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## Energetic Residues from Live-Fire Detonations of 120-mm Mortar Rounds

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Stephanie P. Saari, Jon E. Zufelt, Arthur B. Gelvin, and  
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Cover photo: Mortar crewman loads a 120-mm HE round into a mortar at FP Lower Fox, Fort Richardson, AK. (Photo by Marianne Walsh.)

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## ABSTRACT

Only limited data are available on energetic residues resulting from the firing and detonation of rounds from 120-mm mortars. After a live-fire training exercise at Fort Richardson, Alaska, we sampled a firing point for propellant residues (NG) and the impact area for high-explosives residues (RDX, HMX, and TNT). The firing point was snow-covered soil, and the impact area was snow-covered ice. The total explosives residue mass averaged 19 mg per round at the impact plume, of which 74% was RDX, 9% was HMX, and the remainder was TNT. Approximately  $6 \times 10^{-4}$ % of the explosive mass (2,990 g of Composition B per round) remained following high-order detonations. A plume sampled near a low-order detonation had near-gram quantities of explosives along its edge, 50 times the average of the other plumes, and over 300 g of HE were recovered there the following spring. At the firing point, relatively high concentrations of propellant residues were found, averaging 14 g NG. High-order detonations deposit very little explosive compounds and are not likely to be a threat to groundwater. Low-order detonations will be the major contributor of contamination on impact areas. Firing points need more study but are an area of concern.

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## PREFACE

This report was prepared by Michael R. Walsh, Engineering Resources Branch; Marianne E. Walsh, Environmental Sciences Branch; Charles M. Collins, Environmental Sciences Branch; Stephanie P. Saari, Engineering Resources Branch; Dr. Jon E. Zufelt, Water Resources Branch; and Arthur B. Gelvin, Engineering Resources Branch, Cold Regions Research and Engineering Laboratory, U.S. Army Engineer Research and Development Center; and James W. Hug, Rapid Entry Systems Technology Corporation.

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The Commander and Executive Director of ERDC is COL James R. Rowen, EN. The Director is Dr. James R. Houston.

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## **1 INTRODUCTION**

Firing ranges provide soldiers the opportunity to train using a variety of munitions. However, live-fire training will inevitably result in unexploded ordnance (UXO), low-order detonations [where a significant fraction of the high explosive (HE) remains unconsumed], and small quantities of explosive residues from munitions that detonated as intended (high-order detonation). All of these sources may contaminate the soil and the groundwater, thereby threatening human health and the environment. Because these sources yield different masses and size fractions of energetic compounds, it is vital that range managers know the deposition and fate of these substances in the environment.

Hundreds of thousands of rounds are fired into military impact ranges each year (Foster 1998). The majority of the rounds tested to date have detonated as designed and have deposited very little explosive residue (Hewitt et al. 2003, Taylor et al. 2004, Walsh, M.R., et al. 2005a, Walsh, M.R., et al. 2005b). Nevertheless, it is important to know the quantity and variability of the HE not consumed in the detonation process for specific munitions, as small quantities from many rounds can add up to large quantities of explosives. This is a difficult task because the residues are mixed with soil, and these can contain HE from previous detonations. Additionally, when the HE is impacted into soil, the area over which the residue is deposited cannot be determined, a key element in estimating the mass of HE deposited.

Jenkins et al. (2000) circumvented most of these difficulties by collecting and analyzing live-fire detonation residues from snow-covered surfaces. The frozen ground reduced the mixing of the plume residues with underlying soil, and the snow provided a clean sampling background that decreased the chances of

cross-contamination from prior range activities. The snow also made the dark detonation residues highly visible, allowing the residue plume to be more easily mapped and measured. This demarcation method assumes that all of the deposited HE is within the visible plume area. Refinement of the method was conducted by CRREL (Walsh, M.R., et al. 2005a) on snow-covered ice, which further isolated the detonation from previous range activities. The study validated the then-current and proposed sampling methods.

For this series of tests, we sampled the residue from 10 Composition-B-filled 120-mm mortar rounds fired onto Eagle River Impact Area, Fort Richardson, Alaska, in February 2005 (Appendix A). Composition B (Comp B) is an approximately 60:40 mixture of military-grade RDX and TNT. HMX, a manufacturing impurity in RDX, can constitute up to 9% of the RDX mass. We selected 120-mm rounds for testing because they contain a large mass of HE, they are becoming one of the most commonly used high-mass rounds in the U.S. arsenal (Papadopoulos 2003), and insufficient data on live-fire detonations were available for them. We collected the residues deposited both at the impact points, where the rounds detonated, and at one of the firing points to estimate the HE loads and the propellant loads, respectively.

## 2 FIELD TESTS

### Field Site

The live-fire tests were conducted on the Eagle River Impact Area, Fort Richardson, Alaska (Fig. 1). The rounds were fired by the 172<sup>nd</sup> Stryker Brigade Combat Team, 4<sup>th</sup>/23<sup>rd</sup> Infantry Regiment from the Lower Fox firing point (UTMWGS84: N6799280, E356360) into the impact area approximately 3 km away (N6801200, E354600) on the frozen surface of the Eagle River estuarine salt marsh. The cartridges fired were M933 mortar rounds with M745 point-detonating fuzes containing a total of 2.99 kg of Composition B (Fig. 2). The

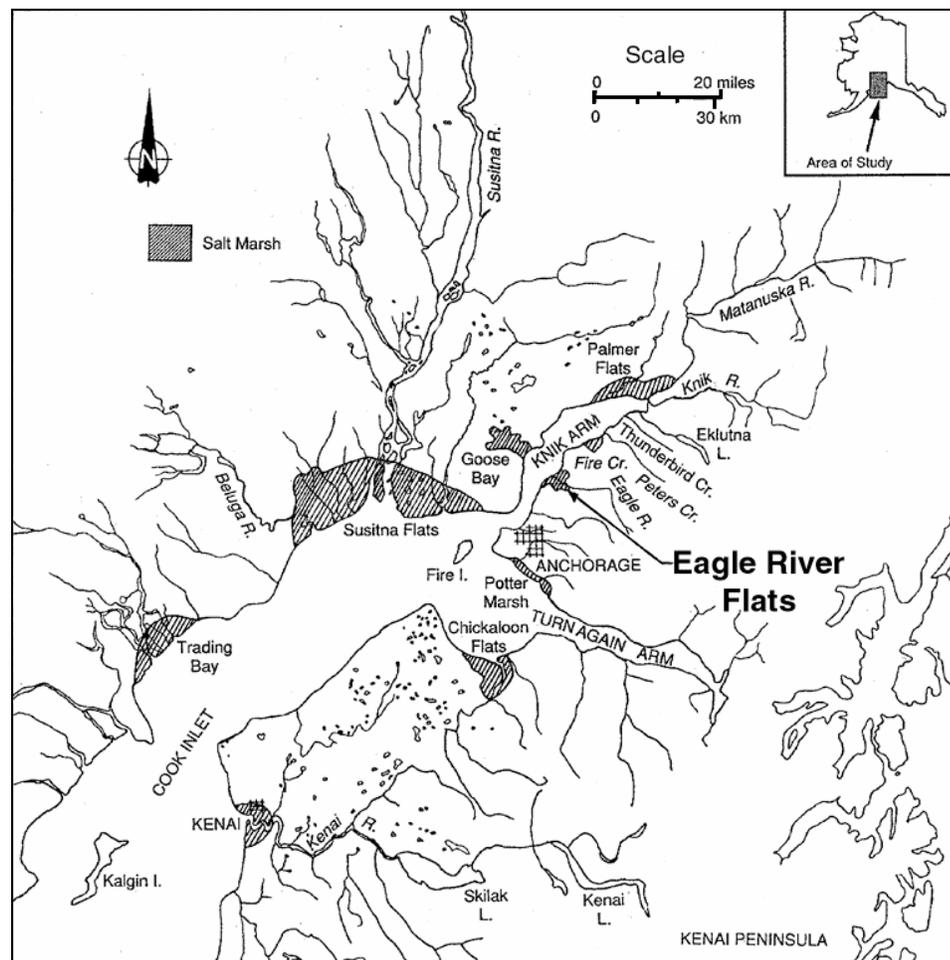


Figure 1. Eagle River Flats.



**Figure 2. Packing cases for mortar rounds used in the tests.**

rounds were fired from an M121 mortar mounted on an M1129 Light Armored Vehicle III (LAV III Stryker mortar carrier) (Fig. 3). Two M230 propelling charges incorporating M45 double-based propellant [nitroglycerin (NG) and nitrocellulose (NC)] were used to fire each projectile the desired distance (Fig. 4).

For our tests, the best conditions are achieved when the rounds are fired into an area underlain with ice and covered with clean snow, and the impact points are spatially separated enough so that the residue plumes do not overlap. As strong winds disperse the residues, making the visual demarcation of the plumes difficult, windless conditions are desirable. Low temperature ( $<0^{\circ}\text{C}$ ) and overcast skies help prevent the dark residues from melting into the snowpack. Because of the cold and the need to collect many samples, it is best if the impact points are easily accessible.

Our impact area generally met these criteria on the days we sampled. Eagle River is a glacially fed river with a built-up estuary composed primarily of fine silts. In winter it is characterized by a wide expanse of ice of varying thickness generally covered with snow and underlain with shallow pockets of water or frozen silts. The ice cover is continuous except along the natural levees lining the river. Most of the detonations we sampled occurred on ice and did not break through into the underlying soils. For the few cases where breakthrough occurred, we did not collect samples from the small soil-rich areas. On the dates of the exercise, thin but sufficient snow covered the ice, allowing us to obtain samples in all areas.



**Figure 3. M1129 LAV-III with an M121 mortar firing a round.**



**Figure 4. Mortar round with propellant charges on the tail assembly.**

The firing was conducted on 17 February 2005. The weather was nearly ideal—mostly cloudy with little wind (5 kph max) and temperatures hovering around  $-2^{\circ}\text{C}$ . A total of 160 rounds were fired from four positions, two each at Firing Point (FP) Lower Fox and FP Perry. The firing exercise took longer than anticipated, and we were unable to sample the impact area on the day of firing. Firing point samples were collected at one of the positions at FP Lower Fox at the conclusion of training on the 17<sup>th</sup>. The impact area was inspected by our UXO technician (Hug) that evening. On the morning of the 18<sup>th</sup> we returned to the impact area and acquired our residue samples. Weather that day had improved, with overcast skies, temperatures around  $-6^{\circ}\text{C}$ , and little wind.

### Sampling Method

The plumes were inspected for continuity and overlap prior to sampling. Nine plumes representing 11 detonations (seven single detonations and two double) were chosen. Our selection was limited by the high number of low-order and dudded rounds observed during firing—at least four of the former and eight of the latter. One of the double plumes sampled was later found to be adjacent to a lower-order detonation. The plumes chosen for sampling were visually demarcated and physically delineated by walking along the edge. The area was then recorded using a global positioning system (Trimble GPS Pathfinder Pro XR,  $\pm 1$  m accuracy).

We collected approximately 100 snow samples from each plume in a systematic–random fashion using a 10-  $\times$  10-  $\times$  1-cm-deep Teflon-lined aluminum scoop. We collected increments randomly while walking in a systematic fashion within the plume (Walsh, M.R., et al. 2005a). These increments were combined into a single sample in a clean, labeled polyethylene bag (multi-increment sampling method). Although less total surface area is sampled than in the method originally developed by Jenkins et al. (2005), the large number of smaller increments provides a more widespread coverage of the plume, reducing the tendency towards sampling bias and better estimating the average concentration of the HE in the plume. The trade-off comes with the small percent of area sampled, which can lead to variability between the samples. Triplicate samples collected from each plume allowed us to test for this uncertainty.

To estimate the mass of energetic residues, the area over which HE is deposited and the average concentration for that area must be quantified. A critical assumption is that the plume represents the major area of deposition. The plume is composed of soot from the detonation, and its depositional pattern can be affected by wind. However, because there is no other way to estimate the area of deposition, we assume that most HE residue is deposited within the plume. We

tested this assumption by taking multi-increment samples from concentric rings outside the plume (OTP). The objectives of OTP sampling are to ensure that the plume was adequately outlined and to determine how much, if any, of the HE is measurable outside of the plume. Samples were obtained for 1-m annuli surrounding the plume edge.

### **Firing Point Samples**

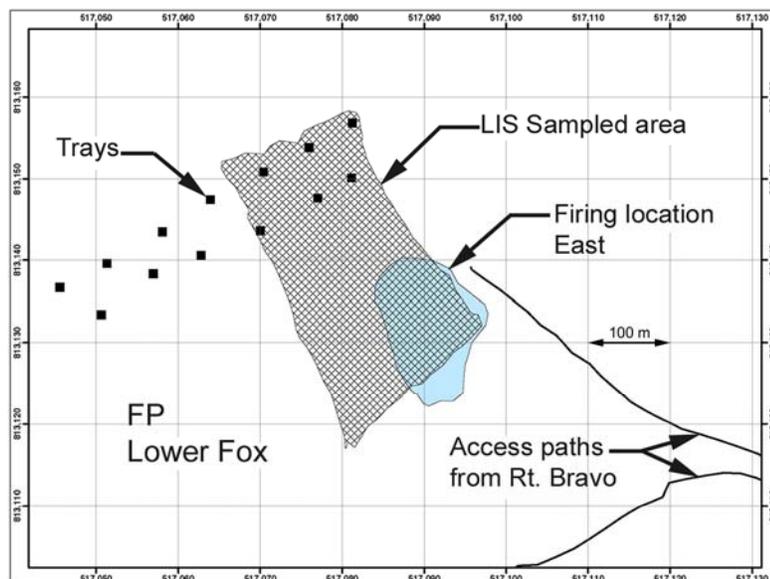
The eastern firing location of FP Lower Fox was chosen as our sampling location. Prior to the exercise, an 80-increment background sample was collected in the area where post-exercise firing point samples were to be collected. A total of 80 rounds were fired from each firing point. As this was a training exercise for several mortar crews, the Stryker mortar carriers cycled in, fired their rounds, and departed, to be replaced by the next vehicle and crew. During the exercise, the vehicles set up in two locations in the snow-covered area. At each location, four mortar carriers cycled through, and 10 rounds were fired by each vehicle crew, giving a total of 40 rounds fired through the location sampled.

Two types of samples were collected following firing. Prior to the arrival of the Strykers, a total of 13 trays were placed in front of the two firing positions. These trays were placed at the edge of the firing point to allow the mortar carriers to maneuver in and out of their firing positions. Following cessation of firing, the trays were collected for removal of any propellant debris. Three multi-increment samples were then collected over a 610-m<sup>2</sup> area in front of one of the East firing positions (Fig. 5). All samples were taken to the lab on Fort Richardson for processing.

### **Impact Point Samples**

A 30-increment snow sample of the impact area was collected prior to firing and served as our background sample. Multiple delays during the exercise prevented us from sampling the impact area with appropriate quality assurance before dusk on the day the rounds were fired, so sample collection was postponed until the following morning. There was no precipitation forecast and little wind at the end of the day, conditions which ensured minimal weather-related degradation of the plumes. We inspected the area following firing, and locations were cleared by our UXO technician (Hug). The unknown location of the unexploded and low-order rounds required that extra care be taken for this task.

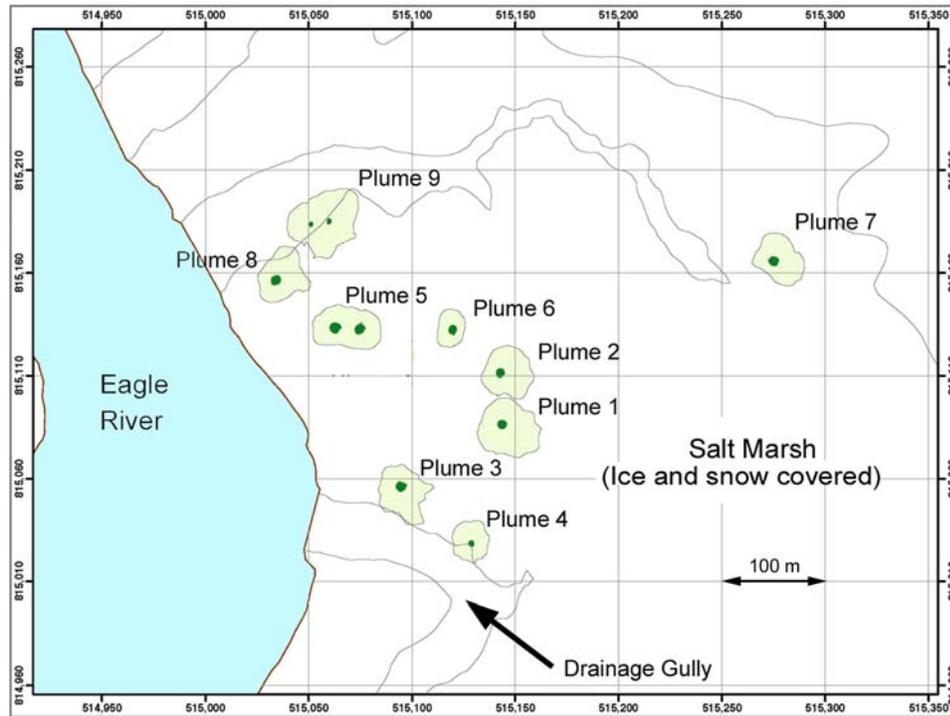
The following morning, seven personnel accessed the impact area to obtain residue samples. Two individuals selected the impact plumes to be sampled and demarcated the plumes both physically, by walking the perceived edges, and with



**Figure 5. Map of FP Lower Fox sampled areas (WGS 84).**

a global positioning system (GPS). Where possible, plumes consisting of a single impact point were demarcated. A total of eight plumes were sampled, two of which were double-impact plumes (Fig. 6). Plume 4 was not completely sampled, as it was from an 81-mm round fired during a previous exercise. The final plume sampled (Plume 9) was adjacent to a low-order impact point. We were unable to sample the low-order impact because of the danger from both nearby unexploded ordnance and the large quantity of unreacted explosives thought to be in the area.

Each plume was sampled using the large-increment sampling method as previously described, with a goal of 100 increments per sample and three samples per plume (Fig. 7a). The crater area was included in the sampling of the plumes (Fig. 7b). Craters were typically around 2 m in diameter and were sampled at least once. Although residue quantities are generally higher in the crater, the crater area is small compared to the overall plume (on the order of 1%) and its residues a fraction of the total estimated amount (approximately 7%). The plumes were each sampled by multiple individuals, adding some variability to the sampling process. Snow depth was minimal, generally less than 2 cm, so no samples were obtained beneath the areas sampled. Multi-increment samples were obtained outside of the demarcated plumes for two impact points. All samples were taken to the lab on Fort Richardson for processing.



**Figure 6. Layout of sampled plumes from GPS data (WGS 84). Craters are the centrally located dark spots within the plumes.**



**a. Sampling a plume.**

**Figure 7. Sampling of detonation plumes.**



**b. The well-defined crater of a high-order detonation.**

**Figure 7 (cont.). Sampling of detonation plumes.**

### **Sample Processing and Analysis**

The multi-increment snow samples from both the firing and impact points were transferred to a lab set up nearby on post for processing. Upon arrival at the lab, the samples were double-bagged and placed in clean polyethylene tubs for thawing. The double-bagging and tubs were necessary because of the inclusion of sharp pieces of frag, various sized shards of steel created from the fracturing of the projectile body during the detonation of the round. These were collected along with the snow samples and would pierce the bags, allowing the sample to leak out when thawed. Samples were shifted from warmer to cooler areas of the logistics bay of the lab to prevent over-warming of the samples ( $>10^{\circ}\text{C}$ ) after melting. The samples were then processed by plume number, saving the firing point samples for last. The process involves filtering the samples through a vacuum system to separate the soot fraction from the aqueous fraction. The soot fraction was collected on one or more filter papers, placed in a clean amber jar, and stored in a refrigerator at  $<5^{\circ}\text{C}$ . Any energetic compounds in the water were concentrated 100:1 using solid-phase extraction (SPE) following the procedures outlined by Walsh and Ranney (1998). The concentrate was split into two aliquots: 3.5 mL for processing and 1.5 mL for back-up. 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, NH, for final processing and analysis.

The filters containing the soot fractions were air-dried and the energetics extracted using acetonitrile. Each sample was shaken with solvent for 18 hours. The energetic concentrations were then determined for the water and the soot fraction using a Reverse-Phase High-Pressure Liquid Chromatograph/Ultraviolet detector (RP-HPLC-UV) and a Gas Chromatograph-Electron Capture Detector (GC-ECD) (Detection limits: 30 $\mu$ g/L). 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).

There was not enough residue on the trays to warrant collection and analysis. To avoid traffic from the mortar carriers setting up in position, the trays had been placed too far from the firing locations to be effective.

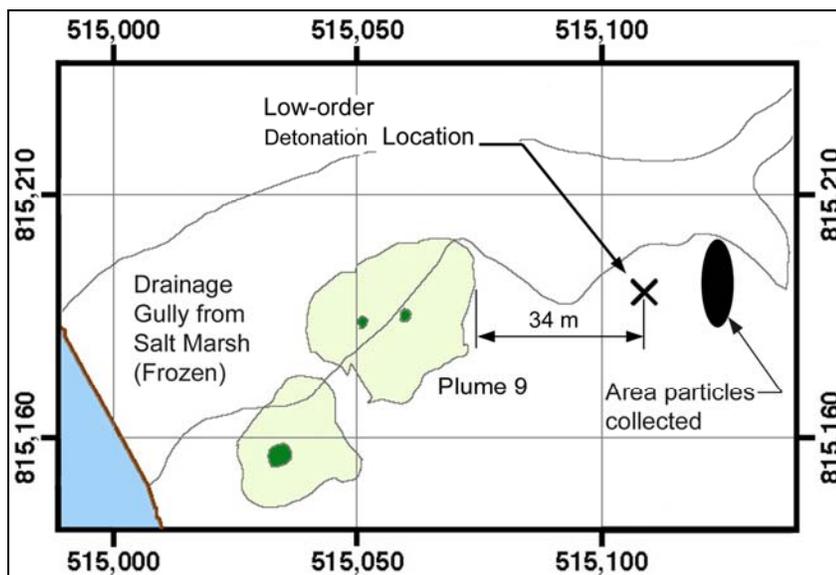
### **Quality Assurance Procedures**

Quality assurance (QA) procedures were conducted both in the field and in the lab. Field QA included triplicate sampling of the plumes and sampling outside the demarcated plumes on two of the plumes. As this was a training exercise, we could not dictate the spacing of the rounds, and with a small impact box with many rounds, rounds landed in close proximity to each other, limiting our ability to do OTP sampling. We did not do any sampling beneath previously sampled areas because the overlying snow depth was quite thin ( $\leq 3$  cm) and prohibited resampling these locations.

We conducted several QA procedures in the processing lab. One blank sample consisting of distilled water was run through a filter assembly and SPE for later analysis at the lab. This procedure is designed to determine if cross-contamination from the filtering apparatus is occurring. One field sample water fraction was divided into three aliquots and run through the SPE to determine if recovery rates from the SPE procedure were consistent. Two laboratory control spikes were run to assure that recoveries of the constituents of concern were adequate. Two SPE blanks were also run.

### **Follow-up Sampling**

In May 2005 the area near Plume 9 was swept by our UXO technician to determine if a low-order round had detonated nearby. Following discovery of a low-order detonation point within 40 m of the Plume 9 detonations (Fig. 8), particles were collected outside the low-order detonation crater to obtain a rough determination of the amount of unreacted HE resulting from the detonation and if it may have influenced the results of sampling Plume 9. An estimate of the HE



**Figure 8. Location of low-order detonation in relation to Plume 9 (WGS 84).**

remaining in the crater area (<3 m radius) was also done. Quantities were too large and thus too hazardous to remove from the site.

In September the firing points were resampled using soil sampling equipment (Walsh 2004). This was done to verify the presence of unreacted propellants from the winter exercise and to determine if soil concentrations derived from the winter estimates are valid. A total of three multi-increment soil samples (4.5-cm diameter by 2-cm deep, 103 increments average) were collected in a systematic-random fashion from the area sampled in February. Samples were processed and analyzed according to procedures outlined in M.E. Walsh et al. (2005) and EPA (1994) at our facility in Hanover. Comparative results will be reported in a later publication.

### 3 RESULTS

#### Firing Point Samples

The background sample taken at the firing point had no detectable quantity of propellant. No analysis was done on the tray residues because of the very small quantity of material collected. However, the lack of residues on the trays was a good indicator that the area sampled using the multi-increment sampling method provided good coverage of the propellant plume. The results for the three multi-increment snow samples following the firing of 40 projectiles are given in Table 1. The three replicates averaged 98 increments each. The decision unit area was 610 m<sup>2</sup>. The constituent measured was nitroglycerin (NG), the prime recoverable energetic component of the M45 double-based propellant. The averaged estimated NG residue over the decision unit (the demarcated plume) was 14 g, with a range of 15 g (4.7–20 g). The large range has been found in previous work (Walsh, M.R., et al. 2005b) and may be attributable to the presence of large but widely scattered pieces of the propellant containers. The estimated per-round generation of NG residue is estimated to be 0.35 g, or 1.4% of the initial energetic load (25.2 g NG). We have no comparable data for other mortars. For 155-mm howitzers, analysis of propellant residues quantities collected from a 900-m<sup>2</sup> area after firing 60 rounds resulted in an estimate of 1.2 mg/round, or approximately  $5 \times 10^{-4}$ % of the initial energetic load of 241 g of DNT.

**Table 1. Results of firing point sampling.**

Sample number	Number of increments	NG (mg)			Mass/unit area (mg/ m <sup>2</sup> )
		Sample 1	Sample 2	Sample 3	
FRA-732	100	1.4	27	28	28
FRA-733	100	1.8	30	32	32
FRA-734	93	3.5	3.7	7.2	7.7
Average	98	2.2	20	22	23

#### Impact Point Samples

A total of eight impact point plumes were sampled and analyzed. Plumes 1–3 and 5–8 were high-order detonation plumes. Of these, all but Plume 5 were single-impact plumes. Plume 9, a double-impact plume, was adjacent to a low-order round and will be treated separately in the analysis that follows. Plume 4 was an 81-mm plume from a previous exercise. The background sample collected the day prior to firing had no detectable explosives when analyzed.

The average results for each plume are shown in Table 2 for the three multi-increment samples averaging 97 increments per sample. The average decision unit area is 470 m<sup>2</sup>, with a range from 200 to 650 m<sup>2</sup>. The constituents measured are RDX, HMX, and TNT, components of the 2.9-kg Comp B explosives load. The average estimated explosives residue load over the average decision unit area is 21 mg, with a range of 43 mg. On a per-round basis, the average total residue load is 19 mg (eight rounds vs. seven plumes). Agreement between replicate samples for each plume is generally within a factor of two. For the seven high-order plumes in this analysis consisting of eight rounds, only  $6 \times 10^{-4}\%$  of the original explosive load for each round is estimated to remain after high-order detonation. A comparison with other munitions is contained in a following section. A more complete data set for these test is contained in Appendix B.

**Table 2. Average estimated plume results of impact point sampling.**

Plume number	Number of increments	RDX mass (mg)	HMX mass (mg)	TNT mass (mg)	Total mass (mg)	% mass remaining
1	101	8.8	0.93	1.1	11	$4 \times 10^{-4}$
2	101	29	1.4	3.2	33	$1 \times 10^{-3}$
3	99	35	2.3	6.9	44	$1 \times 10^{-3}$
5*	97	11	0.069	0.56	12	$4 \times 10^{-4}$
6	101	8.5	0.46	0.24	9.2	$3 \times 10^{-4}$
7	86	0.75	0.00	0.15	0.90	$3 \times 10^{-5}$
8	96	28	3.8	8.3	39	$1 \times 10^{-3}$
Average <sup>†</sup>	97	16	1.3	2.6	21	$6 \times 10^{-4}$

\* Double-impact plume. % mass remaining takes the two rounds into account.

† Not corrected for double plume (#5). Average total mass for the eight rounds is 19 mg.

Plume 9 is treated separately because of its proximity to a suspected low-order detonation. Residue values for two of the three replicates, FRA-727 and FRA-729, are similar to values obtained from the preceding high-order detonations, but one, FRA-728, is an order of magnitude higher (Table 3). When data from the area outside the demarcated plume are examined, FRA-730 and FRA-731, the values average even higher than within the plume, indicating a possible external source. The source is the low-order round found in the spring (Fig. 9).

One other set of OTP samples were taken. Plume 7 was located close to several other plumes, and it provided a good opportunity for testing overlap between plumes as well as residues outside the visible plume. Table 4 depicts the results of this sampling. For the intersecting area of overlapping plumes, very little

**Table 3. Results of sampling a double-impact plume next to a low-order detonation.**

Sample number	Number of increments	Decision unit area (m <sup>2</sup> )	RDX mass (mg)	HMX mass (mg)	TNT mass (mg)	Total mass (mg)
FRA-727	97	830	38	3.7	5.9	48
FRA-728	92	830	200	27	37	260
FRA-729	111	830	37	4.4	5.5	47
FRA-730	77	345	280	50	94	420
FRA-731	78	376	150	32	46	230

**Figure 9. Tail assembly and explosive debris from a low-order 120-mm HE detonation.****Table 4. Results of OTP sampling of a plume in close proximity to others.**

Sample number	Number of increments	Decision unit area (m <sup>2</sup> )	RDX mass (mg)	HMX mass (mg)	TNT mass (mg)	Total estimated mass (mg)
FRA-722	17	9	0.01	0.00	0.00	0.01
FRA-723	33	180	0.16	0.00	0.18	0.34

explosives were detected (0.01 mg). This was approximately 1% of the residue mass found inside the plume. The mass found outside the plume was higher, a total of 0.34 mg, due mostly to a high recovery of TNT. The OTP sample area intersected two adjacent plumes, resulting in a higher than typical value.

Results of the processing and analytical lab QA procedures indicate very good data quality through those phases of the procedure. No analytes were detected from the filtering and SPE blanks. Table 5 depicts the results of the split aliquot. Spike recovery was in the 95% to 105% range for the analytes of concern.

**Table 5. Split aliquot results for Plume 6.**

Sample number	RDX-HPLC (µg/L)	HMX-GC (µg/L)	TNT-GC (µg/L)
FRA-717A	6.4	0.048	0.36
FRA-717B	6.5	0.035	0.35
FRA-717C	6.3	0.046	0.35

### Comparison to Other Munitions

Over the past several years, we have obtained live-fire detonation data for several military HE munitions. These include 60-mm and 81-mm mortar rounds and 105-mm and 155-mm howitzer rounds. For all rounds, the mass of residues from a high-order detonation is quite small. Table 6 shows data from tests involving these rounds.

**Table 6. Comparison of residue deposition from live-fire high-order detonations.**

Type of round	Explosive filler	Mass* (kg)	Rounds tested	Total residues per round (mg)	Residues as % of original mass	Source <sup>†</sup>
Mortars						
60-mm	Comp-B	0.38	5	0.074	$1.9 \times 10^{-5}$	1
81-mm	Comp-B	0.98	14	9.6	$9.8 \times 10^{-4}$	1
120-mm	Comp-B	3.01	7, 8	4.5, 19	$1.5 \times 10^{-4}$ , $6.3 \times 10^{-4}$	1,–
Howitzers						
105-mm	Comp-B	2.24	13	0.27	$1.2 \times 10^{-5}$	1
155-mm	Comp-B	7.14	7	0.30	$4.2 \times 10^{-6}$	2
155-mm	TNT	6.78	7	None detectable	–	2

\* Includes fuze and supplemental TNT charge (Howitzer rounds)

<sup>†</sup> 1) Hewitt et al. (2003); 2) Walsh, M.R., et al. (2005b)

## 4 CONCLUSIONS

We sampled the detonation residue from ten Comp B-filled live-fired 120-mm mortar rounds using a systematic–random multi-increment sampling method. The multi-increment sampling method reduces but does not eliminate sampling bias of an area with heterogeneously distributed energetics. However, because smaller area samples are collected relative to the discrete sampling method (Jenkins et al. 2002), the uncertainty of random error may increase. The close agreement between the triplicate samples for each of our plumes indicates good replication and thus low random error.

For the eight high-order rounds, low concentrations of RDX and TNT were found in all 21 samples, and HMX was found in all but four of the samples. There is an ongoing discussion on the fate of TNT residues, and it has not been resolved whether the quantities we are finding through sampling are valid or if some mechanism is involved that prevents the separation and analysis of these residues in detonation soot (Thorn et al. 2002). Less than 20 mg of explosives residues remained on average for these rounds. To put this in perspective, for these rounds, 50 high-order detonations would result in about 1 gm of unreacted residues, and there would have to be over 150,000 high-order detonations to add up to the equivalent explosives contained in one dud round. The OTP results were inconclusive because of the difficulty in obtaining non-overlapping samples.

One double-impact plume was sampled near a low-order detonation. This plume had residues an order of magnitude or more higher than the other plumes. We collected what extrapolated to almost a gram of explosives from the plume and OTP area during the winter firing exercise. Much more explosives residue was collected in the spring from areas outside the low-order detonation crater (Fig. 10). This one low-order round had residues equivalent to at least 22,000 high-order rounds. With unreacted residues reaching over 30 m to the sampled plumes, it is very likely we recovered little of what was ejected during the low-order detonation. The results of sampling this plume reinforces our hypothesis that residues from high-order rounds are not problematic on ranges and that low-order and dud rounds are the major concern for contaminating soil and water.

Firing point residues once again point to these areas as potential contamination sites. The average per-round deposition was estimated at approximately 0.35 g of NG. If fixed firing points are used extensively and thousands of rounds are fired from the same general area, accumulation of residues may become a prob-

lem and contribute to groundwater contamination. These data emphasize the need for proper disposal of excess propellants to avoid hot-spot contamination.

These results are estimates of unreacted residues from activities associated with a live-fire exercise. They are indicators of possible contaminant masses that will result from such activities. For high-order detonations, many values are at or near detection limits for the analytical instrumentation. It is important to keep in mind that there is much variability between detonations and some variability between rounds and that these results should be considered as approximate.



**Figure 10. HE particle recovered from the 5-m zone outside a low-order impact area.**

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**APPENDIX A: MUNITIONS USED DURING TESTS**

Cartridge, 120 Millimeter, HE, M933

DODAC: 1315-C263

NSN: 1315 01 343 1941

Lot: MM98J033H004

Type: HE

Weight: 14.1 kg

Filler: Composition B

Filler weight: 2.99 kg

Fuze, PD, M745

DODAC: 1390-N660

Type: Point detonating

Weight: 0.23 kg

Propellant, Charge, M230

Propellant composition: M45

Propellant type: Double base / Salt pellet (100:3)

Propellant mass per charge: 130 g

NG Content: 10% (12.6 g) of Part A (Double base)

Charges per round: 2

**APPENDIX B: ANALYSIS DATA FOR SAMPLES****Table B1. Firing point data (Table 1).**

<b>FRA#</b>	<b>Increments</b>	<b>Area sampled (m<sup>2</sup>)</b>	<b>NG mass in snow (µg)</b>	<b>NG mass in soot (µg)</b>	<b>NG mass in sample (µg)</b>	<b>NG mass/area (µg)/(m<sup>2</sup>)</b>
732	100	1	1,400	27,000	28,000	28,000
733	100	1	1,800	29,000	31,000	31,000
734	93	0.93	3,400	3,700	7,100	7,700

**Table B2. Impact point data.**

FRA#	Plume #	Sample Type	Increments	Notes	Filtrate		Plume Area (m <sup>2</sup> )	Area Sampled (m <sup>2</sup> )	RDX Mass (µg)					HMX Mass (µg)					TNT Mass (µg)				
					Vol. (mL)	# of Filters			Snow	Soot	In Sample	Per m <sup>2</sup>	Total	Snow	Soot	In Sample	Per m <sup>2</sup>	Total	Snow	Soot	In Sample	Per m <sup>2</sup>	Total
703	1	LIS-Plume	100		5840	4	646	1.0	5.8	3.5	9.3	9.3	6,000		1.4	1.4	1.4	930	0.7	-	0.7	0.7	450
704	1	LIS-Plume	100		6520	4	646	1.0	9.3	12	21	21	14,000	0.27	1.3	1.6	1.6	1,000	3.5	-	3.5	3.5	2,200
705	1	LIS-Plume	102		6520	4	646	1.0	6.9	3.2	10	9.9	6,400	0.09	1.3	1.4	1.3	860	0.8	-	0.8	0.8	500
706	2	LIS-Plume	105		6200	4	477	1.1	34.2	27	61	58.3	28,000	0.76	2.1	2.9	2.7	1,300	2.2	-	2.2	2.1	990
707	2	LIS-Plume	99		7520	4	477	1.0	37.8	22	60	60.4	29,000	0.68	2.1	2.8	2.8	1,300	6.6	-	6.6	6.7	3,200
708	2	LIS-Plume	100		5860	4	477	1.0	37.4	23	60	60.4	29,000	0.66	2.5	3.1	3.1	1,500	4.6	-	4.6	4.6	2,200
709	3	LIS-Plume	102		7280	4	496	1.0	55.9	3	59	58	29,000	1.7	2.1	3.8	3.7	1,800	11	-	11	11	5,300
710	3	LIS-Plume	100		6800	4	496	1.0	89.0	6.4	95	95	47,000	3.3	3.4	6.8	6.8	3,300	26	-	26	26	13,000
711	3	LIS-Plume	95		6720	4	496	1.0	53.5	3.7	57	60	30,000	1.3	1.7	3.0	3.2	1,600	4.7	-	4.7	5.0	2,500
712	4	LIS-Plume	27	81-mm	2080	1	281	0.3	34.7	1.8	37	140	39,000	0.89	1.8	2.7	10	2,800	26	-	26	97	27,000
713	5	LIS-Plume	101		5420	3	568	1.0	17.0	3.6	21	20	12,000	0.21	-	0.2	0.2	110	1.4	-	1.4	1.4	790
714	5	LIS-Plume	92		5520	4	568	0.9	8.1	4.9	13	14	8,000	-	-	-	-	-	0.5	-	0.5	0.6	330
715	5	LIS-Plume	97		6270	4	568	1.0	14.7	9.3	24	25	14,000	0.16	-	0.2	0.2	92	0.9	-	0.9	1.0	550
716	6	LIS-Plume	110		5960	6	199	1.1	30.2	11	41	37	7,400	0.12	2.1	2.2	2.0	400	0.7	-	0.7	0.6	120
717 Ave	6	LIS-Plume	95	SPE Rep	5690	7	199	1.0	36.3	5.8	42	44	8,800	0.91	1.9	2.8	3.0	590	2.0	-	2.0	2.1	420
718	6	LIS-Plume	98		5765	6	199	1.0	33.2	13	46	47	9,400	0.21	1.6	1.8	1.9	370	0.9	-	0.9	0.9	180
719	7	LIS-Plume	75	+ 50 ml	9540	4	433	0.8	1.6	-	1.6	2.1	920	-	-	-	-	-	0.4	-	0.4	0.5	220
720	7	LIS-Plume	100		8090	4	433	1.0	0.9	-	0.9	0.9	380	-	-	-	-	-	0.3	-	0.3	0.3	120
721	7	LIS-Plume	82		8720	5	433	0.8	1.8	-	1.8	2.2	960	-	-	-	-	-	0.2	-	0.2	0.2	100
722	7	OTP 0-1	17	Adj Plumes	1750	1	9	0.2	0.2	-	0.2	1.5	10	-	-	-	-	-	-	-	-	-	-
723	7	OTP 0-3	33		3600	1	180	0.3	0.3	-	0.3	0.9	160	-	-	-	-	-	0.3	-	0.3	1.0	180
724	8	LIS-Plume	101		6750	4	457	1.0	20.7	29	50	49	22,000	0.71	7.8	8.5	8.4	3,800	13	-	13	13	6,000
725	8	LIS-Plume	88		8300	3	457	0.9	34.5	31	66	74	34,000	1.8	5.3	7.1	8.1	3,700	23	-	23	26	12,000
726	8	LIS-Plume	98		7760	6	457	1.0	40.0	21	61	62	28,000	2.6	5.8	8.3	8.5	3,900	15	-	15	15	7,000
727	9	LIS-Plume	97	Adj Plumes	7250	5	810	1.0	30.7	14	45	46	37,000	0.57	3.9	4.4	4.6	3,700	5.7	-	5.7	5.8	4,700
728	9	LIS-Plume	92		7260	7	810	0.9	135	88	220	240	190,000	4.6	27	31	34	27,000	42	-	42	46	37,000
729	9	LIS-Plume	111		5580	7	810	1.1	33.8	17	51	46	37,000	1.6	4.4	6.1	5.5	4,400	9.4	-	9.4	8.5	6,900
730	9	OTP 0-3	77		4800	3	345	0.8	202	420	620	810	280,000	13	98	110	140	50,000	200	5.4	200	260	94,000
731	9	OTP 3-6	78		2920	2	376	0.8	114	190	300	390	150,000	8.9	58	67	86	32,000	92	3.2	95	120	46,000

**Sample Type and Notes**

LIS: Large increment sample with goal of 100 increments.  
 OTP: Outside the plume sample: Multi-increment annular sample taken outside the demarcated plume.  
 SPE Rep: Average of three 1000-mL aliquots taken from one filtrate sample.  
 Adj Plumes: Plume consists of two adjacent impacts.  
 81-mm: 81-mm plume from a previous exercise. Data not used in this report.  
 +50 mL: 50 mL lost during handling of sample.  
 -: Denotes values below detection limits.

# REPORT DOCUMENTATION PAGE

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<b>14. ABSTRACT</b> Only limited data are available on energetic residues resulting from the firing and detonation of rounds from 120-mm mortars. After a live-fire training exercise at Fort Richardson, Alaska, we sampled a firing point for propellant residues (NG) and the impact area for high-explosives residues (RDX, HMX, and TNT). The firing point was snow-covered soil, and the impact area was snow-covered ice. The total explosives residue mass averaged 19 mg per round at the impact plume, of which 74% was RDX, 9% was HMX, and the remainder was TNT. Approximately $6 \times 10^{-4}$ % of the explosive mass (2,990 g of Composition B per round) remained following high-order detonations. A plume sampled near a low-order detonation had near-gram quantities of explosives along its edge, 50 times the average of the other plumes, and over 300 g of HE were recovered there the following spring. At the firing point, relatively high concentrations of propellant residues were found, averaging 14 g NG. High-order detonations deposit very little explosive compounds and are not likely to be a threat to groundwater. Low-order detonations will be the major contributor of contamination on impact areas. Firing points need more study but are an area of concern.					
<b>15. SUBJECT TERMS</b> 120-mm Mortar Composition B		Firing points High explosives High-order detonation		Ice Low-order detonation Snow	
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