of material deposited on each tray set out to collect propellant residues. The material collected consists mainly of round, clear particles compose of potassium and sulfur that are not propellants and dissolve in acetone (stabilizer or binder component), some metal fragments and beads, pieces of fabric from the propellant bags, and black particles that are aggregates of metal and soot (Fig. 6). Unlike propellant residues collected from 105-mm rounds where the 2,4-DNT was associated with millimeter-sized fibers, the propellant in these samples occurs in irregular, rounded (possibly melted) particles (Fig. 7). These may contain fibers but do not have the characteristic triangular cross section seen in the 105-mm propellant residues. The propellant used for the 105-mm rounds was an 8-mm long by 3-mm-diameter, multi-perforated grain (Fig. 8a), whereas the 155-mm propellant was a 5.5- by 1.5-mm single perforated grain (Fig. 8b) (Technical Manual 9-1300-214). Interestingly, for the propellant used for the 105-mm test, this manual states that “burning of a seven perforation grain produces 12 unburned slivers or pieces of triangular cross section that rep-

resent approximately 15 percent of the total weight of the grain." No description of the residues left by the smaller, single perforation propellant is given.

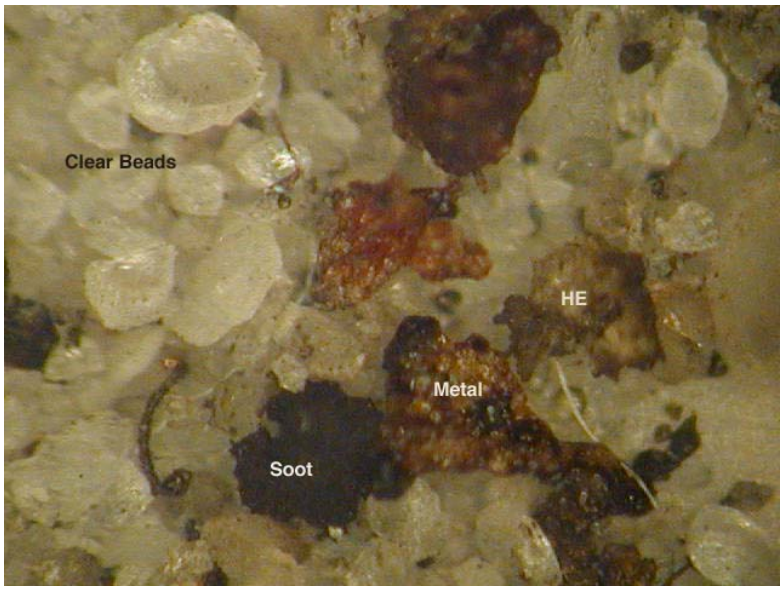


Figure 6. Optical micrograph of material deposited on trays used to collect propellant residues. The field of view is 2 mm.

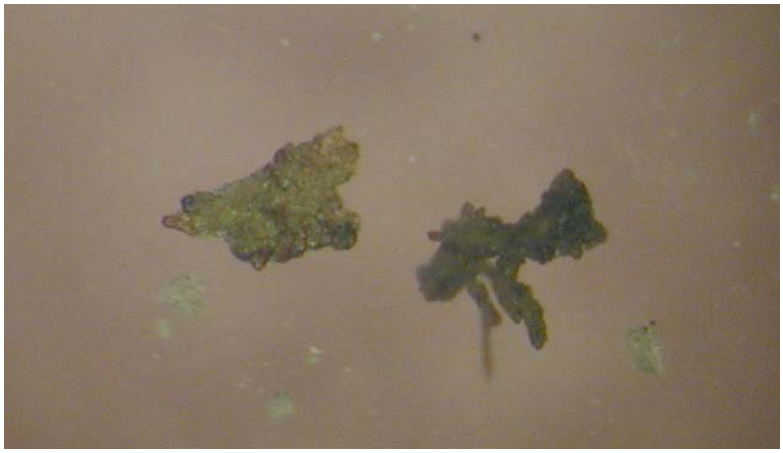
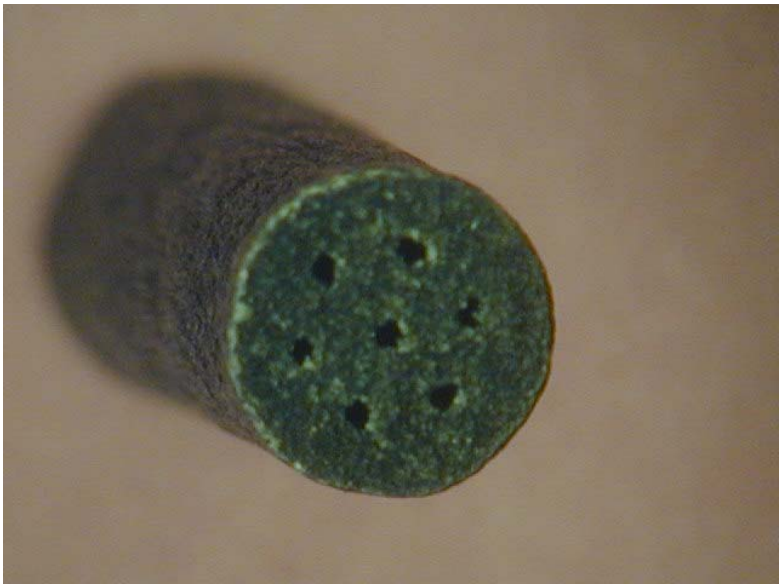


Figure 7. Optical micrograph of 2,4-DNT containing particles. The field of view is 2 mm.



a. Seven-perforation propellant grain used to fire the 105-mm howitzer projectiles.

b. Single-perforated propellant grain used to fire the 155-mm howitzer projectiles.

Figure 8. Optical micrographs of propellant grains. The field of view is 8 mm for both images.

Impact Point Samples

Figure 4 shows the size and location of the plumes sampled. Note that in all cases the Comp B and TNT plumes do not overlap but that two TNT plumes (3 and 4) and two Comp B plumes (5 and 7) have OTP areas that do overlap. The background sample taken from this area had no detectable explosives.

Table 3 shows the results for the Comp B impact point snow samples. Five of the seven plumes had concentrations of RDX above the detection limit, the other two had estimated amounts below the detection limit. The estimated mass of RDX deposited in the plumes ranged from 26 µg (BDL) to 1000 µg, or 10^{-7} to 10^{-5}% of the RDX in the original round. The mean estimated quantity of explosive residues for the seven plumes was 300±250 µg. For three of the plumes (2, 4 and 6), all three multi-increment samples contained RDX above the detection limit. The three samples are within a factor of two of each other.

Table 3. Data collected for the seven live fire detonations of 155-mm, Comp B rounds. The methods detection limit depends both on concentration and on sample size.

Rep no.	Sample type	RDX mass in filtrate (µg)	RDX mass in soot (µg)	TNT mass in filtrate (µg)	TNT mass in soot (µg)	Sampled area (m^2)	Plume area (m^2)	RDX mass deposited (µg)	TNT mass deposited (µg)	RDX plume mean ± s.d. (µg)
1	Plume 1	0.284				1.00	770	218	ND	
2	Plume 1	0.310				1.00	770	238	ND	
3	Plume 1	0.091*				1.00	770	70	ND	180±92
	OTP 0–3 m					1.00	360	ND	ND	
	OTP 3–6m					1.00	410	ND	ND	
1	Plume 2	0.279	0.808			1.00	920	999	ND	
2	Plume 2	0.188	0.770			1.00	920	880	ND	
3	Plume2	0.132	0.583			1.00	920	657	ND	850±170
	OTP 0–3 m				0.044*	1.03	430	ND	19	
	OTP 3–6 m				0.070	1.10	480	ND	31	
1	Plume 3	0.207*				1.50	1050	145	ND	
2	Plume 3	0.090*				1.04	1050	90	ND	
3	Plume 3	0.125*				1.03	1050	127	ND	120±28
	OTP 0–3 m				0.059*	0.60	400	ND	24	

Rep no.	Sample type	RDX mass in filtrate (µg)	RDX mass in soot (µg)	TNT mass in filtrate (µg)	TNT mass in soot (µg)	Sampled area (m^2)	Plume area (m^2)	RDX mass deposited (µg)	TNT mass deposited (µg)	RDX plume mean ± s.d. (µg)
	OTP 3–6 m				0.052*	0.71	450	ND	32	
1	Plume 4	0.316				1.00	1030	324	ND	
2	Plume 4	0.275				1.00	1030	283	ND	
3	Plume 4	0.207				0.94	1030	226	ND	280±49
	OTP 0–3 m				0.074	1.00	390	ND	29	
	OTP 3–6m			0.074*		1.00	450	ND	34	
1	Plume 5	0.098*				1.00	1070	105	ND	
2	Plume 5	0.115*				1.00	1070	122	ND	
3	Plume 5	0.108*				1.00	1070	115	ND	110±9.0
	OTP 0–3 m		0.040*			1.00	440	18	ND	
	OTP 3–6 m				0.045*	1.00	450	ND	20	
1	Plume 6	0.159	0.304			1.00	840	389	ND	
2 Avg†	Plume 6	0.158	0.272			1.00	840	361	ND	
3	Plume 6	0.141	0.174*			1.00	840	265	ND	340±65
	OTP 0–3 m		0.033*			0.66	410	14	ND	
	OTP 3–6 m				0.043*	0.71	466	ND	20	
1 Avg†	Plume 7		0.029*			1.00	900	26	ND	
2	Plume 7	0.422	0.071*	0.21		1.00	900	443	189	
3	Plume 7	0.103*	0.166*			1.00	900	242	ND	240±210
	OTP 0–3 m					0.66	390	ND	ND	
	OTP 3–6 m	0.038*	0.036*			0.71	400	29	ND	

ND- non-detect.
*Present but below the method detection limit. Masses calculated used these values are less reliable.
†Filtrate mass is an average of three replicate aliquots.

TNT was detected in only one of the plumes where its concentration was 6% of the RDX. Because Comp B is a mixture of RDX and TNT, we would have

expected to see TNT in more of these samples. However, TNT is thought to strongly bind to the soot. Thorn et al. (2002) found that it was not possible to recover the TNT from spiked organic (carbon) rich soils.

The 0- to 3-m and the 3- to 6-m OTP areas collectively covered an area roughly 90% as large as the plume. Table 3 shows the results for the OTP samples from the Comp B round detonations. Low concentrations of TNT were detected in 2 of the 14 OTP samples, and below detection levels were found in 6 of the 14 samples. Below detection levels of RDX were found in 3 of the 14 samples. Each value represents less than 3% (30 μg) of the recovered mass of the plumes.

None of the plumes from the TNT rounds contained detectable HE. Because of the proximity of the TNT and Comp B detonation plumes (Fig. 4), we worried about inadvertently sampling one of the Comp B rounds from the previous day. Our results show no RDX, indicating that we sampled only TNT rounds on the second day. We attribute the lack of TNT to its having been consumed in the detonation or irreversibly adsorbed onto soot in the field. Another possibility is that the TNT sorbed onto the soot while both were in solution during the filtering process.* For the OTP surrounding the TNT plumes, no explosive residues were found.

Owing to the thin snow cover (less than 1 to 5 cm) and the cohesive, windblown surface of the snow, we did not take any snow samples below 1 cm. Given the low concentrations of explosives residues on the surface, it is unlikely that unreacted explosives particles were present and that, if present, they were massive enough to travel through the surface into the snow. However, if explosive particles were present beneath the snow surface we would have underestimated the mass of explosives (Walsh et al. 2005).

Comparison with BIP Results

To determine if live fire residues do in fact contain less HE than BIP detonations of 155-mm rounds, we compared our results with previous BIP results (Walsh et al. 2005, Taylor et al. 2004b). More BIP tests than live-fire tests have been conducted because they are easier to arrange and less expensive to do. Also, the tests can be done at a specific location where snow cover, trays, or tarps are present to collect the residue. However, because the rounds' normal detonation train (fuze, primer, and booster) are not used to detonate the round and an unconfined donor charge is used to initiate detonation, BIPs have been found to leave more HE than live-fire detonations.

* Personal communication with Dr. Thomas Jenkins, ERDC-CRREL, 2005.

Walsh et al. (2005) show results for seven Comp B-filled and seven TNT-filled 155-mm rounds that were BIP on a snow cover. For the Comp B rounds, they found between 10^{-3} and 10^{-5} % of the HE originally in the round (0.35 mg median HMX, 10 mg median RDX). Some of the RDX is probably from the C4 donor charge, which is 91% RDX. No TNT was recovered. This range is two to four orders-of-magnitude higher than the range reported here (10^{-7} to 10^{-5}%). For the TNT rounds, the values ranged from below detection to 10^{-4}% of the energetics in the original projectile (more than 6.5 mg mean RDX, more than 6.7 mg mean TNT). RDX was also found in residues of TNT rounds because these were detonated using C4. All these rounds were fuzed.

Seven other unfuzed TNT rounds were BIP over snow and sampled using both trays and snow. These showed significant variation in the amount of TNT in the residue, ranging from 10^{-5} to 2% of the TNT in the original projectile (Hewitt et al. 2003, Taylor et al. 2004b). When high concentrations of TNT were detected, Taylor et al. (2004b) found TNT particles.

Clearly some BIP detonations leave much more HE residue than others. Excluding the three TNT rounds that had high TNT concentrations, BIP detonations deposit on average 10^{-3} to 10^{-4}% of the HE in the round.

4 CONCLUSIONS

We sampled the detonation residue from seven Comp B-filled and seven TNT-filled live-fired 155-mm rounds using the multi-increment sampling method. The multi-increment sampling method used here reduces, but does not eliminate, sampling bias of an area with heterogeneously distributed energetics. However, because smaller area samples are collected relative to the discrete sampling method, the uncertainty of random error increases. The close agreement among the triplicate samples for each of our plumes indicates good replication and thus a low probability of random error. The OTP results indicate that the plumes were delineated correctly and that most of the recoverable residues are represented in the samples.

For the Comp B rounds, low concentrations of RDX were found in 24 of the 35 samples and TNT was found in 9 of the 35 samples. For the TNT rounds, no TNT was found in the residues. We think that any TNT that survived the detonation may have reacted with soot particles, either in the snow or during sample processing, and was destroyed or cannot be extracted. In either case, the TNT from the 155-mm rounds is unavailable for dissolution and consequently is not likely to be of concern as a source for groundwater contamination.

Estimates of the HE mass deposited from the live fire detonations sampled here are an order of magnitude or more lower in concentration than the BIP tests conducted on 155-mm rounds. For the live-fire tests, the mean RDX value of 300 µg is lower than the 10 mg found for blow in place detonations of Comp B rounds. For TNT rounds, no TNT was found above the detection limit for the live-fire tests while more than 13 mg of TNT were found for the blow in place tests. Because most of the live fire tests on training ranges are high order detonations, we think the lower mass values found for the live fire tests are more representative than the blow-in-place values for estimating explosive loads onto training range soils.

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14. ABSTRACT

We quantified the explosives residues deposited by live fire of military munitions to estimate the load of unreacted energetics to soils. This value is needed to estimate potential explosives migration to groundwater. We sampled the impact and firing point residues of seven Composition B filled and seven TNT filled 155-mm howitzer projectiles (one of the five most commonly used rounds in the U.S. arsenal, and live fire residues had not been collected for them). The tests were conducted on an ice- and snow-covered range, which allowed us to sample the residues on an explosives-free surface and to visually demarcate the extent of the residue plume. We used a sampling protocol where 100 snow sample increments of 0.01 m^2 were taken from the entire area of the demarcated plume and combined into one sample. Three replicate samples were taken from within each plume. Samples were also taken outside the visible plume to ensure that sample demarcation was correct. These live-fire detonations were extremely clean. For the Composition B (Comp B) rounds, the mass of RDX and TNT deposited ranged from below detection to 1 mg and 190 µg, respectively, for an individual round. Only 10^{-7} to 10^{-5} % of the high explosives in the original 6.9-kg Comp B round was recovered. For the TNT-filled rounds, no TNT or TNT breakdown products were recovered. Our findings are consistent with other research: live-fire, high-order detonations

15. SUBJECT TERMS

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