ERDC/CRREL TR-06-10

Cold Regions Research
and Engineering Laboratory

US Army Corps
of Engineers®
Engineer Research and
Development Center

Energetic Residues Deposition from 60-mm and 81-mm Mortars

Michael R. Walsh, Marianne E. Walsh, Charles A. Ramsey,
Richard J. Rachow, Jon E. Zufelt, Charles M. Collins, Arthur B.
Gelvin, Nancy M. Perron, and Stephanie P. Saari

May 2006

COVER: Mortar crew preparing to load an M888 HE round with three propellant charges into a 60-mm mortar, FP Upper Cole Point, Fort Richardson, Alaska. (Photo by M.R. Walsh, 19 January 2006)

ERDC/CRREL TR-06-10
May 2006

Energetic Residues Deposition from 60-mm and 81-mm Mortars

Michael R. Walsh, Marianne E. Walsh, Charles A. Ramsey, Richard J. Rachow, Jon E. Zufelt, Charles M. Collins, Arthur B. Gelvin, Nancy M. Perron, and Stephanie P. Saari

Cold Regions Research and Engineering Laboratory
U.S. Army Engineer Research and Development Center
72 Lyme Road
Hanover, New Hampshire 03755-1290

Final report

Prepared for Strategic Environmental Research and Development Program (SERDP)
Arlington, Virginia 22203

ABSTRACT

Military live-fire training missions utilize a variety of energetic materials that are never completely consumed during firing. Many munitions are issued with various types, quantities, and configurations of propellants. In January 2006, CRREL teamed with the 1st Battalion, 501st Parachute Infantry Regiment (PIR) in Alaska to sample areas used during a mortar training mission. Samples were collected from the snow surface at the firing points for both 81-mm and 60-mm mortars, as well as from areas up to 50 m downrange. Test burn points, areas where 10 excess propellant charges were burned, also were sampled. Six plumes comprising seven detonations of 60-mm high-explosive rounds were sampled on the impact range. Samples were analyzed to derive an estimate of the mass of unreacted energetics deposited from each activity. The 81-mm firing point contained 64 g of NG (3.3% of original NG mass). The 60-mm firing point contained 2 mg of NG (0.65% original NG mass), while the 60-mm impact plumes had a median of 50 μg RDX (2×10^{-5}% of the high-explosive [HE] load). Burn points had 840 mg, 1.6% of the original NG mass. These results indicate that further investigations of firing points are critical and that action needs to be taken on burn points.

CONTENTS

ILLUSTRATIONS

TABLES

PREFACE

This report was prepared by Michael R. Walsh, Engineering Resources Branch (ERB), U.S. Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire; Marianne E. Walsh, Environmental Sciences Branch (ESB), CRREL; Charles A. Ramsey, Envirostat, Fort Collins, Colorado; Captain Richard J. Rachow, CRREL-Alaska, Fort Wainwright, Alaska; Dr. Jon E. Zufelt, Water Resources Branch, CRREL; Charles M. Collins, ESB, CRREL; Arthur B. Gelvin, ERB, CRREL, Nancy M. Perron, Snow and Ice Branch; CRREL; and Stephanie P. Saari, ERB, CRREL.

Fieldwork on active impact ranges is a difficult and complicated matter and requires the cooperation and assistance of many people. The authors thank the soldiers and officers of the 1st Battalion, 501st Parachute Infantry Regiment (PIR), for their cooperation during this training mission, enabling the gathering of valuable samples upon which this research is based. The authors also thank George Alexion and L.D. Fleshman of U.S. Army Alaska (USARAK) Range Control for granting access to the range. SSG Brian Bradley of the 716th EOD Detachment, Fort Richardson, Alaska, provided explosive ordnance and sampling support. Internal manuscript review was provided by Dr. Thomas F. Jenkins of CRREL and Dr. Clarence L. Grant, formerly of the University of New Hampshire. Funding was provided by Dr. Thomas Jenkins through SERDP Project ER-1481.

This report was prepared under the general supervision of Thomas J. Tantillo, Chief, Engineering Resources Branch, CRREL; Dr. Lance D. Hansen, Deputy Director, CRREL; and James L. Wuebben, Acting Director, CRREL.

The Commander and Executive Director of the Engineer Research and Development Center is Colonel James R. Rowan. The Director is Dr. James R. Houston.

Energetic Residues Deposition from 60-mm and 81-mm Mortars

MICHAEL R. WALSH, MARIANNE E. WALSH, CHARLES A. RAMSEY,
RICHARD J. RACHOW, JON E. ZUFELT, CHARLES M. COLLINS,
ARTHUR B. GELVIN, NANCY M. PERRON, AND STEPHANIE P. SAARI

1 INTRODUCTION

Military live-fire training missions utilize a variety of energetic materials. In the case of mortars, cartridges are issued with various types and configurations of propellants, depending on the type and age of the round. These energetic materials are never completely consumed during firing and have the potential to contaminate military training ranges where they are used (Pennington et al. 2002, Hewitt et al. 2003, Jenkins et al. 2005). In January 2006, CRREL teamed with the 1st Battalion, 501st Parachute Infantry Regiment (PIR) in Alaska to sample areas used during a mortar training mission. The objectives of this field work were to examine mass loadings at firing points for 60-mm and 81-mm mortars during a live-fire exercise, to obtain controlled baseline data on mortar propellant residues at burn points, and to obtain impact area data for point-detonating 60-mm high-explosive rounds.

2 BACKGROUND

The examination of firing points as a source of energetic residues is a recent thrust in range sustainability research. Studies funded by U.S. Army Alaska (Soil and Water Quality Monitoring Fund) at Fort Wainwright's Donnelly Training Area (DTA) starting in 2000 (Walsh et al. 2001) indicated propellant-related energetic compounds were accumulating at heavily-used firing points. Further research in 2001 and 2002 (Walsh et al. 2004) reinforced the original indications, with the propellant constituents nitroglycerin (NG) and 2,4-dinitrotoluene (2,4-DNT) recovered at several firing points. The State of Alaska lists 2,4-DNT as a hazardous substance. Burn points, areas where excess propellants are burned off following training exercises, had unreacted residues at concentrations several orders of magnitude higher than at firing points, primarily of 2,4- and 2,6-DNT.

Although significant, these findings were only preliminary and much ground-breaking work on sample collection and processing was required. Sample collection was slow and difficult, with a variety of soils and levels of vegetation to deal with. A sample design that gave consistent results was needed, and a method of processing the samples so that subsamples were replicable had to be worked out. These technical issues have been resolved, and we hypothesized that the methods developed would be transferable to other sampling applications.

In 2002, SERDP funded research at Fort Richardson in Alaska to estimate residue deposition from the detonation of 105-mm and 81-mm high-explosive (Composition B) projectiles. Following the firing of the 105-mm howitzers, residues were collected from the snow-covered area in front of one of the guns. Preliminary results indicate concentrations of propellant residues much higher than found at the impact areas (Hewitt et al. 2003, Walsh et al. 2004, Walsh et al. 2005b, Ramsey et al. in prep).

The ease of sample collection on snow and the processing of these samples led us to consider further work on winter firing point sampling as an adjunct to the impact area work we were then conducting for SERDP. The methodology for the collection of samples on snow originally developed by Jenkins et al. (2000a, 2002) was optimized by Walsh et al. (2005a), making sampling much more efficient and repeatable. Leveraging funding from both SERDP and U.S. Army Alaska allowed us to sample active firing points and burn points for 120-mm mortars and the 155-mm howitzer to further this preliminary investigation (Walsh et al. 2005b, 2005c). Results from these tests demonstrated that firing points and burn points are areas of concern for range sustainability and maintenance.

The accumulated information led to the submission of a proposal to SERDP to formally investigate military range firing points. The tests documented here, conducted in cooperation with the U.S. Army at Fort Richardson, Alaska, are both a continuation of the previous work cited above and a fresh start on the new research program targeted at providing reliable estimates of propellant residue deposition at firing points for a variety of weapon systems. With this information, better range maintenance and improved range sustainability for the U.S. military will be possible.

3 FIELD TESTS

Field Site

The tests were conducted at the Eagle River Flats Range, Fort Richardson, Alaska. Eagle River Flats (ERF) is an estuarine salt marsh along the upper Cook Inlet that periodically floods and freezes over the course of the winter, building up layers of ice over the impact area (Fig. 1). With a fresh layer of snow on the ice, this area is ideal for conducting explosives residues tests as the impact detonation plumes are segregated from past activity on the Flats and residues are easily discerned on the snow surface. The Flats were used to collect the samples for the 60-mm impact points.

Figure 1. Eagle River Flats impact area from Firing Point Upper Cole.

At the southwest corner of the Flats lies Cole Point. Cole Point encompasses two firing points, Upper Cole and Lower Cole (Fig. 2). Upper Cole is located on a bluff overlooking Eagle River Flats. It is a 0.4-ha open area used as a bivouac area and observation point as well as a firing point. Firing points for two 81-mm

and one 60-mm mortar were established in this area. Burn points were also set up here. Lower Cole is located along the southeastern base of the Cole Point bluff slightly above the Flats. It is a small area that is not suitable for use as a firing point. A small footbridge crosses the adjacent Otter Creek allowing access to the Flats. It was in this area, about 50 m from Lower Cole, that the second firing point for the 60-mm mortars was established.

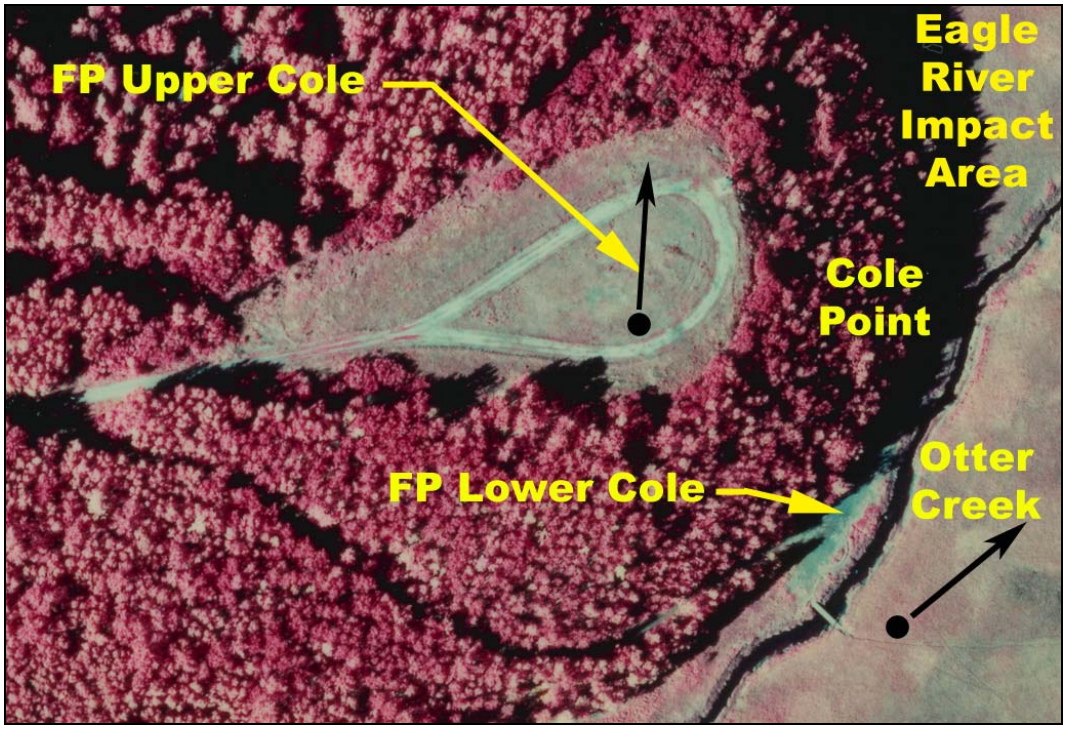


Figure 2. Cole Point area and firing points (●). Arrows indicate direction of fire.

At the time of these tests daytime temperatures ranged from –22°C to –12°C. Winds were calm to variable from the north at under 0.7 m/sec with partially overcast skies. Thick ice fog enveloped the area when winds diminished. Snow depth at the firing points ranged from 25 to 35 cm. In the impact area, snow depth ranged from 2 to 20 cm over ice with a thickness of up to 80 cm. No liquid water resided in the impact area where we sampled the detonation plumes. A light snow fell overnight on the 18th through the morning of the 19th of January 2006, with an accumulation of ≈10 cm. There were about six hours of daylight each day.

Munitions

Three types of munitions were fired during our tests (Table 1). The 60-mm test munitions were M888 high-explosive (HE) cartridges with an M935 point detonating (PD) fuze mounted in the nose (Fig. 3a). For the 81-mm tests, the M374A3 HE cartridge with an M567 PD fuze (Fig. 3b) and the M301A3 illumination cartridge with an M84A1 time fuze were fired. The M374A3 cartridge uses an M205 single-based charge (M10) primarily composed of nitrocellulose (NC). The M301A3 cartridge uses an M185 double-based charge (M9) composed primarily of NC and nitroglycerin (NG). The Army's Propellant Management Guide (1998) formulation for the 60-mm M888 propellant charge (M204) lists the M10 formulation as containing NC at 84.2% (6.8 g) and DNT at 9.9% (0.8 g). This differs from the M10 formulation for the M205 propelling charge for the M374A3 round. Both MIL-P-63194A (M204) (U.S. Army 1981) and MIL-P-48130A (M205) (U.S. Army 1982) refer to MIL-STD-652 (U.S. Army 1969) for the M10 propellant composition. Grains of raw propellant for both charges were analyzed and DNT was not detected in either. The MIL-STD-652C formulation (98% NC) is thus shown for the M204 charge in the table below. All cartridges have additional quantities of energetics (NC and NG) in the ignition cartridges located in the tail assemblies that either propel the round ("zero" charge) or ignite the added propellant charges. The amount of propellant charges used with each round varied, depending on the training requirement.

During previous SERDP-funded research, we examined detonation residues from several common military munitions. One of the munitions families for which we lacked reliable data was the 60-mm mortar. Given the opportunity presented during this field research, we added sampling of the detonation plumes of 60-mm HE rounds to our list of tasks. The M888 HE round contains 358 g of Composition B high explosive (Comp B) in the projectile body consisting of 215 g of RDX and 140 g of TNT. The M935 PD fuze adds 15 g of RDX to the explosive load. Appendix A contains complete munitions data for these tests.

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

Munition	Charge	Propellant	Constituent	Weight (g)	Std # of charges	Function
M888	M702	M9		3.37	1	Ignition
(60-mm HE)			NC	1.94		(Charge “0”)
			NG	1.35		
	Perc M35	Mix #70		0.02	1	Primer
			TNT	0.001		
				8.10	4	Charge 1–4
	M204	M10*	NC	7.9		(Adjustable)
M301A3	M66A1	M9		7.45	1	Ignition
(81-mm illumination)			NC	4.3		(Charge “0”)
			NG	2.98		
	Perc M35	Mix #70		0.01	1	Primer
			TNT	0.001		
	M185	M9		13.3	8	Charge 1–8
			NC	7.65		(Adjustable)
			NG	5.31		
M374A3	M299	M9		7.45	1	Ignition
(81-mm HE)			NC	4.3		(Charge “0”)
			NG	2.98		
	Perc M35	Mix #70		0.02	1	Primer
			TNT	0.001		
	M205	M10		25.4	4	Charge 1–4
			NC	24.8		(Adjustable)

* MIL-STD-652 formulation for the M10 propellant used

Refs: U.S. Army (1969, 1981, 1982, 1998)

a. 60-mm cartridge.

b. 81-mm cartridge.

Figure 3. High-explosive rounds used in tests.

Tests

Our tests were conducted in association with a training mission being conducted by the 1/501st PIR. Coordinating with the mission command, we located firing positions for one of two M252 81-mm mortars at Upper Cole. We flagged off an area approximately 35 m out in the direction of fire to restrict traffic in the area we anticipated sampling. We also designated a firing position at Lower Cole for the M19 mortar. The area in front of this firing position was flagged off downrange for sampling.

The 60-mm tests were run first. The M19 mortar is a light, handheld mortar used for close-in support (Fig. 4). The maximum number of propellant charges on an M888 round that can be used with this weapon is two. For our test, the mortar squads cycled through the firing position firing rounds at close-in targets with either "zero" charge (using the ignition cartridge in the tail to propel the round) or a single M204 propellant charge. The number of rounds fired and the total number of M204 charges used were tracked. An intermittent wind of 0.7 m/s was blowing downrange from behind the mortar squads.

Figure 4. M19 mortar and M888 cartridge with a single M204 propellant charge.

Following the completion of the training for the first group of mortar squads, we sampled the area in front of the position. The propellant residue plume was estimated using visible residues and ejected obturator rings to approximate its bounds. The plume was marked and recorded via GPS (Trimble GPS Pathfinder Pro XR, ± 1-m accuracy) by walking around it. Demarcated sampled areas, or decision units, at 15 m, 25 m, 35 m, and 50 m were flagged downrange of the

position for additional sampling. Trays to collect propellant debris for another research project that had been placed in front of the position, visible in Figure 4, were collected. The snow was then sampled for residues. The sampling method will be covered in the next section.

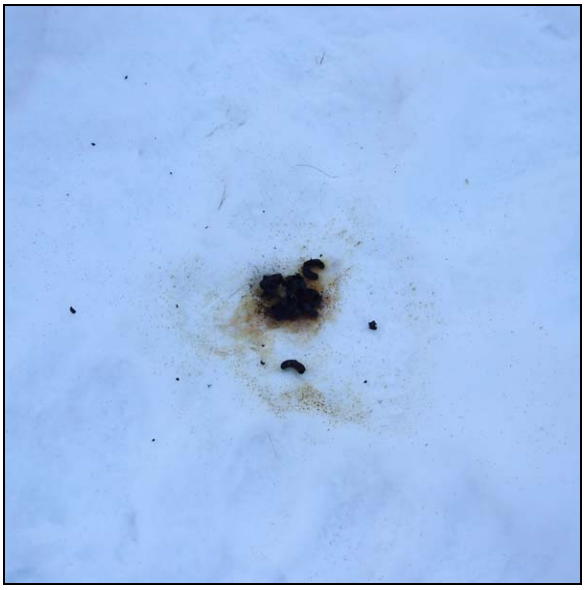
The 81-mm tests were not as straightforward. The space at FP Upper Cole was limited, with two gun positions, the ammunition storage area, the bivouac for the troops, and parking for vehicles all in a limited area. The crowding limited our ability to designate a generous "clean" area for sampling, but the troops were accommodating to the extent possible. The range of the M252 81-mm mortar (Fig. 5) is farther than for the small M19 mortar, requiring the ability to see far downrange to spot the impacts. Low temperatures and a lack of wind contributed to the formation of ice fog, delaying training until just before nightfall on 18 January. With the firing of a few spotting rounds and the sighting in of the weapons, night fell and a light snow started. We departed for the day while the squads practiced their firing with illumination rounds.

Figure 5. M252 mortar and M374A3 cartridge with two M205 propellant charges.

When we returned the following morning, training had been delayed further by the darkness and the snow, but the squad leaders had tracked the number of rounds and charges used throughout the training exercise. Upon completion of firing, we retrieved the collection trays, marked the decision units as outlined above, and sampled these areas for residues.

For the burn tests, we collected 20 excess charges from each of the three munitions to burn in piles of ten. These piles were located and recorded in an area of low residues 30 m downrange of the test mortar position. Both piles for each propellant type were ignited and allowed to burn out (Fig. 6).

a. Burning propellant charges.



b. Residue from charges

Figure 6. Propellant burn test (M204 charges).

The final test was run during the waning hours of 19 January. An M224 60-mm mortar system was used to fire 10 M888 HE rounds into an area designated in the Eagle River Impact Area. The rounds were fired with two M204 propellant charges each. Eight of the 10 rounds detonated. Following the cessation of firing, an EOD specialist from the 716th EOD detachment from Fort Richardson (Bradley) located the dudded rounds and cleared the remaining area. We then drove out to the impact plumes with our sampling equipment. The plumes were demarcated by walking outside the visible area of residues. The outlined plumes were recorded with a GPS unit. Five single-impact plumes and one double-impact plume were sampled. The eighth detonated round landed among some river ice blocks and was not sampled. In the fading light of the afternoon, we were not able to conduct all the quality assurance sampling we had planned. Sampling is described in the next section.

Sampling Method

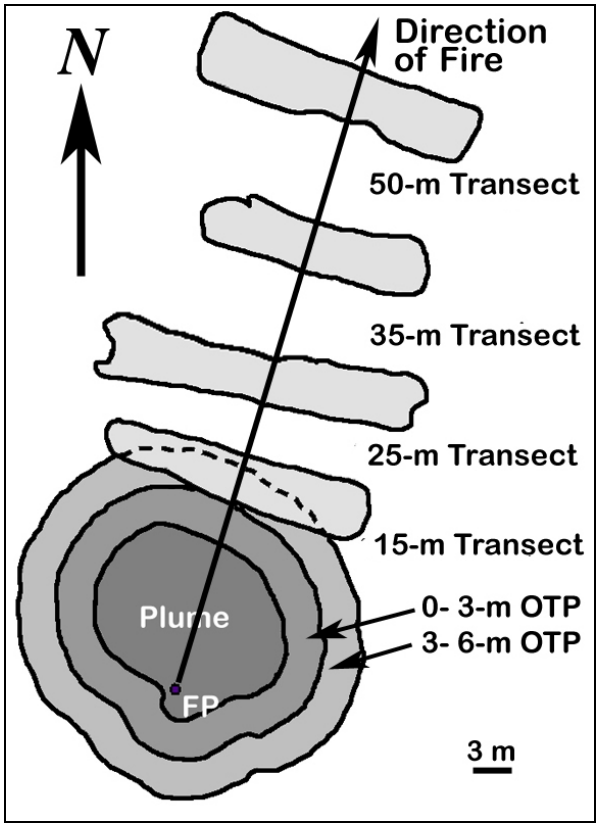
Sampling was done on a fresh snow surface following the protocol established by Walsh et al. (2005a). Briefly, 40 to 100 increments of surface snow are collected within a decision unit (inside the demarcated plume, outside the plume, at depth beneath previously sampled points, etc.), until the decision unit is representatively sampled. The increments for a given sample are collected in a single clean polyethylene bag to make up a multi-increment sample (MIS). Triplicate sampling allowed us to test and compensate for uncertainty derived from the small total area collected from within each decision unit, generally less than 1 m^2.

To estimate the mass of energetic residues, we need to know the area over which the energetic material 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 deflagration or detonation products 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 residues are deposited within the plume and tested this assumption by taking multi-increment samples in concentric annuli around the 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 unconsumed energetics are measurable outside of the plume. Samples were obtained for annuli at varying distances (0–3 and 3–6 m) surrounding the plume edge.

Additional quality control work was done within some of the plumes. Subsurface samples were taken beneath the sample locations to test whether we were sampling deep enough to recover all the residues. Two tests were also run to determine how much influence individual samplers have on residues recovery.

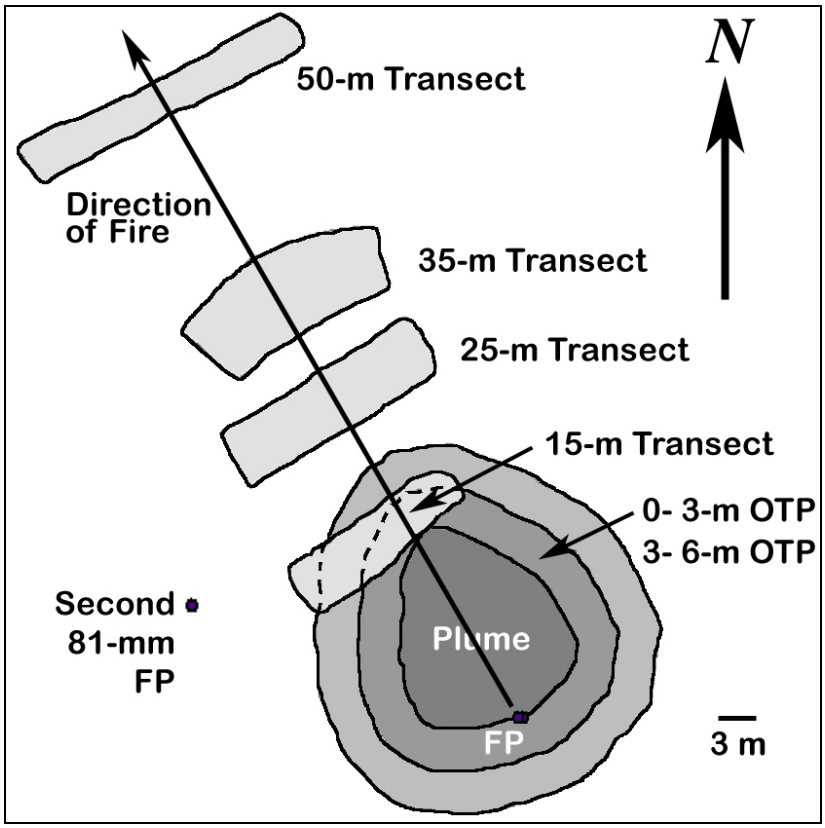
Teflon-lined aluminum scoops are used to obtain either a 10-cm- × 10-cm- × 2-cm-deep volume of snow or a 15-cm- × 15-cm- × 2-cm-deep volume of snow. Sampling depth is normally 1 cm, but because of the loose, low-density surface snow we sampled deeper. Specifics for the firing point, burn point, and impact point sampling follow.

The 60-mm firing point samples were conducted on fresh snow with no snow accumulation during the firing exercise. Three multi-increment surface samples using the 15-cm scoop were taken within the plume, followed by triplicate sub-surface samples taken with a 10-cm scoop from beneath the same area sampled with the 15-cm scoop. One multi-increment surface sample using the 10-cm scoop was also taken. Triplicate multi-increment OTP samples were taken between 0 to 3 m and 3 to 6 m from the plume's edge. Downrange from the firing position, triplicate multi-increment samples were taken from the four 3- × 10-m decision units established at 15 m, 25 m, 35 m, and 50 m from the FP (Fig. 7a).



a. 60-mm mortar firing.

Figure 7. Firing position maps showing decision units sampled.



b. 81-mm mortar.

Figure 7 (cont'd). Firing position maps showing decision units sampled.

The 81-mm firing point samples were taken while snow was falling so the methodology had to be modified to collect samples at a sufficient depth to capture most of the residues. Because of the accumulation of snow during the firing, the triplicate plume samples were sampled to a greater depth (≈6 cm) with a 15- × 15-cm scoop, followed by deeper sampling (≈5 cm) with the 10-cm square scoop (Fig. 8). Triplicate OTP multi-increment samples at 0 to 3 m and 3 to 6 m were taken. The downrange 3- × 10-m areas were also sampled in triplicate for this test as outlined above (Fig. 7b).

Figure 8. Collecting samples at 81-mm firing position.

Following the 81-mm plume sampling, the burn points were created. One of the two burn points for each type of propellant was sampled. The small area of most intense residue (0.06 to 0.5 m^2) as well as the OTP area out to about 0.5 m was completely sampled. Sampling was done with the 10-cm scoops. One set of burn points was left to be sampled at a later date. All burn points were recorded with a GPS unit.

The final samples collected were for the 60-mm impacts. Prior to post-detonation sampling, the plumes were inspected for continuity and overlap. The plumes, with the exception of the double plume, had clear visual separation between them, giving a preliminary indication of no cross contamination between detonations. They were visually demarcated and physically delineated by walking along the edge. The criteria used was a thinning of the plume to the point of difficulty in discerning continuous discoloration of the snow surface. The position and area were then recorded using a global positioning system**.**

We collected approximately one hundred 0.01-m^2 increments from the entire plume for each sample. A single individual collected the triplicate samples from four of the plumes, three individuals each collected a multi-increment sample from one plume, and two individuals collected triplicate multi-increment samples from the double plume (Fig. 9). The logic for this plume sampling strategy was to test for the influence of individual samplers on residue recoveries.

Figure 9. Sampling double-impact plume.

The dwindling daylight prevented us from conducting as much QA sampling as originally planned. Only one plume had subsurface samples taken beneath surface-sampled locations, and only one had triplicate OTP 0- to 3-m samples taken. The remainder of the plumes had a single 0- to 3-m OTP sample taken. No 3- to 6-m OTP samples were obtained. The final GPS work was done by vehicle headlights as the last rays of the setting sun faded.

Sample Processing and Analysis

The multi-increment snow samples were transferred to a lab set up in the Fort Richardson cantonment area for processing. Upon arrival, the samples were transferred from the field bags to clean bags, double-bagged, and placed in clean polyethylene tubs for thawing. Placing the samples in clean bags reduces the chances of cross-contamination from contact with adjoining bags and residues on the exterior of the sample bags. Double-bagging and the tubs were necessary because of the inclusion of sharp pieces of the projectile (frag) or other debris collected with the snow samples. Frag inclusions or plant stems can pierce the sample bags, allowing the thawed sample to leak.

Samples were shifted from warmer to cooler areas of the logistics bay of the lab to prevent over-warming (>10°C) of the samples after melting. The samples were then processed based on completion of melting and sampled area. Samples anticipated to have the least residues were processed first and those anticipated to be more contaminated were done last. Again, this is to reduce the chances of any

cross-contamination. Processing involves filtering the melted samples using a vacuum system and separating the soot fraction from the aqueous fraction (Fig. 10). The soot fraction is collected on filter papers (Whatman glass microfiber 90-mm ∅ grade GF/A) and the filters are placed in a clean amber jar, dried, and stored in a refrigerator at <5°C. A 500-mL aliquot of the filtrate was preconcentrated by passing it through a Waters Porpak RDX (Sep-Pak, 6-cm^3, 500-mg) solid-phase extraction cartridge and eluted with 5 mL of acetonitrile, resulting in a 100:1 concentration of the analytes (Walsh and Ranney 1998). The concentrate is split into two aliquots, 3.5 mL for analysis and 1.5 mL for archiving. When processing was completed, the 3.5-mL splits and the filters were shipped to the analytical chemistry laboratory at CRREL's main office in Hanover, New Hampshire, for final processing and analysis.

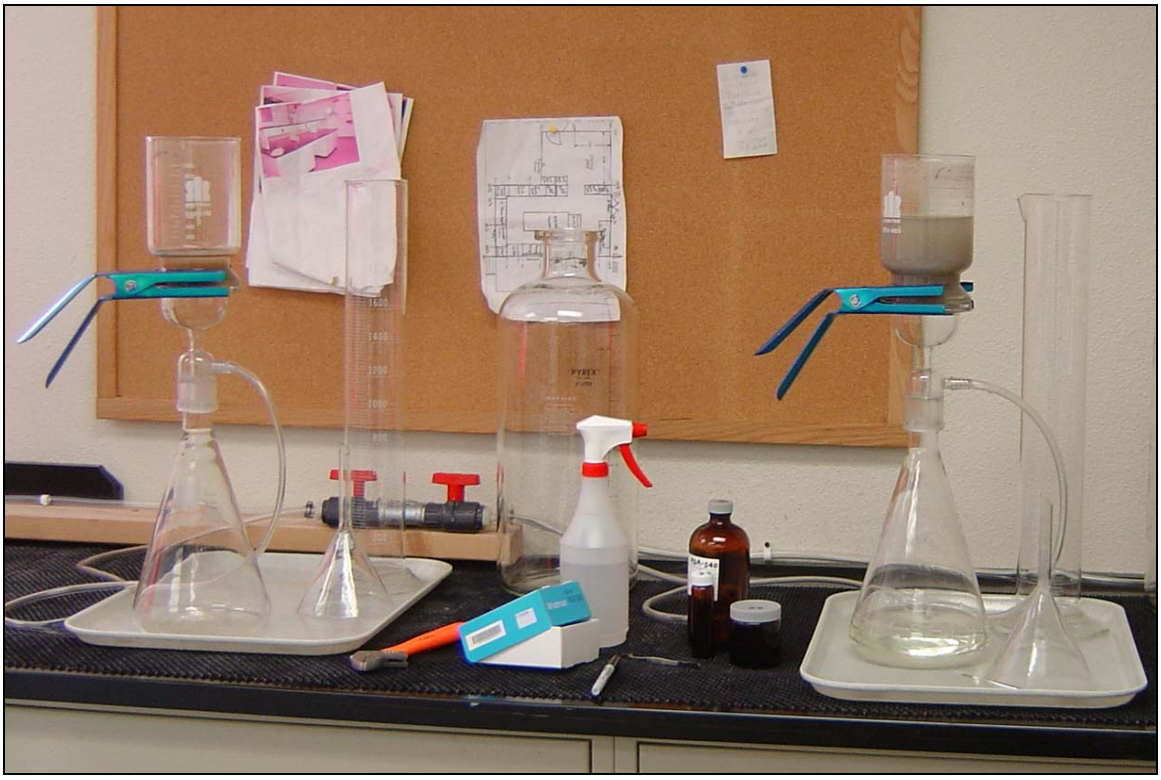


Figure 10. Sample filtration setup.

The filters containing the soot fractions were extracted using acetonitrile. Each sample was shaken with the solvent for 18 hours. The acetonitrile extracts from the solid-phase extraction of the melted snow and of the solid residue on the filters were analyzed by either HPLC or GC-μECD depending on analyte concentration.

Analyte concentrations greater than 100 µg/L were determined following the general procedures of SW 846 Method 8330 (Nitroaromatics and Nitramines by High-Performance Liquid Chromatography [HPLC]) (U.S. Environmental Protection Agency [USEPA] 1994). Lower concentrations were determined using Method 8095 (Nitroaromatics and Nitramines by GC) (USEPA 2000), which uses an electron capture detector and provides detection limits near 1 µg/L for RDX and 20 µg/L for NG in solvent extracts. The advantage of the HPLC method is that the analytical error is very small, about 2% relative standard deviation (RSD) for replicate injections. Although the GC-µECD method can detect much lower concentrations, the analytical error is much greater, approaching 20% RSD.

Prior to HPLC analysis, 1.00 mL of each acetonitrile extract was mixed with 3.00 mL of reagent-grade water. Determinations were made on a modular system from Thermo Electron Corporation composed of a Finnigan SpectraSYSTEM Model P4000 pump, a Finnigan SpectraSYSTEM UV2000 dual wavelength UV/VS 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 × 3.9-mm (4-µm) NovaPak C8 column (Waters Chromatography Division, Milford, Massachusetts) at 28°C and eluted with 1.4 mL/min of 15:85 isopropanol/water (v/v).

For GC analysis, the acetonitrile extracts were transferred to autosampler vials, which were then placed into an HP 7683 Series autosampler tray that was continuously refrigerated by circulating 0°C glycol/water through the trays. A 1-µL aliquot of each extract was directly injected into the HP 6890 purged packed inlet port (250°C) containing a deactivated Restek Uniliner. Primary separation was conducted on a 6-m- × 0.53-mm-ID fused-silica column, with a 0.5-µm film thickness of 5% (phenyl) methylsiloxane (RTX-5 from Restek). The GC oven was temperature-programmed as follows: 100°C for 2 min, 10°C/min ramp to 250°C. The carrier gas was hydrogen at 0.85 psi inlet pressure. The µECD detector temperature was 280°C; the makeup gas was nitrogen at 60 mL/min. Extracts were also analyzed using an RTX-TNT2 confirmation column. Column dimensions were 6-m- × 0.53-mm-ID with a 1.5-µm film thickness. The GC oven was temperature-programmed as follows: 130°C for 1 min, 10°C/min ramp to 160°C, 30°C/min ramp to 270. The carrier gas was hydrogen at 1.6 psi inlet pressure. The µECD temperature was 310°C and the makeup gas was nitrogen at 60 mL/min.

All of the 81-mm mortar firing point samples and burn point samples were analyzed by HPLC. The 60-mm firing point samples were analyzed by both HPLC and GC. The 60-mm impact samples were analyzed by GC.

Calibration standards were prepared from analytical reference materials obtained from Restek Corporation (Bellefonte, Pennsylvania). 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 1000 µg/L was prepared from 8330 Calibration Mix 1 and the single-component solution of NG (1 mg/mL). Spiked water samples at 2 µg/L were prepared by mixing 1.00 mL of the spike solution with 499 mL of water. 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 combined the estimated masses derived for the soot and aqueous fractions. For the aqueous fraction, we divided the average concentration of the extract (µg/L) by 100. We then multiplied by the total volume of filtrate for the sample (L), giving us the mass dissolved in the snow (µg). For the soot fraction, we multiplied the filter extract (µg/L) by the volume of AcN used in the extraction process (L), giving us the mass of residues on the filter (µg). We then combined these mass values and divided by the area sampled, giving us a mass-per-unit-area estimate (µg/m^2). Multiplying this value by the measured area of the plume (m^2) gives us the final estimate for the residue mass for that sample (µg) (Jenkins et al. 2002, Hewitt et al. 2003).

Quality Control Procedures

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

We also conducted QC 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 SPE setup for later analysis at the lab. This procedure was designed to determine whether cross-contamination from the sample filtering apparatus was occurring. Water fractions for several samples were divided into three aliquots and run through the SPE to determine whether recovery rates from the SPE procedure were consistent. SPE blanks were run to determine cartridge filter retention and recovery during the elution process. These processes are described in greater detail in Walsh et al. (2005c).

4 RESULTS

Background Samples

The background samples collected from the FP areas prior to firing were blank, indicating clean test areas. Results are given in Table 3.

Firing Points

A total of 49 multi-increment samples, composed of 2,676 increments, were taken. The demarcated plume sizes were 158 m^2 for the 60-mm FP and 135 m^2 for the 81-mm FP. Because of the difficulty of demarcating the 81-mm FP plume and based on the analysis of the OTP samples, the FP plume analysis was done for both the original demarcated plume area and an expanded plume that includes the OTP area (365 m^2). Sampling and plume data are given in Table 2. Maps of the test areas derived from the GPS data are shown in Figure 7.

Table 2. Data for sampled areas: Firing positions.

Position	Decision unit	Sampling tool size (cm)	Decision unit size (m^2)	Average area sampled (m^2)	Average area sampled (%)
60 mm	Plume: Surface	15 × 15 × 2	158	0.89	0.56%
	Plume: Surface*	10 × 10 × 2	158	0.77	0.63%
	Plume: Subsurface	10 × 10 × 2	158	0.40	0.25%
	OTP: 0–3 m	10 × 10 × 2	168	0.75	0.45%
	OTP: 3–6 m	10 × 10 × 2	220	0.72	0.33%
	15-m transect	10 × 10 × 2	77	0.60	0.78%
	25-m transect	10 × 10 × 2	101	0.60	0.59%
	35-m transect	10 × 10 × 2	70	0.50	0.71%
	50-m transect	10 × 10 × 2	101	0.52	0.51%
81 mm	Plume: Surface	15 × 15 × 2	135	0.96	0.71%
	Plume: Subsurface	10 × 10 × 2	135	0.43	0.32%
	OTP: 0–3 m	10 × 10 × 2	155	0.60	0.39%
	OTP: 3–6 m	10 × 10 × 2	210	0.51	0.24%
	15-m transect	10 × 10 × 2	50	0.60	1.2%
	25-m transect	10 × 10 × 2	71	0.60	0.85%
	35-m transect	10 × 10 × 2	84	0.50	0.60%
	50-m transect	10 x 10 x 2	61	0.53	0.87%

Note: N = 3 for all samples except *(N = 1).

Analytical data averaged for the replicates are given in Table 3. 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: TNT, TNB, 1,3-DNB, 2,4-DNT, RDX, HMX, and NG. Only NG was detected in any of the firing point samples.

The plume in front of the 60-mm FP contained only low concentrations of NG. The OTP and downrange transects contained no detectable quantities of NG, indicating that the demarcated plume held the majority of residues. Subsurface samples also had no detectable quantities of NG, indicating that the surface samples were of adequate depth. Detected mass for the plume averaged 2.7 mg for the triplicate samples (≈40 increments each) and was 0.8 mg for the single 10-cm multi-increment sample (77 increments). Including this sample with the triplicates gives an average mass of 2.2 mg. A total of 25 samples comprising 1,420 increments was taken at the FP.

The 81-mm FP was quite different from the 60-mm position. Both the surface and subsurface samples for the demarcated plume had gram-quantities of NG. The subsurface residues are indicative of the deposition of residues throughout the snowstorm the night of 18 January. Both the OTP triplicate samples also contain NG residues, albeit at a much reduced mass. The downrange transects all contain measurable quantities of NG. Repeatability for all samples is within a factor of two except for the 25-m transect, which appears to have contained a partial propellant grain (likely due to the proximity of the second 81-mm mortar FP) and one of the OTP samples. For characterization purposes, we lumped the subsurface measurements with the surface measurements and looked at the effect of adding the OTPs with the plume, giving us a new plume size of 500 m^2 with the OTPs. The adjusted total residue (to two significant digits) is affected by the subsurface samples (20% of combined total) but not by the OTPs (<0.3%). Although the OTP residues are significant by themselves, they are not significant when taken in context with the original plume NG residue mass load. A total of 24 samples comprising 1,300 increments was taken at the FP. A more complete data set can be found in Appendix B.

Table 3. Analytical data for NG in plumes: Firing point tests.

Position	Sample type*	Replicate mass (mg)	Average mass (mg)	Range ratio
Both	Background	—	ND	—
60 mm	Plume: 15- × 15-cm scoop	4.9		
		1.3		
		2.0	2.7	3.7
	Plume	0.76	2.2†	6.4†
	Plume: Subsurface	ND	—	—
	OTP: 0–3 m	ND	—	—
	OTP: 3–6 m	ND	—	—
	15-m transect	ND	—	—
	25-m transect	ND	—	—
	35-m transect	ND	—	—
	50-m transect	ND	—	—
81 mm	Plume: 15- × 15-cm scoop	58,000		
		41,000		
		53,000	51,000	1.4
	Plume: Subsurface	17,000		
		14,000		
		8,500	13,000	2.0
	OTP: 0–3 m	150		
		210		
		570	310	3.8
	OTP: 3–6 m	60		
		83		
		96	80	1.6
	15-m transect	12		
		15		
		20	16	1.7
	25-m transect	41		
		2.1		
		2.8	15	19
	35-m transect	5.5		
		4.0		
		5.5	5.0	1.4
	50-m transect	1.2		
		1.5		
		1.8	1.5	1.5
	Plumes + Subsurface		64,000	–
	Plumes + Subsurface + OTPs		64,000	–

ND = Not detected by analytical instrumentation
* Sample taken with 10-× 10-cm scoop unless otherwise noted
† Average of all four multi-increment samples

Extrapolating further, we expanded the 81-mm firing point plume out to the 50-m transect, enlarging the plume area to encompass all the sampled decision units as well as the areas in between (Fig. 11). The objective of this exercise was to test whether expanding the plume downrange will significantly increase the estimated mass of residues. The new plume was divided into areas based on the location of the sampled transects. The residue mass within each transect was then calculated using mass concentration data derived from Tables 2 and 3.

Recalculated mass (µg) = Transect mass concentration (µg/m^2) * Transect zone area (m^2). (1)

The recalculated NG residue masses from these zones were added to the original mass calculation for the plume surface, subsurface, and OTP values. We did not try to correct for the influence of the second 81-mm mortar position in this analysis, which added to the residue load in part of the expanded plume. With the 60-mm firing position, there is of course no effect as no residues were detected outside the demarcated plume.

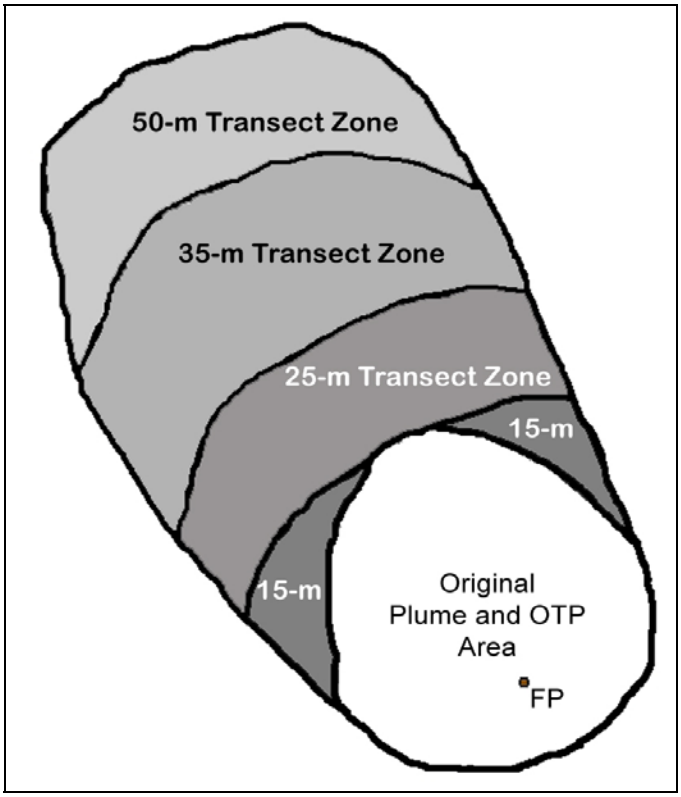


Figure 11. Extrapolated 81-mm FP plume using expanded transect zones.

The theoretical plume that encompasses the original demarcated plume, the OTPs, and the transects has an estimated mass larger than the separate decision units combined. The increases in mass for the expanded transects (transect zones in Fig. 11) range from 138% to 420%. The projected mass difference is 98 mg (360% of original mass for all transects). Although significant within the context of the area beyond the OTPs, the recalculated mass is not significantly greater than the original mass calculations (<0.2%). Data are given in Table 4.

Table 4. Estimated FP residue mass values using plume extrapolation: 81-mm mortar.

Decision unit	Decision unit size: New (m^2)	Original mass (mg)*	Recalculated mass (mg)	Difference from original (%)
Plume	135	64,000	64,000	—
OTP: 0–3 m	168	310	310	—
OTP: 3–6 m	210	80	80	—
15-m transect zone	120	16	38	138%
25-m transect zone	295	15	64	327%
35-m transect zone	433	5.0	26	420%
50-m transect zone	320	1.5	7.7	413%
Transect mass		38	136	360%
Theoretical plume	1680	64,428	64,526	0.15%

* From Table 3

A rough mass balance can be done on the NG load in the propellants (Table 1). Table 5 contains data on the number and types of rounds fired from the two test positions as well as the sources of and the total masses of NG involved. Using these data as well as those from Tables 3 and 4, the results in Table 6 were derived.

The analysis for the 60-mm mortar is straightforward, as only one type of round was fired from the mortar position. The only propellant component with NG was the ignition cartridge. For the 81-mm mortar, two types of rounds with differing propellant charges were used. The M301A3 illumination round has NG in both the propelling charges and the ignition cartridge, whereas the M374A3 HE round has NG only in the ignition cartridge. This makes deriving the per-round mass balance difficult. What we did in Table 6 was estimate the ignition cartridge efficiency for the 81-mm rounds as equivalent to the 60-mm round. That gives us a value for the 81-mm HE ignition cartridges, from which we can derive an estimate for the M374A3 round. Using this value, we calculated a value for the M301A3 round. Further analysis of the M301A3 round will yield a rough estimate of the mass balance for the propelling charges, but the utility of such an

estimate is questionable. Previous work (Jenkins et al. 2000b) indicates that NG from the ignition cartridge also can be found at the detonation point of mortar rounds, although we did not find any in our samples.

Table 5. Original masses of NG utilized in firing point tests.

Position	Type of round	Source of NG	Sources consumed	Mass of NG in source (g)	Total mass (g)
60 mm	M888	Primer	25	0	0
		Ignition	25	1.35	33.8
		M204 charge	5	0	0
Total					33.8
81 mm	M301A3	Primer	61	0	0
		Ignition	61	2.98	181.8
		M185 charge	314	5.31	1,667.3
	M374A3	Primer	40	0	0
		Ignition	40	2.98	119.2
		M205 charge	81	0	0
Total					1,968.3

Table 6. Calculated mass balance for NG in propellants for mortar cartridges.

Position	Type of round	Original mass (g)	Recovered mass (g)	Number of rounds	Recovered mass (%)	Mass per round (mg)
60 mm	M888	33.8	0.0022	25	6.5×10^{-3}	0.088
81 mm	M301A3	1849	64	61	3.5%	1000
	M374A3	119	0.0077*	40	6.5×10^{-3}	19

* The estimate for the M374A3 round was derived from the M888 round.

Burn Points

Propellant charges for each of the three different mortar cartridges were burned in two piles of ten each. These piles were on the snow surface and unconfined (Fig. 6). No specific background samples were taken at these locations. We relied instead on data collected from the transect samples taken for the just-completed 81-mm FP test. Those samples indicated NG levels ranging from 320 µg/m^2 to 60 µg/m^2 as the distance from the firing position (FP-1) increased. Figure 12 is a map of the burn points. Appendix C contains more complete data for this test.

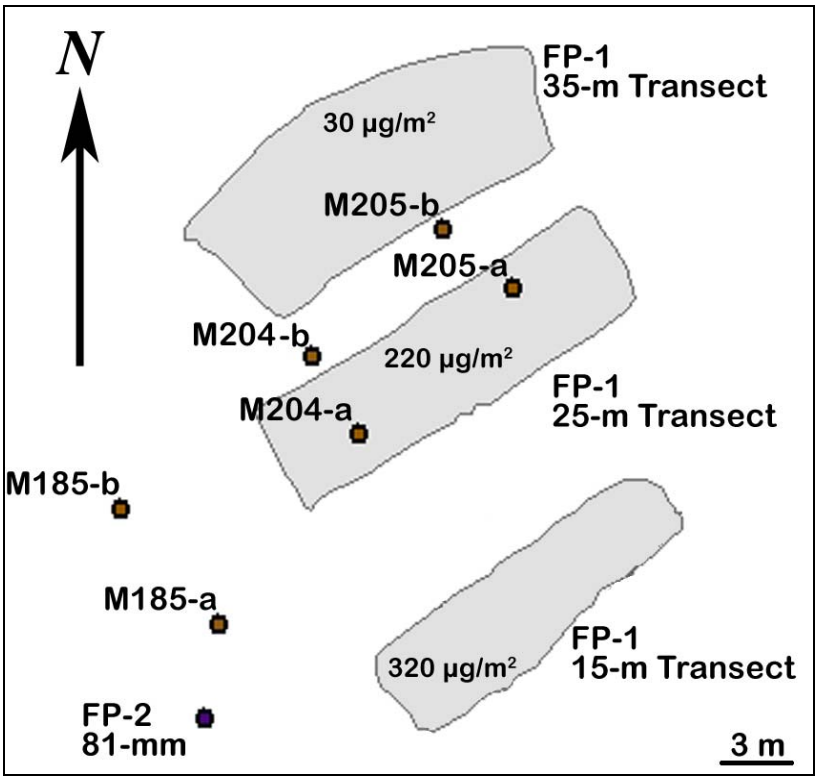


Figure 12. Burn point map.

One of the two burned piles (-a) was sampled for each propellant type. Because these areas were not large, they were sampled completely (Table 7). An area surrounding the burn area was also sampled. A total of one multi-increment and five discrete samples was taken at the burn points. The second burn area (-b) was left for sampling in the future to determine whether any attenuation of the energetic residues occurs over the winter.

Table 7. Data for sampled areas: Burn points.

Charge/propellant	Decision unit	Decision unit size (m^2)	Area sampled (m^2)	Area sampled (%)
M185/M9	Burn point (a)	0.063	0.063	100%
	OTP	0.50	0.50	100%
M204/M10	Burn point (a)	0.44	0.44	100%
	OTP	0.34	0.34	100%
M205/M10	Burn point (a)	0.54	0.54	100%
	OTP	0.46	0.40	87%

The samples were analyzed for a series of energetic compounds: TNT, TNB, 1,3-DNB, 2,4-DNT, RDX, HMX, and NG. During the melting and filtering process, it was visually evident by color that a large amount of material was present in the aqueous portion (Fig. 13). Thinking this was indicative of high quantities of unreacted residues, we processed these samples last and tried to keep the pre- and post-processed samples separated from other samples to prevent cross-contamination.

Figure 13. Filtering propellant burn area sample (M205-a).

The data for the burn point sample analyses are presented in Table 8. Only NG was detected in any of the samples. From Table 1, only the M185 charge contains NG. Analysis of the data indicates that about 1.7% of the original NG in the propellant remains after unconfined burning. The analyses of the M204 and M205 samples indicate trace amounts of NG in the OTP samples but none detected in the burn point samples. This is likely an artifact from the previous firing of the rounds from the mortar positions. The detection levels in the OTPs are consistent with the 30- to 220-$\mu g/m^2$ levels in the 25- and 35-m transects that are used as background levels for this test (Fig. 12). For the M204 OTP, the background level should be around 0.097 mg for the area sampled. For the M205 OTP, the background level should be closer to 0.012 mg for the area sampled. Both data points are close to these values, indicating that the NG recovered was from the background residues resulting from the firing of the 81-mm mortars. These quantities are small compared to the residues recovered for M185 propellant burn.

Table 8. Analytical data for NG in plumes: Burn point tests.				
Propellant	**Decision unit**	**Original mass (mg)**	**Recovered mass (mg)**	**Mass remaining**
M185	Burn point (a)	53,100	840	1.6%
	OTP	0.0	33	0.06%
M204	Burn point (a)	0.0	-ND-	—
	OTP	0.0	0.071	—
M205	Burn point (a)	0.0	-ND-	—
	OTP	0.0	0.023	—

Impact Points

Seven M888 mortar round impacts were sampled. Of the seven, five generated non-overlapping plumes and two detonations overlapped, creating a double-impact plume. The rounds were fired on a cold (–13°C) windless day during a light snowfall. The plumes were generally concentric around the detonation points (Fig. 14). Samples were taken both within the demarcated plumes and within a 0- to 3-m annulus surrounding the plumes. A total of 34 multi-increment samples consisting of 2,732 increments was collected. Table 9 contains the physical data for the plumes. Appendix D contains more detailed data for this test.

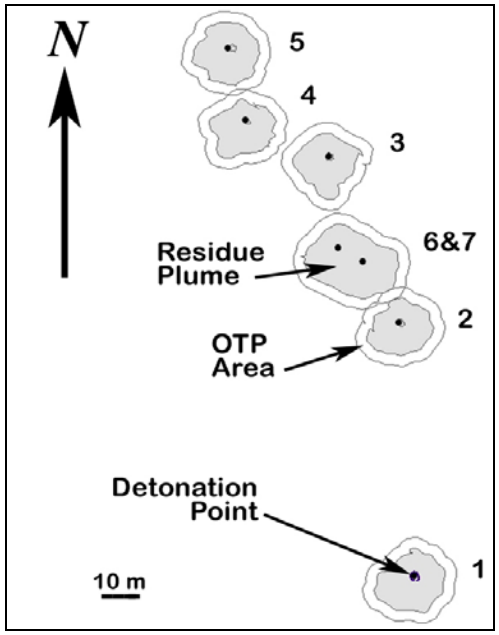


Figure 14. 60-mm M888 HE round detonation plumes: Sampled plumes.

Table 9. Data for sampled areas: Impact points.

Plume	Decision unit	Sampling scoop size (cm)	# of samples	Decision unit size (m^2)	Average area sampled (m^2)	Average area sampled (%)
1	Plume: Surface	10	3	233	0.91	0.39%
	OTP: 0–3 m	10	3	200	0.96	0.48%
2	Plume: Surface	15	3	200	1.0	0.50%
	Plume: Subsurface	10	3	200	0.42	0.21%
	OTP: 0–3 m	10	1	186	0.49	0.26%
3	Plume: Surface	10	3	207	1.0	0.48%
	OTP: 0–3 m	10	1	194	0.53	0.27%
4	Plume: Surface	10	3	201	0.92	0.46%
	OTP: 0–3 m	10	1	192	0.56	0.29%
5	Plume: Surface	10	3	228	0.99	0.44%
	OTP: 0–3 m	10	1	194	0.60	0.31%
6 & 7	Plume: Surface	10	6	360	1.0	0.28%
	OTP: 0–3 m	10	3	238	0.72	0.30%
Average	Plumes	–	3.5	214*	0.97	0.41%
	OTPs	–	1.7	193*	0.64	0.31%
Median	Plumes	–	–	207*	0.99	0.44%
	OTPs	–	–	194*	0.60	0.29%

* Does not include the double plume (6 & 7)

Each M888 cartridge body contains 358 g of Comp B high explosive consisting of 215 g of RDX and 140 g of TNT. Up to 9% of the RDX (19 g) can be HMX, a manufacturing by-product of RDX. The M935 point-detonating fuze contains an additional 15 g of RDX. Detonation residues were analyzed for TNT, TNB, 1,3-DNB, 2,4-DNT, RDX, HMX, and NG. Only RDX was detected in the samples. Table 10 contains the analytical data for the analyses of the impact area samples.

Table 10. Analytical data for RDX in plumes: Impact point test.

Plume	Sample type	Replicate mass (µg)	Average mass (µg)	Range ratio	% RSD
1	Plume: LIS	51			
	Plume: LIS	100			
	Plume: LIS	120	90	2.3	39
	OTP: 0–3 m	ND			
	OTP: 0–3 m	ND			
	OTP: 0–3 m	ND	—	—	
2	Plume: LIS	47			
	Plume: LIS	60			
	Plume: LIS	36	48	1.7	25
	Plume: Subsurface	ND			
	Plume: Subsurface	ND			
	Plume: Subsurface	ND	—	—	
	OTP: 0–3 m	ND	—	—	
3	Plume: LIS	200			
	Plume: LIS	160			
	Plume: LIS	220	190	1.4	16
	OTP: 0–3 m	ND	—	—	
4	Plume: LIS	31			
	Plume: LIS	58			
	Plume: LIS	40	43	1.9	32
	OTP: 0–3 m	ND	—	—	
5	Plume: LIS	81			
	Plume: LIS	54			
	Plume: LIS	46	60	1.8	30
	OTP: 0–3 m	ND	—	—	
6 & 7	Plume: LIS	67			
	Plume: LIS	100			
	Plume: LIS	100			
	Plume: LIS	110			
	Plume: LIS	120			
	Plume: LIS	120	100	1.8	19
	OTP: 0–3 m	ND			
	OTP: 0–3 m	ND			
	OTP: 0–3 m	ND	—	—	
Average	Plumes (N = 6)		88	1.8	
	Detonations (N = 7)		73	1.7	
Range	Plumes		147	0.9	
	Detonations		147	1.2	
Median	Plumes		90	1.8	
	Detonations		50	1.7	

The average residue mass deposition was 73 µg RDX per detonation, ranging from a high of 190 µg to a low of 43 µg with a median of 50 µg, based on the residues of plumes 6 and 7 being evenly split between the two detonations. The repeatability between replicates is very good, averaging less than a factor of two difference between the high and low values (range ratio). Only one set of replicates has a difference greater than a factor of two, plume #1 at 2.3. The relative standard deviation (RSD) for the samples ranges from 16% to 39%. If we pool all of the percent RSD estimates, we obtain an overall estimate of 26% with 15 degrees of freedom. There were no explosives detected outside the demarcated plumes, and the one plume that was sampled beneath surface sample points had no detectable explosives in the subsurface samples. These QA results indicate a good representation of the residues from the detonations.

5 DISCUSSION

Testing out of doors always presents challenges. In our case, snow was the confounding factor. At the time of the tests, it was falling quite heavily for a period (Fig. 5 and 7), making plume demarcation especially difficult at the 81-mm firing point. We compensated for this to some extent by sampling deeper, 6 cm or more instead of the usual 2 cm. In this case, the subsurface samples were critical, amounting to 25% of the surface residue load or 20% of the total residue load within the plume. We were quite concerned that we had not adequately delineated the plume, and the results somewhat bear this out, with an estimated total of 390 mg of NG recovered from the 6-m-wide annulus surrounding the plume. However, when taken into context with the recovered residue load from within the plume (64 g), the quantity is not very significant (≈0.6%). Almost 80% of this was within the first 3 m of the annulus, indicating that we were a little undersized on the plume delineation but not enough to significantly affect the results.

The downrange firing point transects were of great interest. We did not have a good feel for the distance over which detectable amounts of residues could be found at a firing point. Previous work (Pennington et al. 2002, Walsh et al. 2004, Ramsey et al. in press) has been done at firing points but the ability to determine residues on a per-round basis was not possible. We have come closer in this study. The M185 propellant charges were the only charges containing NG, the only energetic constituent recovered from the 81-mm transects. Although NG is found in the ignition cartridges as well, the quantity is low and, from the 60-mm mortar test results, very little NG from the cartridges is deposited at the firing points after firing. If we assume that the contribution from the M374A3 ignition cartridges is minimal and that all the NG found in the transects is from the propellant charges of the 61 M301A3 cartridges fired, we get the following estimate for mass per round at each of the transects: 15 m: 260 µg/round; 25 m: 250 µg/round; 35 m: 82 µg/round; and 50 m: 25µg/round. This compares to the 1.1 g/round found within the combined plume/OTP area. We could not go out more than 50 m for this test as we would have been over the edge of a bluff and into the woods. Using exponential curve fitting,

$$Y = 52.595 * e^{-0.186X} \quad (2)$$

and assuming the mass at X = 0.0 is equal to half the plume load (500 mg), we get a value of 1 µg/round at ≈60 m out from the firing point ($R^2 = 0.997$) (Fig. 15).

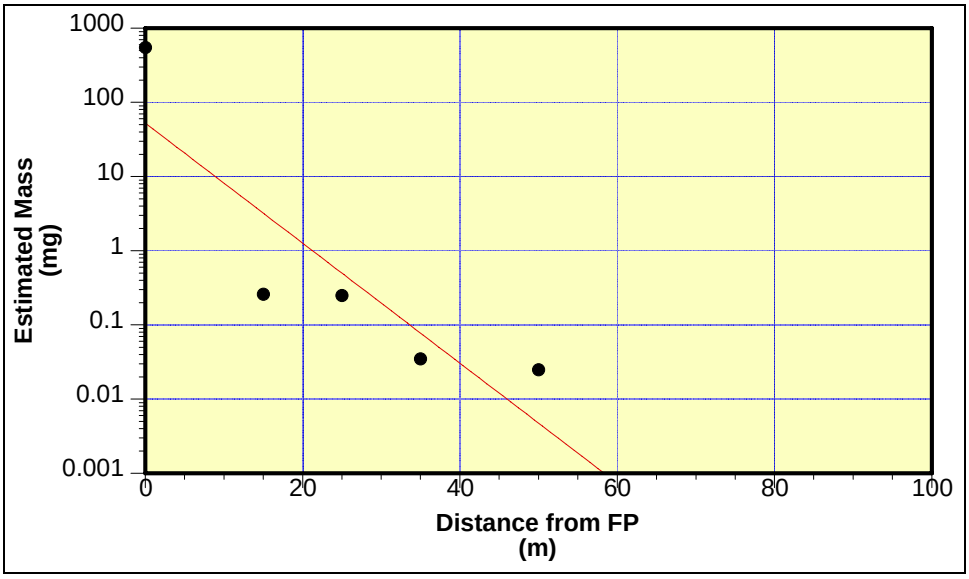


Figure 15. Exponential curve fit for FP residues (●): Case 1.

Curve fitting for only the transects, we get:

$$Y = 0.9494*e^{-0.0765X} \quad (3)$$

which gives us a value of 1 µg/round NG at 90 m ($R^2 = 0.975$) (Fig. 16). The actual cutoff for 1 µg/round is likely between the distances given by (2) and (3).

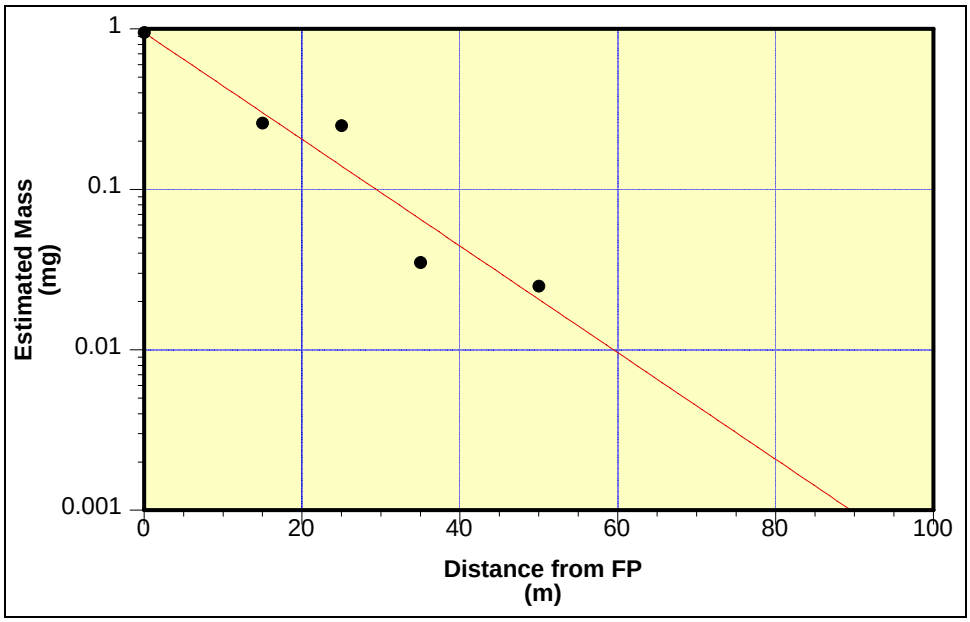


Figure 16. Exponential curve fit for FP residues (●): Case 2.

We had similar concerns with the impact point samples. The snow was tapering off when the troops fired the rounds and the plumes were easier to delineate. Still, a thin covering of snow overlaid the detonation plumes. We were running up against sunset when we started sampling, so we had time to do only the 0- to 3-m OTP samples on the plumes. In this case, the OTP samples had no detectable residues, indicating that the plume delineations were sufficient. The one plume from which triplicate subsurface samples were taken also had no detectable energetics.

In our ongoing effort to examine the possible sources of error in our field sampling method, we conducted some tests while sampling the impact plumes. In one test, three samplers each obtained a multi-increment sample from within and outside a detonation plume. The data were compared for variability. The samplers were then randomly assigned a plume from which they were to obtain triplicate samples to test how repeatable their sampling was in comparison to the jointly sampled plume. Data are shown in Table 11.

Table 11. Sampler variation test results.

Sampler	Sample type	Replicate mass (µg)	Average mass (µg)	Range ratio
1	Plume: Impact #1	51		
2	Plume: Impact #1	100		
3	Plume: Impact #1	120	90	2.3
1	Plume: Impact #5	81		
	Plume: Impact #5	54		
	Plume: Impact #5	46	60	1.8
2	Plume: Impact #3	200		
	Plume: Impact #3	160		
	Plume: Impact #3	220	190	1.4
3	Plume: Impact #4	31		
	Plume: Impact #4	58		
	Plume: Impact #4	40	43	1.9
4	Plume: Impact #6 & 7	67		
	Plume: Impact #6 & 7	100		
	Plume: Impact #6 & 7	100	89	1.5
5	Plume: Impact #6 & 7	110		
	Plume: Impact #6 & 7	120		
	Plume: Impact #6 & 7	120	120	1.1

What is indicated in our limited study is that different samplers may recover different quantities of energetic residues from a plume but the difference may not be significant. Comparing the results of impact plume #1 with those of impact plumes #3–5, the spread of values for plume #1 (2.3x) is larger than for the triplicate samples done by each sampler (average difference of 1.7x), but both are around 2. A range for replicates in this type of test of two or less is considered very good. For the double plume, two samplers each took triplicate samples to get a better grasp of the difference between individuals. In this case, one individual averaged a recovery of 89 µg of RDX with a spread of 1.5x whereas the other sampler averaged a recovery of 120 µg with a spread of 1.1x. The spread between the two samplers is 1.3x, with no overlap between the replicate groups. Five of the six replicates are within 20%, a very close match. This indicates a small but consistent difference.

Two other factors pertaining to the nature of the material being sampled should be noted. The residues for the impact point plumes and areas outside the firing points had very low concentrations of residues. Many times, the analysis indicates that the concentrations of the sample residues are at or near the detection limits of the analytical instrumentation. This normally makes analyses for these decision units difficult, as a very small amount of residues can make a large relative difference between replicates. We were fortunate for the most part not to have this problem. In two cases, we had what are often called outliers, or abnormally high residue values (81 FP OTP 0–3 and 81 FP 25-m transect). When firing mortars, pieces of the propellant container are ejected along with the projectile. This debris may be indicative of unburned propellant. The heterogeneous nature of this distribution and the increased distance the particles may be thrown makes consistent sampling difficult and may have led to the high values at these two decision units.

It is interesting to note the differences between the burn points, firing points, and impact points. For the burn points, we recovered about 2% of the original mass of NG in the propellant of the M185 charge after burning. At the firing point, the recovery was about 3%. These values are very close. For the impact points, the recovery rate averaged a mere 2×10^{-5}%. There is a tremendous difference in residue deposition between high-order detonations and firing points. This is further emphasized by the small area over which the FP deposition may occur (150 m^2 in our tests) and the large area the impact plumes encompass (over 1,400 m^2 for the six rather small 60-mm plumes sampled). There is a difference in the original mass of energetics, 2 kg of NG for 100 rounds vs. 2.6 kg of HE for seven rounds, but the concentration of residues at firing points can quickly accrue. This is not to say that the explosive load of the projectiles isn't a concern. Two of the 10 rounds fired during our test did not detonate, depositing 730 g of

HE on the Flats. When the bodies of these projectiles eventually corrode and the explosive load leaches out onto the firing range, a high-level point source will occur (Taylor et al. 2004). If 1,000 M888 rounds are fired into an impact area and the dud rate is 20%, as we witnessed during our study, over 73 kg of HE (60% RDX, 39% TNT) will be distributed within a limited area of the impact area and will eventually be released into the environment. With the millions of rounds fired each year in training ranges throughout the United States and the world (Dauphin and Doyle 2000), the need for the accurate tracking of munitions to maintain viability of our training ranges is obvious.

This study was conducted in association with a training exercise by the Army. Although the troops were very cooperative and assisted whenever possible, their mission was training and not research support. We therefore did not have control over how the tests were conducted or when. Ideally, we would have had the mortars set up alone in a large field, firing a fixed number of rounds with a fixed number of propellant charges each. This would have given us a better understanding of the per-round propellant residues loading. In the future, this may happen. The information we did get from these tests is a great start and we thank the troops for the opportunity to work with them and also for their efforts beyond the call of duty to help us with this critical research.

6 CONCLUSIONS

A series of firing point tests were conducted on energetics associated with a live-fire training mission involving 60-mm and 81-mm mortars at Fort Richardson, Alaska, in January 2006. A firing point was sampled for the 60-mm M19 mortar firing 25 M888 HE cartridges with varying quantities of M204 propellant charges. Residues recovered from the demarcated plume (158 m^2) indicated 0.65% of the original NG propellant load remained. No other constituents were detected (we did not analyze for nitrocellulose, NC, the major energetic constituent of the propellant) and no energetic residues were detected outside the demarcated plume. A firing point also was sampled for the 81-mm M252 mortar firing 40 M374A3 HE cartridges and 61 M301A3 illumination cartridges with varying quantities of M205 and M185 propellant charges, respectively. Residues collected from within the demarcated plume (135 m^2) indicated that 3.3% of the original NG propellant load remained, mostly from the 61 M301A3 rounds (>98%). The M185 propellant charge contains NG, whereas the M205 charge does not. A significant amount of NG was recovered from samples taken from a 380-m^2 annulus around the demarcated plume, but this quantity amounted to only 0.61% of the recovered NG from within the plume. Smaller quantities of NG were detected out to the limits of our sampling (50 m) with a projected deposition distance of between 60 and 90 m downrange for the conditions under which we tested.

A series of burn point tests were conducted following firing point tests. Unconfined 10-charge piles for each of the three different cartridges were burned on the snow surface, sampled, and analyzed. Only one of the three propellants, the M9 propellant in the M185 charge, had detectable quantities of energetics following burning. About 2% of the original NG load was recovered. Again, we did not analyze for NC.

Following the burn point tests, 10 M888 mortar rounds were fired into the Flats. Eight of the 10 rounds detonated, and seven of the eight detonation points comprising six plumes were sampled for energetic residues. Only RDX was recovered from the plumes. The average residue quantity per detonation was 73 µg, 2×10^{-5}% of the original HE load. No detectable residues were found in subsurface or OTP samples. While collecting samples, we conducted tests on consistency among and repeatability for different samplers. In a limited study examining sampling repeatability among several samplers, we found that individual samplers are able to sample in a very repeatable manner (range <1.7x), but there may be a significant difference in the range of recoveries between samplers. For single multi-increment samples the range between samplers was 2.3x and for

triplicate multi-increment samples the range between samplers was 1.3x. Overall repeatability of triplicate samples was quite good for all replicates (N = 24 sets of three) with only three sets with a range greater than 2.0x.

This study reinforces the importance of maintaining firing points to avoid their becoming a source of energetic residues on ranges. Burn points have not been addressed in a focused manner and may become the next area of research required for a holistic approach to munitions management and range sustainability. High-order detonations of munitions in impact areas are not a critical consideration in range sustainment, but tracking dudded rounds needs to have a higher priority than current practice as these rounds will become an energetics source in the future.

These results are estimates of unreacted residues from activities associated with a live-fire mortar mission. They are indicators of possible residue masses that will result from such activities. Many values are at or near detection limits for the analytical instrumentation and difficult to interpret. It is important to keep in mind that there is much variability between activities and some variability between rounds and that these results should be considered to be approximate.

REFERENCES

Dauphin, L., and C. Doyle (2000) Study of ammunition dud and low order detonation rates. U.S. Army Defense Ammunition Center—Technical Center for Explosives Safety. Technical report written for U.S. Army Environmental Center, Aberdeen Proving Ground, Maryland.

Hewitt, A.D., T.F. Jenkins, T.A. Ranney, J.A. Stark, M.E. Walsh, S. Taylor, M.R. Walsh, D.J. Lambert, N.M. Perron, N.H. Collins, and R. Kern (2003) Estimates for explosives residues from the detonation of army munitions. U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, Technical Report ERDC/ CRREL TR-03-16.

Jenkins, T.J., T.A. Ranney, P.H. Miyares, N.H. Collins, and A.D. Hewitt (2000a) Use of surface snow sampling to estimate the quantity of explosives residues resulting from land mine detonations. U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, Technical Report ERDC/CRREL TR-00-12.

Jenkins, T.J., T.A. Ranney, M.E. Walsh, P.H. Miyares, A.D. Hewitt, and N.H. Collins (2000b) Evaluating the use of snow-covered ranges to estimate the explosives residues that result from detonation of army munitions. U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, Technical Report ERDC/CRREL TR-00-15.

Jenkins, T.F., M.E. Walsh, P.H. Miyares, A.D. Hewitt, N.H. Collins, and T.A. Ranney (2002) Use of snow-covered ranges to estimate explosives residues from high-order detonations of army munitions. *Thermochimica Acta*, **384**: 173–185.

Jenkins, T.F., A.D. Hewitt, M.E. Walsh, T.A. Ranney, C.A. Ramsey, C.L. Grant, and K.L. Bjella (2005) Representative sampling for energetic compounds at military training ranges. *Environmental Forensics*, **6**: 25–55.

Pennington, J.C., T.F. Jenkins, G. Ampleman, S. Thiboutot, J.M. Brannon, J. Lynch, T.A. Ranney, J.A. Stark, M.E. Walsh, J. Lewis, C.A. Hayes, J.E. Mirecki, A.D. Hewitt, N. Perron, D. Lambert, J. Clausen, and J.J. Delfino (2002) Distribution and fate of energetics on DoD test and training ranges: Interim Report 2. U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, Technical Report ERDC TR-02-8.

Ramsey, C.A., S. Taylor, and M.E. Walsh (in prep) Propellant residues from the 105s.

Taylor, S., J.H. Lever, B. Bostick, M.R. Walsh, M.E. Walsh, and B. Packer (2004) Underground UXO: Are they a significant source of explosives in soil compared to low- and high-order detonations? U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, ERDC/CRREL Technical Report TR-04-23.

U.S. Army (1969) Military Standard: Propellants, solid, for cannons: Requirements and packing. MIL-STD-652C (MU) U.S. Government Printing Office, Washington, DC.

U.S. Army (1981) Military Specification: Propellant, M1 for 60-mm mortar M204 propelling charge. MIL-P-63194A (AR) U.S. Government Printing Office, Washington, DC.

U.S. Army (1982) Military Specification: Propellant, M1 for 81-mm mortar M205 propelling charge. MIL-P-48130A (AR) U.S. Government Printing Office, Washington, DC.

U.S. Army (1998) Propellant management guide. U.S. Army Defense Ammunition Center, Logistics Review and Technical Assistance Office, Savanna, Illinois.

U.S. Environmental Protection Agency (1994) SW846 Method 8330. Nitroaromatics and nitroamines by HPLC. USEPA Office of Solid Waste standard methods of analysis test methods for evaluating solid wastes, physical and chemical methods. Update II (www.epa.gov/epaoswer/hazwaste/test/pdfs/8330.pdf).

U.S. Environmental Protection Agency (2000) SW846 Method 8095. Explosives by gas chromatography. Update IVB (www.epa.gov/epaoswer/hazwaste/test/pdfs/8095.pdf).

Walsh, M.E., and T.A. Ranney (1998) Determination of nitroaromatic, nitramine, and nitrate ester explosives in water using solid-phase extraction and GC-ECD. U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, Special Report 98-2.

Walsh, M.E., C.M. Collins, C.H. Racine, T.F. Jenkins, A.B. Gelvin, and T.A. Ranney (2001) Sampling for explosives residues at Fort Greely, Alaska. U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, ERDC/CRREL Technical Report TR-01-15.

Walsh, M.E., C.M. Collins, A.D. Hewitt, M.R. Walsh, T.F. Jenkins, J. Stark, A. Gelvin, T.S. Douglas, N. Perron, D. Lambert, R. Bailey, and K. Myers (2004) Range characterization studies at Donnelly Training Area, Alaska: 2001 and 2002. U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, Technical Report ERDC/CRREL TR-04-3.

Walsh, M.R., M.E. Walsh, C.A. Ramsey, and T.F. Jenkins (2005a) An examination of protocols for the collection of munitions-derived explosives residues on snow-covered ice. U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, ERDC/CRREL Technical Report TR-05-08.

Walsh, M.R., S. Taylor, M.E. Walsh, S.R. Bigl, K. Bjella, T.A. Douglas, A.B. Gelvin, D.J. Lambert, N.M. Perron, and S.P. Saari (2005b) Residues from live-fire detonations of 155-mm howitzer rounds. U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, ERDC/CRREL Technical Report TR-05-14.

Walsh, M.R., M.E. Walsh, C.M. Collins, S.P. Saari, J.E. Zufelt, A.B. Gelvin, and J.W. Hug (2005c) Energetic residues from live-fire detonations of 120-mm mortar rounds. U.S. Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire, ERDC/CRREL Technical Report TR-05-15.

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 (page 7). 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	MA00K061001	25
1315005637067	C256	Cartridge, 81-mm HE, M274A3, w/fuze, PD, M576	MA84B153025	40
1315001437048	C226	Cartridge, 81-mm IL, M301A3, w/fuze, time, M84A1	LOW85C108013	61

Notes: Drawn from Fort Richardson Ammo Supply Point 17 Jan 06
Data from DA Form 5515: Training Ammunition Control Document S/N 1017041

Table A2. Explosives loads prior to detonation: Impact plume test.

Munition	DODIC	Energetics quantities (g)			
		RDX	TNT	HMX	Lead azide
Cartridge, 60 mm, M888	B643	215	140	0	0
Fuze, point detonating, M935	N342	15	0	0	0.2

APPENDIX B: FIRING POINT DATA

Table B1 contains sampling data, analytical data, and final results for the 60-mm firing point test. The analytical and final results are for NG, the only constituent recovered from the samples.

Table B1. 60-mm mortar firing position data.

		SAMPLING						PROCESSING			FILTRATE ANALYSES			SOOT ANALYSES		RESULTS		
Number FRAM-06	Plume	Area (m^2)	Field Rep.	# Incrs.	Scoop Area (m^2)	Sampled Area (m^2)	Decision Unit Descriptor	Filtrate Vol. (mL)	# Filters	AcN for Filters (mL)	SPE Extract (µg/L)	Filtrate Conc. (µg/L)	Mass in Snow (µg)	Filter Extract (µg/L)	Mass on Filter (µg)	Mass in Sample (µg)	Per Unit Area ($µg/m^2$)	Total Mass (µg)
3	FP-LCP	158	1	38	0.0225	0.855	Plume-Surface	2120	1	20	876	8.76	19	412	8.2	27	19	4900
4	FP-LCP	158	2	41	0.0225	0.9225	Plume-Surface	2540	1	20	93	0.93	2.4	270	5.4	8	8.4	1300
5	FP-LCP	158	3	40	0.0225	0.9	Plume-Surface	2500	1	20	121	1.21	3.0	416	8.3	11	13	2000
6	FP-LCP	158	4	77	0.01	0.77	Plume-Surface	2120	1	20	52	0.52	1.1	129	2.6	4	4.8	760
7	FP-LCP	158	1	38	0.01	0.38	Plume-Subsurf	880	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
8	FP-LCP	158	2	41	0.01	0.41	Plume-Subsurf	1030	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
9	FP-LCP	158	3	40	0.01	0.4	Plume-Subsurf	1050	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
10	FP-LCP	168	1	71	0.01	0.71	OTP 0-3 m	2390	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
11	FP-LCP	168	2	73	0.01	0.73	OTP 0-3 m	3010	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
12	FP-LCP	169	3	80	0.01	0.8	OTP 0-3 m	3010	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
13	FP-LCP	220	1	72	0.01	0.72	OTP 3-6 m	2720	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
14	FP-LCP	220	2	69	0.01	0.69	OTP 3-6 m	2760	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
15	FP-LCP	220	3	75	0.01	0.75	OTP 3-6 m	3120	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
16	FP-LCP	77	1	60	0.01	0.6	15-m Transect	1200	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
17	FP-LCP	77	2	60	0.01	0.6	15-m Transect	1220	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
18	FP-LCP	77	3	60	0.01	0.6	15-m Transect	1190	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
19	FP-LCP	100	1	60	0.01	0.6	25-m Transect	1400	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
20	FP-LCP	100	2	60	0.01	0.6	25-m Transect	1240	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
21	FP-LCP	100	3	60	0.01	0.6	25-m Transect	1310	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
22	FP-LCP	70	1	50	0.01	0.5	35-m Transect	1580	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
23	FP-LCP	70	2	50	0.01	0.5	35-m Transect	1420	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
24	FP-LCP	70	3	50	0.01	0.5	35-m Transect	1760	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
25	FP-LCP	100	1	55	0.01	0.55	50-m Transect	1760	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
26	FP-LCP	100	2	50	0.01	0.5	50-m Transect	1660	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–
27	FP-LCP	100	3	50	0.01	0.5	50-m Transect	1680	1	20	*-ND-*	<0.2	*-ND-*	*-ND-*	*-ND-*	–	–	–

Table B2 contains sampling data, analytical data, and final results for the 81-mm firing point test. The analytical and final results are for NG, the only constituent recovered from the samples.

Table B2. 81-mm mortar firing position data.

		SAMPLING						PROCESSING			FILTRATE ANALYSES			SOOT ANALYSES		RESULTS		
Number FRAM-06	Plume	Area (m^2)	Field Rep.	# Incrs.	Scoop Area (m^2)	Sampled Area (m^2)	Decision Unit Descriptor	Filtrate Vol. (mL)	# Filters	AcN for Filters (mL)	SPE Extract (µg/L)	Filtrate Conc. (µg/L)	Mass in Snow (µg)	Filter Extract (µg/L)	Mass on Filter (µg)	Mass in Sample (µg)	Per Unit Area ($\mu g/m^2$)	Total Mass (µg)
28A*								2390			1,000,000	10,000	23,900					
28B*								2390			1,100,000	11,000	26,290					
28C*								2390			1,000,000	10,000	23,900					
28 (AVE)	FP-UCP	135	1	42	0.0225	0.945	Plume-Surface	2390	1	20	1,033,333	10,333	24,697	19,000,000	380,000	404,697	428,251	57,813,885
29	FP-UCP	135	2	42	0.0225	0.945	Plume-Surface	3520	1	20	680,000	6,800	23,936	13,000,000	260,000	283,936	300,461	40,562,235
30 AVE	FP-UCP	135	3	44	0.0225	0.99	Plume-Surface	3710	1	20	820,000	8,200	30,422	18,000,000	360,000	390,422	394,366	53,239,410
30A*								3710			790,000	7,900	29,309					
30B*								3710			850,000	8,500	31,535					
30C*								3710			820,000	8,200	30,422					
31	FP-UCP	135	1	42	0.01	0.42	Plume-Subsurf	1640	1	20	500,000	5,000	8,200	2,200,000	44,000	52,200	124,286	16,778,610
32	FP-UCP	135	2	42	0.01	0.42	Plume-Subsurf	1630	1	20	290,000	2,900	4,727	2,000,000	40,000	44,727	106,493	14,376,555
33	FP-UCP	135	3	44	0.01	0.44	Plume-Subsurf	1500	1	20	390,000	3,900	5,850	1,100,000	22,000	27,850	63,295	8,544,825
34	FP-UCP	155	1	58	0.01	0.58	OTP 0-3 m	1890	1	20	17,000	170	321	12,000	240	561	967	149,885
35	FP-UCP	155	2	57	0.01	0.57	OTP 0-3 m	2000	1	20	22,000	220	440	16,000	320	760	1,333	206,615
36	FP-UCP	155	3	64	0.01	0.64	OTP 0-3 m	1890	1	20	24,000	240	454	95,000	1,900	2,354	3,678	570,090
37	FP-UCP	210	1	51	0.01	0.51	OTP 3-6 m	1880	1	20	4,200	42	79	3,400	68	147	288	60,480
38	FP-UCP	210	2	53	0.01	0.53	OTP 3-6 m	2030	1	20	4,300	43	87	6,100	122	209	394	82,740
39	FP-UCP	210	3	48	0.01	0.48	OTP 3-6 m	1870	1	20	5,100	51	95	6,200	124	219	456	95,760
40	FP-UCP	50	1	60	0.01	0.6	15-m Transect	1400	1	20	4,900	49	69	3,700	74	143	238	11,900
41	FP-UCP	50	2	60	0.01	0.6	15-m Transect	1320	1	20	5,000	50	66	5,800	116	182	303	15,150
42	FP-UCP	50	3	60	0.01	0.6	15-m Transect	1820	2	40	6,900	69	126	3,000	120	246	410	20,500
43	FP-UCP	71	1	60	0.01	0.6	25-m Transect	1140	1	20	4,300	43	49	15,000	300	349	582	41,322
44	FP-UCP	71	2	60	0.01	0.6	25-m Transect	1070	1	20	660	6.6	7.1	540	11	18	30	2,130
45	FP-UCP	71	3	60	0.01	0.6	25-m Transect	1280	1	20	920	9.2	12	610	12	24	40	2,840
46	FP-UCP	84	1	50	0.01	0.5	35-m Transect	2120	1	20	640	6.4	14	950	19	33	66	5,544
47	FP-UCP	84	2	50	0.01	0.5	35-m Transect	2540	4	80	430	4.3	11	160	13	24	48	4,032
48	FP-UCP	84	3	50	0.01	0.5	35-m Transect	2760	1	20	550	5.5	15	910	18	33	66	5,544
49	FP-UCP	61	1	53	0.01	0.53	50-m Transect	2020	1	20	190	1.9	3.8	300	6	10	19	1,159
50	FP-UCP	61	2	51	0.01	0.51	50-m Transect	1970	1	20	280	2.8	5.5	330	6.60	12	24	1,464
51	FP-UCP	61	3	55	0.01	0.55	50-m Transect	2810	1	20	240	2.4	6.7	440	8.80	16	29	1,769

Note: *A, B, and C are triplicate 500-mL aliquots of the filtrate that were concentrated by solid phase extraction and analyzed for QC purposes.

APPENDIX C: BURN POINT DATA

Table C1 contains sampling data, analytical data, and final results for the propellant burn point test. The analytical and final results are for NG, the only constituent recovered from the samples.

Table C1. Propellant burn point data.

	SAMPLING							PROCESSING			FILTRATE ANALYSES			SOOT ANALYSES		RESULTS		
					Scoop	Sampled		Filtrate		AcN for	SPE	Filtrate	Mass in	Filter	Mass on	Mass in	Per Unit	Total
Number		Area	Field		Area	Area	Decision Unit	Vol.		Filters	Extract	Conc.	Snow	Extract	Filter	Sample	Area	Mass
FRAM-06	Plume	(m^2)	Rep.	# Incrs.	(m^2)	(m^2)	Descriptor	(mL)	# Filters	(mL)	(µg/L)	(mg/L)	(mg)	(mg/L)	(mg)	(mg)	(mg/m^2)	(mg)
86	M185	0.063	1	–	0.0225	0.063	Burn Area	1440	1	200	59000	59	85	3800	760	840	13,400	840
87		0.50	1	–	0.01	0.50	OT Burn Area	3920	4	100	1600	1.6	6.3	270	27	33	67	33
88	M205	0.44	1	–	0.01	0.44	Burn Area	4320	3	120	*-ND-*	*-ND-*	–	*-ND-*	*-ND-*	–	–	–
89		0.34	1	–	0.01	0.34	OT Burn Area	2170	1	100	7.1*	0.0071	0.015	0.56	0.056	0.071	0.21	0.071
90	M204	0.54	1	–	0.01	0.54	Burn Area	3550	1	100	*-ND-*	*-ND-*	–	*-ND-*	*-ND-*	–	–	–
91		0.46	1	40	0.01	0.40	OT Burn Area	2140	1	100	*-ND-*	*-ND-*	–	0.23	*-ND-*	–	–	–
											*IN 15 M TRANSECT							

APPENDIX D: IMPACT POINT SAMPLE DATA

Table D1 contains sampling data, analytical data, and final results for the 60-mm HE impact plumes test. The analytical and final results are for RDX, the only constituent recovered from the samples.

Table D1. Impact plume data.

		SAMPLING						PROCESSING			FILTRATE ANALYSES			SOOT ANALYSES		RESULTS		
Number FRAM-06	Plume	Area (m^2)	Field Rep.	# Incrs.	Scoop Area (m^2)	Sampled Area (m^2)	Decision Unit Descriptor	Filtrate Vol. (mL)	# Filters	AcN for Filters (mL)	SPE Extract (µg/L)	Filtrate Conc. (µg/L)	Mass in Snow (µg)	Filter Extract (µg/L)	Mass on Filter (µg)	Mass on Snow (µg)	Per Unit Area (µg/m^2)	Total Mass (µg)
52	1	233	1	83	0.01	0.83	Plume-Surface	1100	1	20	12	0.12	0.14	2.1	0.042	0.18	0.21	50
53	1	233	2	90	0.01	0.90	Plume-Surface	1300	1	20	30	0.30	0.39	1	0.02	0.41	0.45	100
54	1	233	3	100	0.01	1.00	Plume-Surface	1380	1	20	38	0.38	0.53	<1	-ND-	0.53	0.53	120
55	1	200	1	100	0.01	1.00	OTP 0-3 m	970	2	40	*-ND-*	<0.035	*-ND-*	*-ND-*	*-ND-*	–	–	–
56	1	200	2	95	0.01	0.95	OTP 0-3 m	900	2	40	*-ND-*	<0.035	*-ND-*	*-ND-*	*-ND-*	–	–	–
57	1	200	3	92	0.01	0.92	OTP 0-3 m	980	1	20	*-ND-*	<0.035	*-ND-*	*-ND-*	*-ND-*	–	–	–
58A	2						–	1960	–	–	7.4	0.074	0.15	–	–	–	–	–
58B	2						–	1960	–	–	7.6	0.076	0.15	–	–	–	–	–
58C	2						–	1960	–	–	6.1	0.061	0.12	–	–	–	–	–
58-AVG	2	200	1	47	0.0225	1.06	Plume-Surface	1960	1	20	7.0	0.070	0.14	5.6	0.11	0.25	0.24	47
59	2	200	2	44	0.0225	0.99	Plume-Surface	1550	1	20	9.3	0.093	0.14	7.8	0.16	0.30	0.30	60
60	2	200	3	48	0.0225	1.08	Plume-Surface	1720	1	20	8.4	0.084	0.14	2.6	0.053	0.20	0.18	36
61	2	200	1	47	0.01	0.47	Plume-Subsurf	1390	1	20	*-ND-*	<0.035	*-ND-*	*-ND-*	*-ND-*	–	–	–
62	2	200	2	39	0.01	0.39	Plume-Subsurf	1790	1	20	*-ND-*	<0.035	*-ND-*	*-ND-*	*-ND-*	–	–	–
63	2	200	3	41	0.01	0.41	Plume-Subsurf	1340	1	20	*-ND-*	<0.035	*-ND-*	*-ND-*	*-ND-*	–	–	–
64	2	286	–	49	0.01	0.49	OTP 0-3 m	740	1	20	*-ND-*	<0.035	*-ND-*	*-ND-*	*-ND-*	–	–	–
65	3	207	1	100	0.01	1.00	Plume-Surface	1400	1	20	39	0.39	0.54	22	0.44	0.98	0.98	200
66	3	207	2	100	0.01	1.00	Plume-Surface	1320	1	20	38	0.38	0.50	14	0.28	0.78	0.78	160
67	3	207	3	100	0.01	1.00	Plume-Surface	1500	1	40	53	0.53	0.80	7.1	0.28	1.1	1.1	220
68	3	194	–	53	0.01	0.53	OTP 0-3 m	1130	1	20	*-ND-*	<0.035	*-ND-*	*-ND-*	*-ND-*	–	–	–
69	4	201	1	91	0.01	0.91	Plume-Surface	1460	1	20	10	0.10	0.14	<1	*-ND-*	0.14	0.16	31
70	4	201	2	94	0.01	0.94	Plume-Surface	1550	1	20	13	0.13	0.21	3.2	0.064	0.27	0.29	58
71	4	201	3	91	0.01	0.91	Plume-Surface	1370	1	20	11	0.11	0.15	1.5	0.03	0.18	0.20	40
72	4	192	–	56	0.01	0.56	OTP 0-3 m	700	1	20	*-ND-*	<0.035	*-ND-*	*-ND-*	*-ND-*	*-ND-*	*-ND-*	
73	5	228	1	99	0.01	0.99	Plume-Surface	1190	1	20	27	0.27	0.32	1.6	0.032	0.35	0.35	81
74	5	228	2	99	0.01	0.99	Plume-Surface	1420	1	20	15	0.15	0.21	1.2	0.024	0.23	0.24	54
75	5	228	3	100	0.01	1.00	Plume-Surface	1250	1	20	15	0.15	0.18	1	0.02	0.20	0.20	46
76	5	194	–	60	0.01	0.60	OTP 0-3 m	1340	1	20	*-ND-*	<0.035	*-ND-*	*-ND-*	*-ND-*	–	–	–
77	6 & 7	360	1	82	0.01	0.82	Plume-Surface	1110	1	20	14	0.14	0.15	<1	*-ND-*	0.15	0.19	67
78	6 & 7	360	2	103	0.01	1.03	Plume-Surface	1650	1	20	18	0.18	0.29	<1	*-ND-*	0.29	0.28	100
79	6 & 7	360	3	112	0.01	1.12	Plume-Surface	1720	1	20	18	0.18	0.31	<1	*-ND-*	0.31	0.28	100
80	6 & 7	360	4	115	0.01	1.15	Plume-Surface	2900	1	20	11	0.11	0.32	1	0.02	0.34	0.30	110
82	6 & 7	360	6	92	0.01	0.92	Plume-Surface	2400	1	20	12	0.12	0.28	1.4	0.028	0.31	0.33	120
81-AVG	6 & 7	360	5	94	0.01	0.94	Plume-Surface	2140	1	20	14	0.14	0.29	1.9	0.038	0.33	0.35	120
81A							–	2140	–	–	13	0.13	0.28	–	–	–	–	–
81B							–	2140	–	–	13	0.13	0.29	–	–	–	–	–
81C							–	2140	–	–	14	0.14	0.30	–	–	–	–	–
83	6 & 7	238	1	97	0.01	0.97	OTP 0-3 m	1490	2	40	*-ND-*	<0.035	*-ND-*	*-ND-*	*-ND-*	–	–	–
84	6 & 7	238	2	67	0.01	0.67	OTP 0-3 m	720	1	20	*-ND-*	<0.035	*-ND-*	*-ND-*	*-ND-*	–	–	–
85	6 & 7	238	3	52	0.01	0.52	OTP 0-3 m	570	1	20	*-ND-*	<0.035	*-ND-*	*-ND-*	*-ND-*	–	–	–

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	2. REPORT TYPE	3. DATES COVERED *(From - To)*
May 2006	Technical Report	

4. TITLE AND SUBTITLE

Energetic Residues Deposition from 60-mm and 81-mm Mortars

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

Michael R. Walsh, Marianne E. Walsh, Charles A. Ramsey, Richard J. Rachow, Jon E. Zufelt, Charles M. Collins, Arthur B. Gelvin, Nancy M. Perron, and Stephanie P. Saari

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

U.S. Army Engineer Research and Development Center
Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, New Hampshire 03755-1290

8. PERFORMING ORGANIZATION REPORT NUMBER

ERDC/CRREL TR-06-10

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Strategic Environmental Research and Development Program
Arlington, Virginia 22203

10. SPONSOR/MONITOR'S ACRONYM(S)

SERDP

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

Available from NTIS, Springfield, Virginia 22161.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Military live-fire training missions utilize a variety of energetic materials that are never completely consumed during firing. Many munitions are issued with various types, quantities, and configurations of propellants. In January 2006, CRREL teamed with the 1st Battalion, 501st Parachute Infantry Regiment (PIR) in Alaska to sample areas used during a mortar training mission. Samples were collected from the snow surface at the firing points for both 81-mm and 60-mm mortars, as well as from areas up to 50 m downrange. Test burn points, areas where 10 excess propellant charges were burned, also were sampled. Six plumes comprising seven detonations of 60-mm high-explosive rounds were sampled on the impact range. Samples were analyzed to derive an estimate of the mass of unreacted energetics deposited from each activity. The 81-mm firing point contained 64 g of NG (3.3% of original NG mass). The 60-mm firing point contained 2 mg of NG (0.65% original NG mass), while the 60-mm impact plumes had a median of 50 μg RDX (2×10^{-5}% of the HE load). Burn points had 840 mg, 1.6% of the original NG mass. These results indicate that further investigations of firing points are critical and that action needs to be taken on burn points.

15. SUBJECT TERMS

Burn areas	Firing points	Mortars	Propellants	Residues
Energetics	Impact areas	Nitroglycerin	RDX	Snow

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER *(include area code)*
U	U	U	U	58	