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Cold Regions Research and Engineering Laboratory

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Energetic Residues from Blow-in-Place Detonation of 60-mm and 120-mm Fuzed High-Explosive Mortar Cartridges

Michael R. Walsh, Charles M. Collins, and Alan D. Hewitt

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COVER: Explosive Ordnance Disposal (EOD) specialist from the 716th EOD detachment wiring up the initiator for a 120-mm high-explosive projectile, Eagle River Flats, Fort Richardson, AK, February 2008.
(Image by Michael R. Walsh, CRREL).

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Final report

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Abstract: Military live-fire training missions frequently result in unexploded ordnance on training ranges. Disposal of the rounds, often done in situ, is necessary in some cases for range safety or maintenance. In February 2008, the U.S. Army Cold Regions Research and Engineering Laboratory teamed with the 716th Explosive Ordnance Disposal detachment at Fort Richardson, AK, to detonate two series of seven 60-mm and 120-mm fuzed high-explosive (HE) rounds to determine the resulting energetic residues. Each round was detonated using a single block of C4 (91% RDX) as a donor charge. All rounds were separated to allow each detonation plume to be sampled as a distinct decision unit. Samples were collected from the snow surface using multi-increment sampling for residues analysis. The 60-mm plumes averaged 200 mg of HE, 0.022% of the original mass. The 120-mm plumes averaged 25 mg of HE, 7.1×10^{-4}% of the original mass. Quality assurance procedures were conducted both in the field and at the laboratory to ensure data fidelity.

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Preface

This report was prepared by Michael R. Walsh, Engineering Resources Branch, and Alan D. Hewitt and Charles M. Collins, Environmental Sciences Branch, Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Engineer Research and Development Center (ERDC). Manuscript review was provided by Dr. C. L. Grant and Christopher R. Williams. Funding was provided by the U.S. Army Garrison, Alaska, Soil and Water Monitoring Program (Gary Larson, coordinator).

Field work of this nature is complex and requires the involvement and cooperation of many different people and entities. The authors thank L. D. Fleshman, Range Facility Manager, U.S. Army, Alaska, for his support of this and the many tests we have conducted on his ranges over the years. We also thank SFC Jason Doty and the men of the 716th Explosive Ordnance Disposal detachment at Fort Richardson, AK, for taking time from their busy schedules to obtain the munitions required for these tests and then blowing them up. Jeff Bryant of Bering Sea Eccotech supported us as the Site Safety Officer and as our unexploded ordnance technician (UXO Tech III), helping us to avoid any encounters with UXOs. Our field crew included Jon Zufelt, Stephanie Saari, Anna Wagner, Jennifer Fadden, Rebecca Terry (U.S. Army Corps of Engineers, Jacksonville, FL), and Art Gelvin. Back at the lab, Nancy Perron and Marianne Walsh joined in the analysis of the samples. A lot had to happen right and on time to make these tests successful, and this crew made it happen. Our thanks to all of them.

This report was prepared under the general supervision of Dr. Bert Davis, Director, CRREL. The Commander and Executive Director of ERDC is COL Gary E. Johnston. The Director is Dr. James R. Houston.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
cubic inches	1.6387064 E-05	cubic meters
cubic yards	0.7645549	cubic meters
degrees Fahrenheit	(F-32)/1.8	degrees Celsius
feet	0.3048	meters
inches	0.0254	meters
pounds (mass)	0.45359237	kilograms

Nomenclature

AcN	acetonitrile
HMX	octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
NG	nitroglycerine
RDX	hexahydro-1,3,5-trinitro-1,3,5-triazine
TNT	2,4,6-trinitrotoluene

1 Introduction

Firing ranges provide soldiers the opportunity to train using a variety of munitions. However, live-fire training with high-explosive munitions will result in the generation of energetic residues on the range. The major sources include unexploded (non-functioning) ordnance, low-order detonations with a significant fraction of the high-explosive filler remaining unconsumed, and small quantities of explosive residues from fully functioning high-order detonations. These are potential and contributing sources of unconsumed energetic materials that can contaminate the soil and the groundwater and, in sufficient quantities, can threaten human health and the environment and result in the loss of use of the facility.

Hundreds of thousands of rounds are fired into military impact ranges each year (Foster 1998). The majority of these rounds detonate cleanly and efficiently and deposit very little explosive residue (Hewitt et al. 2003; Taylor et al. 2004; Walsh et al. 2005a, 2006b; Walsh 2007). However, a small percentage of the ordnance, estimated to be less than 2%, does not function properly, resulting in unexploded ordnance (Dauphin and Doyle 2000). Unexploded ordnance (UXO) is a serious range safety hazard. Along with low-order detonations, where only part of the explosive filler is consumed, they are the most significant point source for high-explosive (HE) contamination on an impact range. Range closures due to contamination have driven the military toward more thorough range maintenance, including clearance of UXO. Studies show that the disposal of these items in situ (blow-in-place [BIP]) is not as efficient as the live-fire detonation of munitions and may result in the deposition of significant quantities of explosives on the range (Hewitt et al. 2003; Walsh et al. 2005a, 2006a).

The data set for BIP residues is limited, due in part to the difficulty of quantifying residues from the detonation of a munition. The methods developed by Jenkins et al. (2000) and Walsh et al. (2005c, 2007) on snow-covered ice for both live-fire and BIP detonations allow the isolation of detonation residues from previous range activities, the effective demarcation of the residue plume, and the efficient collection of residues for analysis. This report addresses the major remaining data gap in range use of common U.S. Army high-explosive munitions, the BIP disposal of unexploded, fuzed 60-mm and 120-mm mortar cartridges.

In 2008, we conducted a series of BIP tests on fuzed 60-mm and 120-mm mortar cartridges. The study objective was to determine the explosives residues quantities on a per-round basis and to compare these results with those of previous results obtained under similar conditions.

2 Field Tests

Field site

The tests were conducted on the Eagle River Impact Area, Fort Richardson, AK. Eagle River Flats (ERF) is an estuarine salt marsh along the upper Cook Inlet that periodically floods and freezes over the winter, building up layers of ice over the impact area (Figure 1). With a fresh layer of snow on the ice, this area is ideal in the winter for conducting explosive residues tests because the detonations are segregated from past activity on the Flats and residue plumes are easily discerned on the snow surface. At the time of these tests in February 2008, temperatures ranged from -4°C to near freezing. Winds were variable from the north at under 3 m/sec with partially overcast skies. Snow depth ranged from 10 to 30 cm, and ice thickness varied to up to 65-cm deep. The snow surface was consolidated by prior wind and sun exposure but was not crusted over. No snow fell and no drifting occurred during the tests. Little unfrozen water lay beneath the ice.

Figure 1. Eagle River Flats impact area in winter.

The tests were conducted in a location designated as Area C on the Flats. The test area is underlain by a shallow ponded area—frozen to depth during testing—and an “upland” (mudflat) zone between the pond and the river levee. This area is easily accessible from the access road to the edge of the Flats. An ice road was cleared and plowed to the test site and parallel roads plowed perpendicular to the prevailing winds to provide access to the detonation points (Figure 2).

Munitions

Two munitions were detonated during our tests (Table 1). The 60-mm test munitions were M888 high-explosive cartridges with an M935 point detonating (PD) fuze mounted in the nose (Figure 3a). For the 120-mm tests, the M933 HE cartridge with an M745 point detonating fuze (Figure 3b) was detonated. The donor charge for both munitions was a single block of C4. Appendix A contains complete munitions data for these tests.

Figure 2. Ice road to BIP sites from ERF access road.

Tests

Our tests were conducted in association with the 716th Explosive Ordnance Disposal (EOD) detachment, Fort Richardson, AK. Coordinating with the mission command, we located detonation points for each set of seven rounds on either side of the access roads to enable testing with the wind blowing in either direction. The 716th EOD detachment was responsible for drawing the munitions, setting the charges, and detonating the rounds.

The 120-mm tests were run first. A background surface snow sample from the test area was collected before detonation activity. Clean ice blocks were cut for the tests from a nearby freshwater lake to be used to prevent pene-

Table 1. Explosives constituents for munitions used during firing point tests.

Munition	Component	Constituent	Weight (g)
M888	HE Filler	Comp B	358
		RDX[a]	215
		TNT	140
	M935 Fuze	—	13.1
		RDX[a]	12.7
	M702 Ign. Ctg.[b]	Prop M9	3.37
		NG	1.35
M933	HE Filler	Comp B	2,990
		RDX[a]	1,794
		TNT	1,166
	M745 Fuze	—	10.2
		RDX[a]	7.9
		HMX	0.13
	M981 Ign. Ctg.[b]	Prop M44	68
		NG	30
M112 (Donor)	C4	—	567
		RDX[a]	516

[a]RDX may contain up to 9% HMX in Composition B explosive.
[b]Ignition cartridge.

tration to ground when the rounds were detonated. These blocks were 30- to 45-cm thick. Each fuzed M933 HE cartridge was placed 15 m from the access road and 40-m apart on an ice block approximately 1-m long by 0.5-m wide by 0.4-m thick. A block of C4 explosive (M112) was placed adjacent to the body of the horizontal cartridge near the nose end. A blasting cap initiator and time fuze were then attached to the donor charge. When the area was clear, the rounds were set off simultaneously. One donor initiator failed to function properly and was replaced within 20 min. The area was once again cleared and the round detonated. At the time of detonation, the temperature was -3.8°C with a north wind of 0–3 m/sec. There was no precipitation and no drifting of snow.

Following clearance of the detonation points, the plumes were demarcated by walking the visible perimeter of the soot-discolored snow with a global positioning satellite (GPS) system (Trimble GPS Pathfinder Pro XR; ±1-m accuracy). The outline of the plume was recorded, as was the detonation point for each event. Triplicate 10- x 10- x 2.5-cm deep multi-increment (MI) surface snow samples were then taken within each plume, and duplicate MI samples were also taken from the 0- to 2-m annulus outside the

a. M888 60-mm HE cartridge with M112 donor charge on ice surface.

b. M933 120-mm HE cartridge on ice block.

Figure 3. Munitions used in BIP tests.

visible plume. To obtain the MI samples within the plume, parallel lanes 2-m apart were walked throughout the plume and increments systematically collected every 3 m from a randomly selected starting location at the beginning of the first lane. For outside-the-plume (OTP) samples, a similar procedure was used except there was only one lane through the middle of the annulus and samples were systematically collected from either side of the lane from a random starting point. On one plume, triplicate 20- x 20- x 2.5-cm MI surface samples were taken directly followed by 10- x 10- x 2.5-

cm "subsurface" samples from the area just sampled. These quality assurance procedures were done to determine if we adequately delineated the plume and if we sampled deep enough to collect the majority of the residues at the sampled points. For a full description of energetics sampling on snow, see Walsh et al. (2007).

The following day, the procedure was repeated for the 60-mm mortar cartridges. In this case, however, the rounds were set directly on the ice at a distance of 42-m apart. All rounds detonated simultaneously and the sampling procedure repeated. One additional test was performed on one of the detonation plumes. The plume was divided into three zones based on perceived soot density. Each of these gradient zones was then sampled in duplicate to determine the difference in energetics concentrations. This test was performed to determine the effect of "gradient bias," or the tendency to sample only where the greatest evidence of contamination exists (Walsh et al. 2005c).

Sample processing and analysis

The multi-increment snow samples were transferred to a lab set up nearby on post for processing. The samples were melted, filtered (Figure 4), and the aqueous fraction concentrated using solid-phase extraction (Walsh and Ranney 1998; Walsh et al. 2007). When processing was completed, the solid-phase extraction (SPE) cartridges and the soot fraction filters were shipped to the analytical chemistry laboratory at CRREL's main office in Hanover, NH, for final processing and analysis.

The filters containing the soot fractions were extracted using acetonitrile. Each sample was shaken with the solvent for 18 h. The acetonitrile extracts from the solid phase extraction of the melted snow and of the solid residue on the filters were analyzed by high-performance liquid chromatography (HPLC). Analyte concentrations were determined following the general procedures of SW 846 Method 8330 to determine nitroaromatics and nitramines by HPLC (USEPA 1994). The HPLC method has an analytical error that is very small, about 2% relative standard deviation (RSD) for replicate injections.

Before HPLC analysis, 1 mL of each acetonitrile extract was mixed with 3 mL of reagent-grade water. Determinations were made on a modular system from Thermo Electron Corporation (Waltham, MA) composed of a

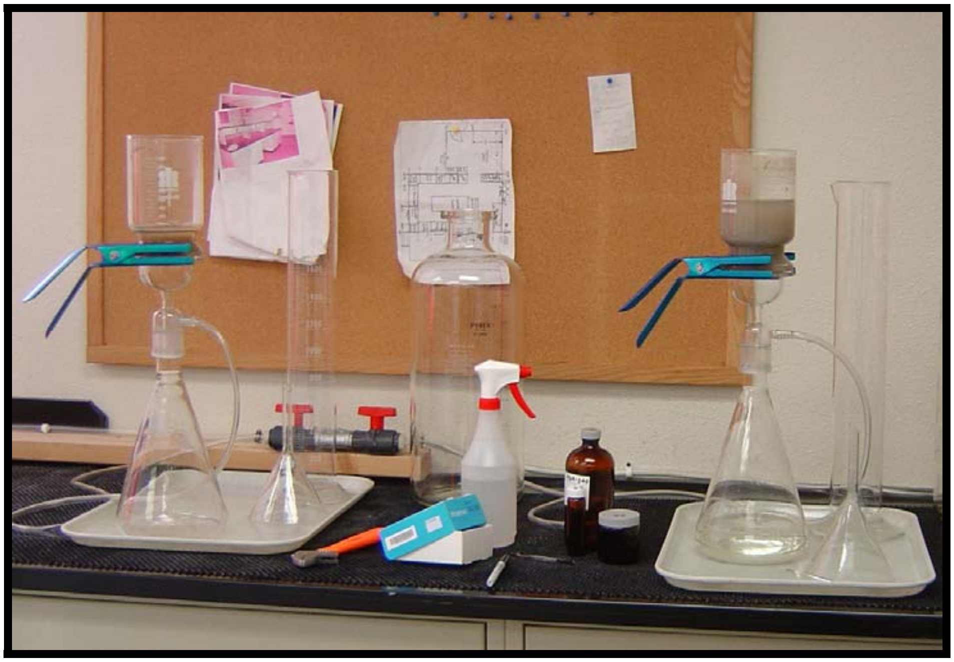

Figure 4. Sample filtration setup.

Finnigan SpectraSYSTEM Model P4000 pump, a Finnigan SpectraSYSTEM UV2000 dual wavelength ultraviolet/visible absorbance detector set at 210 and 254 nm (cell path 1 cm), and a Finnigan SpectraSYSTEM AS300 autosampler. Samples were introduced with a 100-µL sample loop. Separations were achieved on a 15-cm x 3.9-mm (4-µm) NovaPak C8 column (Waters Chromatography Division, Milford, MA) at 28°C and eluted with 1.4 mL/min of 15:85 isopropanol/water (v/v).

Calibration standards were prepared from analytical reference materials obtained from Restek Corporation (Bellefonte, PA). The analytical reference materials were 8095 Calibration Mix A (1 mg/mL) and a single-component solution of NG (1 mg/mL). A spike solution at 1,000 µg/L was prepared from 8095A Calibration Mix and the single-component solution of NG (10,000 µg/L). Spiked water samples at 2 µg/L were prepared by mixing 0.10 mL of the spike solution to 500 mL of water in a volumetric flask. Following SPE, the extract target concentration was 200 µg/L for each analyte.

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). We used a detection limit of 0.02 mg/L for HMX, RDX, and TNT and 0.05 mg/L for NG. Values below these limits are labeled as ND in the data.

Quality assurance procedures

Quality assurance (QA) procedures were conducted both in the field and in the lab. Field QA, noted previously, included replicate sampling within the residue plumes, sampling outside the demarcated plumes, using multiple sampling designs, and sampling below previously sampled points.

We also conducted QA procedures in the processing lab. Blank samples consisting of filtered water (Barnstead E-Pure filtration system; 80 MΩ minimum) were periodically run through a filter assembly and pre-concentrated using SPE for later analysis at the lab. This procedure is designed to determine if cross-contamination from the sample filtering apparatus or glassware is occurring. SPE laboratory control samples (LCSs) were run to determine cartridge filter performance. These processes are described in greater detail in Walsh et al. (2005b).

3 Results

Baseline samples

The background sample collected from the firing points before the test was blank, indicating clean test areas. Results are given in Appendix D.

BIP detonation plumes

A total of 88 multi-increment samples composed of 7,811 increments were taken to characterize the BIP detonation plumes. The demarcated plume sizes ranged from approximately 400 m^2 for a 60-mm detonation to 2,000 m^2 for a 120-mm detonation, averaging 1,500 m^2 for the 120s and 500 m^2 for the 60s (Table 2). OTP areas varied from approximately 200 m^2 to 580 m^2, averaging about 30% of the plume area for the 120s and 46% of the plume area for the 60s. Areas were calculated with geographic information system software using the GPS field data points. In most cases, the 10-cm scoop was used to sample the plumes, OTP areas, and subsurface. On average, 0.08% of the plume areas and 0.2% of the OTP areas were sampled for the 120s, and 0.19% of the plume areas and 0.4% of the OTP areas were sampled for the 60s (Table 3). A map of the detonation plumes derived from the GPS data is given in Figure 5.

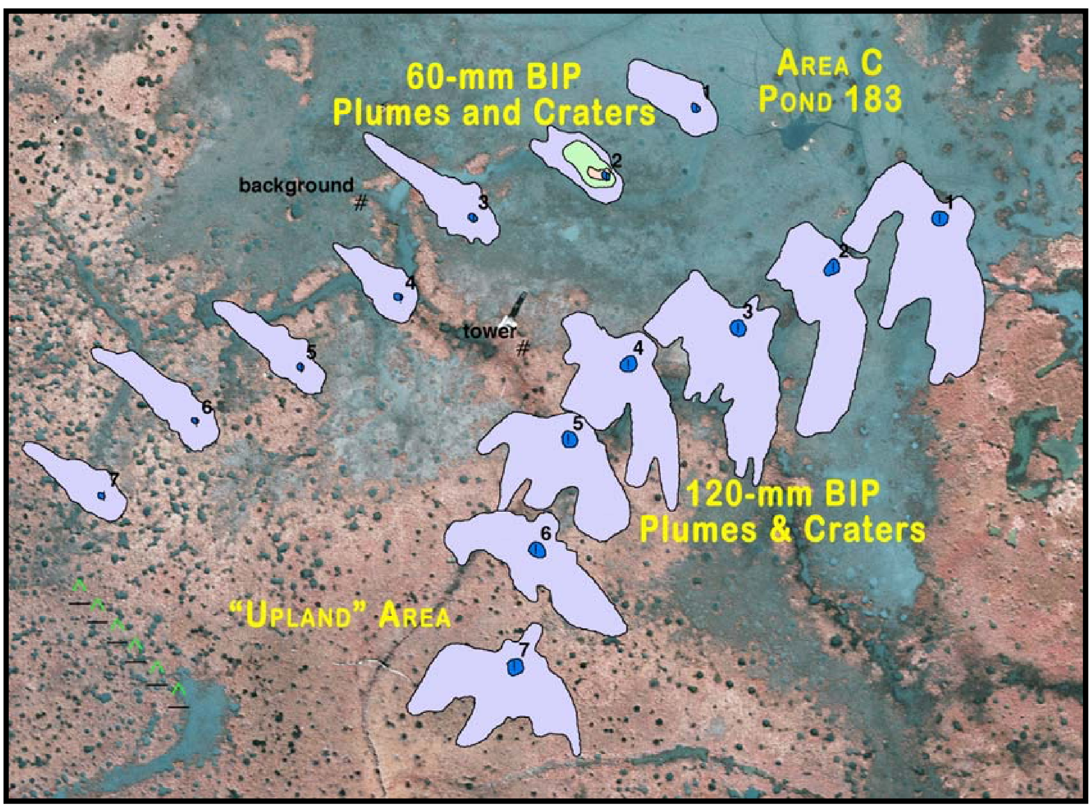

Figure 5. Plume shape and locations.

Table 2. Data for sampled areas—decision unit areas.

Detonation No.	Round Type	Plume		Plume+OTP		OTP Area (m^2)
		Length (m)	Area (m^2)	Length (m)	Area (m^2)	
1	120 mm	280	2,000	290	2,600	580
2	120 mm	210	1,500	220	1,900	420
3	120 mm	270	1,800	240	2,300	520
4	120 mm	250	1,500	240	2,000	490
5	120 mm	220	1,400	210	1,800	440
6	120 mm	200	1,200	210	1,700	410
7	120 mm	230	1,400	240	1,900	470
	Averages	**240**	**1,500**	**240**	**2,000**	**480**
1	60 mm	94	480	110	680	200
2	60 mm	96	470	110	680	200
3	60 mm	140	620	150	910	290
4	60 mm	94	400	100	590	200
5	60 mm	120	500	130	740	240
6	60 mm	130	600	140	870	270
7	60 mm	100	430	110	650	220
	Averages	**110**	**500**	**120**	**730**	**230**
7-medium	60 mm	54	150	—	—	—
7-dark	60 mm	23	27	—	—	—

Table 3. Data for sampled areas—sampling statistics.

Munition	Decision Unit	Sampling Tool Size (cm)	Average No. of Increments	Average Area Sampled (m^2)	Average Area Sampled (%)
120 mm	Plume 1	10 x 10 x 2.5	137	1.37	0.07%
	OTP 1	10 x 10 x 2.5	100	1.00	0.17%
	Plume 2	10 x 10 x 2.5	142	1.42	0.07%
	OTP 2	10 x 10 x 2.5	100	1.00	0.24%
	Plume 3	10 x 10 x 2.5	97	0.97	0.05%
	OTP 3	10 x 10 x 2.5	100	1.00	0.19%
	Plume 4	10 x 10 x 2.5	148	1.48	0.10%
	OTP 4	10 x 10 x 2.5	100	1.00	0.20%
	Plume 5	10 x 10 x 2.5	102	1.02	0.07%
	OTP 5	10 x 10 x 2.5	101	1.01	0.23%
	Plume 6	10 x 10 x 2.5	105	1.05	0.08%
	OTP 6	10 x 10 x 2.5	100	1.00	0.24%
	Plume 7	10 x 10 x 2.5	123	1.23	0.09%
		20 x 20 x 2.5	30	1.20	0.08%
	Subsurface 7	10 x 10 x 2.5	30	0.30	0.02%
	OTP 7	10 x 10 x 2.5	63	0.63	0.14%
Averages	**Plume**		**122**	**1.22**	**0.08%**
	OTP		**95**	**0.95**	**0.20%**
60 mm	Plume 1	10 x 10 x 2.5	80	0.80	0.17%
	OTP 1	10 x 10 x 2.5	100	1.00	0.50%
	Plume 2	10 x 10 x 2.5	84	0.84	0.18%
	-Light	10 x 10 x 2.5	53	0.53	0.20%
	-Medium	10 x 10 x 2.5	87	0.87	0.49%
	-Dark	10 x 10 x 2.5	41	0.41	1.52%
	OTP 2	10 x 10 x 2.5	84	0.84	0.41%
	Plume 3	10 x 10 x 2.5	100	1.00	0.16%
	OTP 3	10 x 10 x 2.5	95	0.95	0.33%
	Plume 4	10 x 10 x 2.5	96	0.96	0.24%
	OTP 4	10 x 10 x 2.5	87	0.87	0.45%
	Plume 5	10 x 10 x 2.5	107	1.07	0.21%
	OTP 5	10 x 10 x 2.5	89	0.89	0.37%
	Plume 6	10 x 10 x 2.5	92	0.92	0.15%
	OTP 6	10 x 10 x 2.5	83	0.83	0.31%
	Plume 7	10 x 10 x 2.5	100	1.00	0.23%
		20 x 20 x 2.5	26	1.04	0.24%
	Subsurface 7	10 x 10 x 2.5	26	0.26	0.06%
	OTP 7	10 x 10 x 2.5	89	0.89	0.41%
Averages	**Plume**		**94**	**0.94**	**0.19%**
	OTP		**90**	**0.90**	**0.40%**

Analytical data averaged for the replicates are given in Table 4. Two significant digits are used for the data in this table and throughout this report. The samples were analyzed for a series of energetic compounds: RDX, HMX, TNT, and NG. The NG is contained in the ignition cartridge in the tail of the mortar cartridge. In combination with the nitrocellulose matrix in which it is embedded, it is less sensitive than the donor and filler charges (low explosive as opposed to high explosive). Its normal means of reaction is deflagration (rapid burning) rather than detonation. This, in combination with its distance from the donor charge, results in less material consumed during the BIP operation. The HMX is a byproduct in the manufacturing process for RDX and is found in quantities of 8% to 12% in the Type B RDX in the Comp B filler (U.S. Army 2004). It is also found in very small quantities in the fuze of the 120-mm cartridge. More complete data sets can be found in Appendixes B and C.

Table 4. Analytical data for energetics in plumes.

Munition	Detonation No.	Total Mass (mg)			For RDX		For HMX	
		HMX	RDX	NG	Range	RSD	Range	RSD
120 mm	1	<0.02	4.6	3,900	1.8	20%	—	0%
	2	4.4	13	4,400	2.5	10%	2.4	28%
	3	8.0	19	3,300	8.9	23%	4.0	25%
	4	4.3	46	3,900	31	34%	0.5	6%
	5[a]	<0.02	6.3	4,500	2.1	17%	—	0%
	6	4.4	37	7,600	9.9	14%	2	18%
	7 (100)	<0.02	17	3,500	3.7	13%	—	0%
	7 (20)[b]	<0.02	35	8,100	—	—	—	0%
	Averages	**3.0**	**22**	**4,800**	**11**	**22%**	**1.2**	**11%**
60 mm	1	4.2	32	200	8.8	16%	1.3	18%
	2	9.6	49	240	6.7	7.2%	3.7	19%
	3	50	400	240	99	13%	21	21%
	4	27	270	170	3.5	0.73%	7.8	17%
	5	36	220	290	150	35%	17	24%
	6	4.4	30	250	9.8	16%	2.2	28%
	7 (100)	20	220	230	27	6.4%	2.7	7.0%
	7 (20)	21	260	200	190	38%	5.5	13%
	Averages	**22**	**180**	**230**	**56**	**16%**	**8.2**	**19%**

Notes:
Range is the difference between the highest and lowest values for the analyte.
[a]RDX value includes the OTP mass (0.35 mg).
[b]Two of three values for RDX are below quantitation range; range and RSD not calculated.

Using the results presented in Table 4, we can derive the average efficiency of the BIP operations. For the 120s, 7.1 x 10^{-4} % of the cartridge and donor charge HE load remained on average after detonation. If only HMX and RDX are considered, 1.1 x 10^{-3}% remained on average after detonation. The residues rate ranged from 1.3 x 10^{-4} % for BIP No. 1 to 1.4 x 10^{-3}% for BIP No. 4. NG residues averaged 16%. For the 60s, 2.3 x 10^{-2}% of the cartridge and donor charge HE load remained on average after detonation. For the RDX and HMX alone, 2.7 x 10^{-2}% remained on average. The residues rates ranged from 3.9 x 10^{-3}% for BIP No. 6 to 5.1 x 10^{-2}% for BIP No. 3. NG residues averaged 17%, quite close to the value obtained for the 120s. The averaged HE residues deposition mass was 25 mg/round for the 120s and 200 mg/round for the 60s. Very little TNT was detected in the 60-mm residues and none was detected in the 120-mm residues. Table 5 summarizes these data and Table 8 (Discussion) compares them to other detonation tests.

Table 5. Summary for blow-in-place detonations.

Munition	No. of Rounds	Plume Area (m^2)	RDX (mg)	HMX (mg)	TNT (mg)	Total (mg)	Total (%)[a]
60-mm mortar (M374)	7	500	180	22	ND	200	2.3 x 10^{-2}
120-mm mortar (M1)	7	1,600	22	3.0	ND	25	7.7 x 10^{-4}

[a]Explosives load includes the contribution of the C4 donor charge.
ND, not detected (below detection limits of instrumentation).

The gradient test yielded the expected results. In the small, darkest zone, 42% of the residues mass was recovered from just 6% of the area. In the intermediate zone, 44% of the mass was recovered from 32% of the area. In the lightest zone, only 15% of the mass was recovered from an area encompassing 63% of the plume. Looking at the ratios of recovered energetics to percent of area sampled within the plume, the dark area contained seven times more residues per unit area than the plume as a whole. Table 6 summarizes the data from this test.

The field QA procedure results indicate that the majority of detectable energetic residues were within the sampled depth of the demarcated plume area and meet data quality objectives. Table 7 contains the results for both series of tests. The amount of HE residues found in the sampled area outside the demarcated plume (OTP) compared to inside the plume is expressed as a percentage of the plume mass under OTP:Plume. For the OTP

Table 6. Gradient test results for HMX and RDX.

Zone	Total Mass (mg)				Area (m^2)	% of Area	% of Mass	Ratio Mass/Area
	HMX		RDX					
Plume[a]	9.6	—	49	—	470	100%	100%	1.0
Light	0.0	0%	8.8	16%	300	63%	15%	0.23
Medium	2.7	44%	24	44%	150	32%	44%	1.4
Dark	3.4	56%	21	40%	27	6%	42%	7.2
Total	6.1	64%	54	110%	470	—	—	—

[a]Averaged results for total plume from Table 4, 60-mm Plume 2.

sampling, the target value is <5% of the plume mass. Only one of the 14 OTP samples exceeded 5%, 5.5% for plume 5. The OTP residue mass for plume 5 was thus added to the plume mass in Table 4. The target value for the subsurface mass to plume mass (SS:Plume) is <1% of the plume mass. Neither of the subsurface samples exceeded the target value. Values for the RSDs of the triplicate plume samples, found in Table 4, were also very good. The target value is <30% RSD. Only three of the 32 sets of data for the HE residues exceeded 30%, and all were less than 40%. Average RSD for the 32 sets of data is 17% (0% to 38%).

Table 7. Field quality assurance test results.

Plume No.	60-mm BIPs				120-mm BIPs			
	RDX		HMX		RDX		HMX	
	OTP:Plume	SS:Plume	OTP:Plume	SS:Plume	OTP:Plume	SS:Plume	OTP:Plume	SS:Plume
1	0.0%	—	0.00%	—	0.0%	—	0.00%	—
2	0.0%	—	0.00%	—	0.0%	—	0.00%	—
3	0.2%	—	0.00%	—	0.0%	—	0.00%	—
4	0.6%	—	0.00%	—	1.7%	—	0.00%	—
5	0.8%	—	0.00%	—	5.5%	—	0.00%	—
6	0.0%	—	0.00%	—	0.9%	—	0.00%	—
7 (100)	1.6%	0.59%	3.20%	0.09%	0.0%	0.0%	0.00%	0.00%
7 (20)	1.3%	0.50%	3.06%	0.11%	0.0%	0.0%	0.00%	0.00%
Averages	**0.42%**	**0.54%**	**0.45%**	**0.10%**	**1.2%**	**0.00%**	**0.00%**	**0.00%**

Finally, the QA results from the lab are also very good. All filtration blanks were clean with the exception of one that had trace amounts of NG on the filter. The source of the NG could not be determined but did not adversely affect other data. The SPE glassware test blanks had no detectable energetics, and the LCS runs returned values from 90% to 105% on average (0.18–0.21 mg/L). Data can be found in Appendix D.

4 Discussion

Working with energetics residues is a difficult proposition. This is especially true with an unconfined charge, such as the block of C4 used as a donor charge (Brochu et al. 2004). Residues are particulate in form and quite heterogeneously distributed. The quantity of residues also tend to be quite low, especially for the larger munitions that are more efficient when detonated. These low quantities result in many analyte concentrations at or near the analytical detection limits. Another confounding factor we came up against was the high quantities of NG in the samples. Because the rounds had not been fired, the ignition cartridges in the tails of the mortars were not expended, and the full load of propellant was present in these cartridges. Because the propellant is designed to burn rather than detonate, the BIP process is inefficient in the disposal of the material. Relatively large quantities of NG in the field samples made analysis of the samples difficult.

The configuration of the donor charge on the test munitions was according to standard EOD practice. The use of a complete block of C4, containing 516 g of RDX, to initiate a 60-mm mortar cartridge, containing less than 370 g of high explosives, may seem excessive, but it is standard practice. Part of the reason why the BIP of the 60-mm cartridge was so much “dirtier” than the BIP of the 120-mm cartridge was the presence of such a large amount of unconfined explosive during the operation. Detonation tests of blocks of C4 alone indicate relatively high residues rates, 2.6×10^{-3}% (n = 11), compared to residue rates from fully functioning rounds (<2×10^{-4}%) and BIP operations with the larger projectiles (<8×10^{-4}%) (Walsh 2007). With the 120s, the resulting detonation of the cartridge assists in the consumption of the donor charge, making the overall process much more efficient. Work needs to be done to refine the protocol for configuring a BIP operation.

Overall, the data fit in well with other BIP and live-fire data. Table 8 summarizes these data for tests conducted on snow by CRREL since early 2002. The trend has been that BIPs are not as clean as live-fire detonations, larger rounds consume the HE more efficiently than the smaller rounds, and mortar cartridges are less efficient than howitzer rounds.

With the exception of the live-fire 60-mm HE cartridges, this is demonstrated by the results shown in the table.

Table 8. HE munitions BIP and live-fire detonation energetics residues data.

Weapon System	BIP[a] (TNT, HMX, RDX)	Live-Fire Detonation (TNT, HMX, RDX)
Mortars		
60 mm (Comp B)	200 mg / 2.3 x 10^{-2}%	0.076 mg / 2.0 x 10^{-5}%
81 mm (Comp B)	150 mg / 1.0 x 10^{-2}%	9.4 mg / 1.0 x 10^{-3}%
120 mm (Comp B)	25 mg / 7.7 x 10^{-4}%	21 mg / 4.8 x 10^{-4}%
Howitzers		
105 mm (Comp B)	50 mg / 1.9 x 10^{-3}%	0.27 mg / 1.3 x 10^{-5}%
155 mm (Comp B)	17 mg / 2.2 x 10^{-4}%	0.31 mg / 4.4 x 10^{-6}%
155 mm (TNT)	15 mg / 2.1 x 10^{-4}%	0.00 mg / 0.0 x 10^{-6}%

[a]Includes donor charge mass.

5 Conclusions

Two tests were conducted on the ice-covered Eagle River Flats impact area of Fort, Richardson, AK, to determine the quantity and percent levels of energetics residues remaining after standard blow-in-place detonation of fuzed 60-mm and 120-mm mortar cartridges using a single block of C4 as a donor charge. Seven rounds of each high-explosive munition were detonated and the resultant plumes sampled in triplicate. Quality assurance procedures were conducted in the field to ensure the detonation plumes were correctly demarcated and the sampling was valid. Multi-increment sampling on the snow surface was used to characterize the decision units. The averaged result for the 60-mm test was 200 mg of RDX and HMX residues per round, giving a residues rate of 0.022% of the original analyte load (fuze plus filler plus donor charge). Residues found in a 2-m band outside the demarcated plume averaged 0.43% of the plume load, and subsurface sampling below previously sampled points yielded less than 0.32% of the surface sample mass. The averaged result for the 120-mm test was 27 mg of RDX and HMX residues per round, giving a residues rate of 0.00077% of the original analyte load (fuze plus filler plus donor charge). Residues found in a 2-m band outside the demarcated plume averaged 0.58% of the plume load, and subsurface sampling below previously sampled points contained undetectable amounts of high explosives. The results of these tests fit well with deposition data for other munitions.

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Appendix A: Munitions Data

Table A1 contains information relevant to the munitions used during the tests covered in this report. Table A2 contains data on the explosive load of the test components. Propellant charges are given in Table 1. The amount of propellant used per round can and did vary throughout the tests.

Table A1. Munitions data.

NSN	DODIC	Nomenclature	Lot No.	Drawn for Tests
1310011493185	B643	Cartridge, 60 MM HE, M888, W/Fuze, PD, M935	MA-99A057-001	8
1315013431941	C623	Cartridge, 120 MM HE, M933, W/Fuze, PD, M745	MM-97K025-002	8
1375007247040	M023	Charge, Demolition, M112	—	20

Note: Drawn from Fort Richardson Ammo Supply Point, 11 February 2008.

Table A2. Energetics loads before detonation.

Munition	Energetics Quantities (g)			
	TNT	RDX	HMX	NG
Cartridge, 60 mm, M888	140	215	0	0
Fuze, Point detonating, M935	0	15	0	0
Cartridge, Ignition, M702	0	0	0	1.35
Cartridge, 120 mm, M933	1,166	1,793	0	0
Fuze, Point detonating, M745	0	43	0	0
Cartridge, Ignition, M981	0	0	0	30
Charge, Demolition, M112	0	516	0	0

Note: HMX may compose up to 9% of the mass of RDX.

Appendix B: 120-mm Data

Table B1 contains sampling data, analytical data, and final results for the 120-mm BIP test. Detection limits are 0.02 mg/L for RDX, HMX, and TNT and 0.05 mg/L for NG.

Table B1. 120-mm Mortar BIP test data.

Sample ID	Plume No. and Rep	Type	Snow Melt Analyte Mass (µg)			Filters Analyte Mass (µg)			No. of Increment	Area (m^2) Sampled	DU Area (m^2)	Total Mass (mg)		
			HMX	RDX	NG	HMX	RDX	NG				HMX	RDX	NG
FRA-001	1-1	OTP 0–2 m	ND	ND	7.5	ND	ND	ND	100	1.00	575	0.00	0.00	4.3
FRA-002	1-2	OTP 0–2 m	ND	ND	6.0	ND	ND	ND	100	1.00	575	0.00	0.00	3.5
FRA-003	1-1	Plume-1	ND	4.3	3,800	BQL	BQL	606	162	1.62	2,000	0.0	5.4	5,439
FRA-004	1-2	Plume-1	ND	3.1	2,319	BQL	BQL	218	125	1.25	2,000	0.0	4.9	4,058
FRA-005	1-3	Plume-1	ND	2.2	890	BQL	BQL	531	125	1.25	2,000	0.0	3.6	2,274
		Plume Averages	—	**3.2**	**2,336**	—	—	**452**	—	—	—	**0.0**	**4.6**	**3,923**
FRA-006	2-1	OTP 0–2 m	ND	ND	11.94	ND	ND	5.8	100	1.00	423	0.00	0.00	7.5
FRA-007	2-2	OTP 0–2 m	ND	ND	15.07	ND	BQL	5.8	100	1.00	423	0.00	0.00	8.8
FRA-008	2-1	Plume-2	ND	8.0	2,475	5.8	4.9	1,936	150	1.50	1,500	5.8	12.9	4,411
FRA-009	2-2	Plume-2	ND	8.0	3,659	3.8	3.6	1,710	143	1.43	1,500	4.0	12.1	5,632
FRA-010	2-3	Plume-2	ND	9.0	2,481	3	4.0	324	133	1.33	1,500	3.4	14.6	3,164
		Plume Averages	—	**8.3**	**2,872**	**4.2**	**4.2**	**1,323**	—	—	—	**4.4**	**13.2**	**4,403**
FRA-011	3-1	OTP 0–2 m	ND	—	10	ND	ND	6.7	100	1.00	519	0.00	0.00	8.9
FRA-012	3-2	OTP 0–2 m	ND	—	7.9	BQL	ND	4.9	100	1.00	519	0.00	0.00	6.7
FRA-013	3-1	Plume-3	ND	6.0	1,638	4.6	2	ND	97	0.97	1,770	8.4	14.5	2,989
FRA-014	3-2	Plume-3	ND	9.0	1,358	5.4	3.8	519	97	0.97	1,770	9.9	23.5	3,426
FRA-015	3-3	Plume-3	ND	7.7	1,566	3.2	3.2	321	97	0.97	1,770	5.9	19.9	3,444
		Plume Averages	—	**7.6**	**1,521**	**4.4**	**3.0**	**420**	—	—	—	**8.0**	**19.3**	**3,286**

Table B1 (cont'd). 120-mm Mortar BIP test data.

Sample ID	Plume No. and Rep	Type	Snow Melt Analyte Mass (µg)			Filters Analyte Mass (µg)			No. of Increment	Area (m^2) Sampled	DU Area (m^2)	Total Mass (mg)		
			HMX	RDX	NG	HMX	RDX	NG				HMX	RDX	NG
FRA-016	4-1	OTP 0–2 m	ND	2.3	11	BQL	BQL	3.2	100	1.00	490	0.00	1.1	6.9
FRA-017	4-2	OTP 0–2 m	ND	0.90	12	ND	ND	5.6	100	1.00	490	0.00	0.44	8.8
FRA-021	4-1	Plume-4	1.5	35	2,836	*3*	8.6	78	148	1.48	1,510	4.6	44.4	2,972
FRA-022	4-2	Plume-4	1.2	36	2,988	3.0	25	<u>2,415</u>	148	1.48	1,510	4	61.5	5,513
FRA-023	4-3	Plume-4	0.97	26	2,944	*3*	4.5	96	148	1.48	1,510	4.1	31.0	3102
		Plume Averages	**1.2**	**32**	**2,923**	**3.0**	**13**	**863**	—	—	—	**4.3**	**45.6**	**3,862**
FRA-025	5-1	OTP 0–2 m	ND	0.81	7.6	ND	BQL	4.5	103	1.03	435	0.00	0.34	5.12
FRA-026	5-2	OTP 0–2 m	ND	0.82	8.2	BQL	BQL	5.4	100	1.00	435	0.00	0.36	5.87
FRA-024	5-1	Plume-5	ND	3.9	1,809	ND	BQL	1,014	100	1.00	1,400	0.0	5.5	3,952
FRA-027	5-2	Plume-5	ND	5.5	2,740	ND	BQL	660	103	1.03	1,400	0.0	7.5	4,621
FRA-028	5-3	Plume-5	ND	4.4	2,321	ND	BQL	1,266	103	1.03	1,400	0.0	5.9	4,875
		Plume Averages	—	**4.6**	**2,290**	—	—	**980**	—	—	—	**0.0**	**6.3**	**4,483**
FRA-029	6-1	OTP 0–2 m	ND	0.88	12	BQL	BQL	5.1	100	1.00	411	0.00	0.36	6.9
FRA-030	6-2	OTP 0–2 m	ND	0.80	17	BQL	ND	8.2	100	1.00	411	0.00	0.33	10
FRA-031	6-1	Plume	ND	18	2,851	3	10	<u>8,610</u>	105	1.05	1,240	3.5	33.3	13,535
FRA-032	6-2	Plume	ND	21	2,394	4.3	8.4	1,062	105	1.05	1,240	5.1	34.7	4,081
FRA-033	6-3	Plume	0.79	23	3,062	*3*	14	1,347	105	1.05	1,240	4.5	43.2	5,207
		Plume Averages	—	**20.7**	**2,769**	**3.4**	**11**	**3,673**	—	—	—	**4.4**	**37.1**	**7,608**
FRA-034	7-1	OTP 0–2 m	ND	BQL	13	ND	ND	2.4	63	0.63	465	0.00	0.00	11
FRA-035	7-2	OTP 0–2 m	ND	BQL	184	ND	ND	2.4	63	0.63	465	0.00	0.00	138
FRA-042	7-1	Plume	ND	6.4	2,140	BQL	8.8	355	123	1.23	1,440	0.0	17.7	2,921
FRA-043	7-2	Plume	ND	7.2	2,822	BQL	8.0	1,290	123	1.23	1,440	0.0	17.8	4,815
FRA-044	7-3	Plume	ND	6.0	2,156	BQL	6	323	123	1.23	1,440	0.0	14.0	2,902
		Plume Averages	—	**6.5**	**2,373**	—	**7.6**	**656**	—	—	—	**0.0**	**16.5**	**3,546**

Table B1 (cont'd). 120-mm Mortar BIP test data.

Sample ID	Plume No. and Rep	Type	Snow Melt Analyte Mass (µg)			Filters Analyte Mass (µg)			No. of Increment	Area (m²) Sampled	DU Area (m²)	Total Mass (mg)		
			HMX	RDX	NG	HMX	RDX	NG				HMX	RDX	NG
FRA-045	7-1	Surf Plume	ND	15	4,508	BQL	29	3,680	37	1.48	1,440	0.0	60.8	11,338
FRA-046	7-2	Surf Plume	ND	10	4,193	ND	*9*	3,438	26	1.04	1,440	0.0	26.6	10,566
FRA-048	7-3	Surf Plume	ND	10	1,726	ND	*4*	96	26	1.04	1,440	0.0	19.0	2,524
		Plume Averages	—	**11.6**	**3,476**	ND	**14.0**	**2,405**	—	—	—	**0.0**	**35.5**	**8,143**
FRA-036	7-1	SS Plume	ND	ND	14	ND	ND	30	37	0.37	1,440	0.0	0.0	169
FRA-037	7-2	SS Plume	ND	ND	7.7	ND	ND	1.1	26	0.26	1,440	0.0	0.0	49
FRA-041	7-3	SS Plume	ND	ND	11	ND	ND	4.5	26	0.26	1,440	0.0	0.0	85

Notes:
41 samples; 4,059 increments.
Italicized numbers are values at or near quantitation value limits (reported as value limit).
Underlined bold numbers represent high NG value that may be affecting HMX and RDX values.
ND, not detected (below detection limits of instrumentation); BQL, below quantitative limits (reported as zero).
Rep, repetition.
The minimum mass reported (mg) is computed by multiplying 5x the detection limit in the AcN extract (mg/L) times the volume of AcN used to extract the sample (quantitation mass limit).

Appendix C: 60-mm Data

Table C1 contains sampling data, analytical data, and final results for the 60-mm BIP test. Detection limits are 0.02 mg/L for RDX, HMX, and TNT and 0.05 mg/L for NG.

Table C1. 60-mm Mortar BIP test data.

Sample ID	Plume No. and Rep	Type	Snow Melt Analyte Mass (µg)				Filters Analyte Mass (µg)			No. of Incre-ment	Area (m^2) Sampled	DU Area (m^2)	Total Mass (mg)			
			HMX	RDX	TNT	NG	HMX	RDX	NG				HMX	RDX	TNT	NG
FRA-049	1-1	OTP 0–2 m	ND	BQL	ND	ND	ND	BQL	ND	100	1.00	199	0.0	0.0	0.0	0.0
FRA-050	1-2	OTP 0–2 m	ND	BQL	ND	ND	ND	ND	BQL	100	1.00	199	0.0	0.0	0.0	0.0
FRA-051	1-1	Plume-1	BQL	26	ND	132	7.8	37	166	80	0.80	480	4.7	38	0.0	180
FRA-052	1-2	Plume-1	BQL	22	ND	140	7.7	27	234	80	0.80	480	4.6	29	0.0	220
FRA-053	1-3	Plume-1	BQL	20	ND	112	5.6	29	214	80	0.80	480	3.3	29	0.0	190
		Plume Averages	**—**	**23**	**—**	**128**	**7.0**	**31**	**205**	**—**	**—**	**—**	**4.2**	**32**	**0**	**200**
FRA-054	2-1	OTP 0–2 m	ND	BQL	ND	BQL	ND	ND	BQL	84	0.84	205	0.0	0.0	0.0	0.0
FRA-055	2-2	OTP 0–2 m	ND	BQL	ND	BQL	ND	BQL	ND	84	0.84	205	0.0	0.0	0.0	0.0
FRA-056	Light-1	Plume-2-Light	ND	8.2	ND	19.3	ND	6.7	29	53	0.53	290	0.0	8.1	0.0	26
FRA-057	Light-2	Plume-2-Light	ND	10	ND	10.0	ND	6.7	9.8	53	0.53	290	0.0	9.4	0.0	11
FRA-061	Med-1	Pl.-2-Med	ND	60	ND	382	14	92	735	87	0.87	150	2.3	26	0.0	190
FRA-062	Med-2	Pl.-2-Med	ND	56	ND	379	18	65	813	87	0.87	150	3.1	21	0.0	210
FRA-063	Dark-1	Plume-2-Dark	4.8	121	ND	563	50	224	1008	41	0.41	27	3.6	23	0.0	100
FRA-064	Dark-2	Plume-2-Dark	4.5	127	ND	549	44	179	976	41	0.41	27	3.2	20	0.0	100
FRA-067	2-1	Plume-2	3.2	50	ND	143	11	31	240	85	0.85	470	7.6	45	0.0	210
FRA-068	2-2	Plume-2	4.3	63	ND	207	13	31	270	85	0.85	470	9.8	52	0.0	260
FRA-069	2-3	Plume-2	3.9	62	ND	205	16	27	223	83	0.83	470	11	50	0.0	240
		Plume Averages	**3.8**	**58**		**185**	**13**	**29**	**244**	**—**	**—**	**—**	**9.6**	**49**	**—**	**240**

Table C1 (cont'd). 60-mm Mortar BIP test data.

Sample ID	Plume No. and Rep	Type	Snow Melt Analyte Mass (µg)				Filters Analyte Mass (µg)			No. of Incre-ment	Area (m²) Sampled	DU Area (m²)	Total Mass (mg)			
			HMX	RDX	TNT	NG	HMX	RDX	NG				HMX	RDX	TNT	NG
FRA-070	3-1	OTP 0–2 m	BQL	1.4	ND	ND	ND	ND	ND	95	0.95	291	0.0	0.43	0.0	0.0
FRA-071	3-2	OTP 0–2 m	BQL	2.7	ND	ND	ND	ND	ND	95	0.95	291	0.0	0.82	0.0	0.0
FRA-072	3-1	Plume-3	8.1	245	(8.2)	138	73	424	272	100	1.00	620	50	410	5.1	260
FRA-073	3-2	Plume-3	9.2	254	(3.3)	157	54	298	191	100	1.00	620	39	340	2.0	220
FRA-074	3-3	Plume-3	5.4	196	(2.8)	134	92	516	272	100	1.00	620	60	440	1.7	250
		Plume Averages	**7.6**	**231**	**4.8**	**143**	**73**	**413**	**245**	—	—	—	**50**	**400**	**3.0**	**240**
FRA-075	4-1	OTP 0–2 m	BQL	3.9	BQL	BQL	BQL	5.0	BQL	87	0.87	196	0.0	2.0	0.0	0.0
FRA-076	4-2	OTP 0–2 m	BQL	3.2	BQL	BQL	BQL	2		87	0.87	196	0.0	1.2	0.0	0.0
FRA-077	4-1	Plume-4	8.4	415	(1.9)	297	50	228	152	96	0.96	400	25	270	0.8	190
FRA-081	4-2	Plume-4	9.9	434	(1.3)	237	49	216	126	96	0.96	400	24	270	0.6	150
FRA-082	4-3	Plume-4	5.0	286	(1.3)	187	72	365	228	96	0.96	400	32	270	0.5	170
		Plume Averages	**7.8**	**378**	**1.5**	**240**	**57**	**270**	**169**	—	—	—	**27**	**270**	**0.6**	**170**
FRA-083	5-1	OTP 0–2 m	BQL	2.8	BQL	BQL	ND	3.3	ND	89	0.89	243	0.0	1.65	0.0	0.0
FRA-084	5-2	OTP 0–2 m	BQL	3.3	BQL	ND	BQL	3.0	ND	89	0.89	243	0.0	1.70	0.0	0.0
FRA-085	5-1	Plume-5	22	413	(11)	358	76	241	567	107	1.07	500	46	300	5.1	430
FRA-086	5-2	Plume-5	13	233	(9.2)	352	48	89	83	107	1.07	500	28	150	4.3	200
FRA-087	5-3	Plume-5	16	311	(9.1)	366	59	137	149	107	1.07	500	35	210	4.2	240
		Plume Averages	**17**	**319**	**10**	**359**	**61**	**156**	**266**	—	—	—	**36**	**220**	**4.5**	**290**
FRA-088	6-1	OTP 0–2 m	ND	BQL	ND	ND	ND	ND	BQL	83	0.83	271	0.0	0.0	0.0	0.0
FRA-089	6-2	OTP 0–2 m	ND	BQL	ND	ND	ND	BQL	BQL	83	0.83	271	0.0	0.0	0.0	0.0
FRA-090	6-1	Plume-6	BQL	22	ND	160	4.9	19	174	98	0.98	600	3.0	25	0.0	200
FRA-091	6-2	Plume-6	BQL	20	ND	161	8.3	29	290	98	0.98	600	5.1	30	0.0	280
FRA-093	6-3	Plume-6	BQL	22	ND	165	6.9	25	192	80	0.80	600	5.2	35	0.0	270
		Plume Averages	—	**21**	—	**162**	**6.7**	**24**	**219**	—	—	—	**4.4**	**30**	—	**250**

Table C1 (cont'd). 60-mm Mortar BIP test data.

Sample ID	Plume No. and Rep	Type	Snow Melt Analyte Mass (µg)				Filters Analyte Mass (µg)			No. of Incre-ment	Area (m^2) Sampled	DU Area (m^2)	Total Mass (mg)			
			HMX	RDX	TNT	NG	HMX	RDX	NG				HMX	RDX	TNT	NG
FRA-092	7-1	OTP 0–2 m	ND	4.5	(1.6)	ND	2	7.2	BQL	98	0.98	216	0.44	2.6	0.35	0.0
FRA-094	7-2	OTP 0–2 m	ND	4.9	(1.0)	ND	3.0	11	BQL	80	0.80	216	0.81	4.2	0.27	0.0
FRA-101	7-1	Plume-7	4.3	166	(3.2)	191	45	330	360	100	1.00	430	21	210	1.4	240
FRA-102	7-2	Plume-7	4.6	177	(2.0)	183	38	302	290	100	1.00	430	18	210	0.8	200
FRA-103	7-3	Plume-7	4.1	167	(3.4)	225	41	375	354	100	1.00	430	19	230	1.5	250
		Plume Averages	**4.3**	**170**	**2.8**	**199**	**41**	**336**	**335**	—	—	—	**20**	**220**	**1.2**	**230**
FRA-104	7-1	Surf P-7	9.4	260	(5.1)	267	43	636	354	27	1.08	430	21	360	2.0	250
FRA-105	7-2	Surf P-7	4.7	184	(2.3)	170	51	429	309	26	1.04	430	23	250	1.0	200
FRA-106	7-3	Surf P-7	3.3	138	(1.4)	142	39	250	227	26	1.04	430	18	160	0.6	150
		Plume Averages	**5.8**	**194**	**2.9**	**193**	**45**	**438**	**297**	—	—	—	**21**	**260**	**1.2**	**200**
FRA-095	7-1	SS Plume-7	ND	1.4	ND	ND	ND	ND	ND	27	0.27	430	0.0	2.2	0.0	0.0
FRA-096	7-2	SS Plume-7	BQL	*0.5*	ND	0.4	ND	ND	ND	26	0.26	430	0.0	0.8	0.0	0.6
FRA-097	7-3	SS Plume-7	BQL	*0.5*	ND	ND	ND	ND	ND	26	0.26	430	0.0	0.8	0.0	0.0
		Plume Averages	—	**1**	—	**0.4**	—	—	—	—	—	—	—	**1.3**	—	**0.21**

Notes:
47 samples; 3,752 increments.
Rep, repetition.
ND, not detected (below detection limits of instrumentation); BQL, below quantitation limits (values reported as zero).
Values in parentheses are estimated TNT concentrations.
Italicized numbers are values at or near quantitation value limits (reported as value limit).
Underlined bold numbers represent abnormal NG value that may be affecting HMX and RDX values.
The minimum mass reported (mg) is computed by multiplying 5x the detection limit in the AcN extract (mg/L) times the volume of AcN used to extract the sample (quantitation mass limit).

Appendix D: Laboratory QA Data

Table D1 contains data derived from laboratory quality assurance runs. Detection limits are 0.02 mg/L for RDX, HMX, and TNT and 0.05 mg/L for NG. The background sample had no detectable (ND) quantities of explosives in it. A small amount of NG was recovered from the filter of Water Blank-2. The source of this contamination was not traceable.

Table D1. Quality assurance data.

		Water Concentrations mg/L				Filter Concentrations mg/L				Target Concentrations (mg/L)			
Sample ID	Description	HMX	RDX	TNT	NG	HMX	RDX	TNT	NG	HMX	RDX	TNT	NG
FRA-018	Water Blank-1	<0.02	<0.02	—	<0.050	<0.02	<0.02	<0.02	<0.05	<0.02	<0.02	<0.02	<0.050
FRA-019	SPE Blank-1	<0.02	<0.02	—	<0.050	—	—	—	—	<0.02	<0.02	<0.02	<0.050
FRA-020	**SPE LCS-1**	0.216	0.204	—	0.197	—	—	—	—	0.20	0.20	0.20	0.20
FRA-038	Water Blank-2	<0.02	<0.02	—	<0.050	<0.02	<0.02	<0.02	**0.51**	<0.02	<0.02	<0.02	<0.050
FRA-039	SPE Blank-2	<0.02	<0.02	—	<0.050	—	—	—	—	<0.02	<0.02	<0.02	<0.050
FRA-040	**SPE LCS-2**	0.210	0.201	—	0.176	—	—	—	—	0.20	0.20	0.20	0.20
FRA-058	Water Blank-3	<0.02	<0.02	<0.02	<0.05	<0.02	<0.02	<0.02	<0.05	<0.02	<0.02	<0.02	<0.050
FRA-059	SPE Blank-3	<0.02	<0.02	<0.02	<0.05	—	—	—	—	<0.02	<0.02	<0.02	<0.050
FRA-060	**SPE LCS-3**	0.202	0.202	0.174	0.177	—	—	—	—	0.20	0.20	0.20	0.20
FRA-078	Water Blank-4	<0.02	<0.02	<0.02	<0.05	<0.02	<0.02	<0.02	<0.05	<0.02	<0.02	<0.02	<0.050
FRA-079	SPE Blank-4	<0.02	<0.02	<0.02	<0.05	—	—	—	—	<0.02	<0.02	<0.02	<0.050
FRA-080	**SPE LCS-4**	0.206	0.205	0.183	0.187	—	—	—	—	0.20	0.20	0.20	0.20
FRA-098	Water Blank-5	<0.02	<0.02	<0.02	<0.05	<0.02	<0.02	<0.02	<0.05	<0.02	<0.02	<0.02	<0.050
FRA-099	SPE Blank-5	<0.02	<0.02	<0.02	<0.05	—	—	—	—	<0.02	<0.02	<0.02	<0.050
FRA-100	**SPE LCS-5**	0.216	0.195	0.182	0.204	—	—	—	—	0.20	0.20	0.20	0.20
FRA-047	Background	ND	ND	ND	ND	ND	ND	ND	ND	0	0	0	0
Averages for LCS runs		**0.21**	**0.20**	**0.18**	**0.19**	—	—	—	—	**0.20**	**0.20**	**0.20**	**0.20**

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14. ABSTRACT

Military live-fire training missions frequently result in unexploded ordnance on training ranges. Disposal of the rounds, often done in situ, is necessary in some cases for range safety or maintenance. In February 2008, the U.S. Army Cold Regions Research and Engineering Laboratory teamed with the 716th Explosive Ordnance Disposal detachment at Fort Richardson, Alaska, to detonate two series of seven 60-mm and 120-mm fuzed high-explosive (HE) rounds to determine the resulting energetic residues. Each round was detonated using a single block of C4 (91% RDX) as a donor charge. All rounds were separated to allow each detonation plume to be sampled as a distinct decision unit. Samples were collected from the snow surface using multi-increment sampling for residues analysis. The 60-mm plumes averaged 200 mg of HE, 0.022% of the original mass. The 120-mm plumes averaged 25 mg of HE, 7.1 x 10^{-4}% of the original mass. Quality assurance procedures were conducted both in the field and at the laboratory to ensure data fidelity.

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