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Energetic Residues and Crater Geometries from the Firing of 120-mm High-Explosive Mortar Projectiles into Eagle River Flats, June 2007

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COVER: Crater produced by a 120-mm high-explosive mortar projectile.

Watershed, Wetlands, and Fish and Wildlife Monitoring of ERF Impact Area at Fort Richardson, Alaska

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Final report

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Abstract: Fourteen 120-mm high-explosive mortar projectiles were fired into the Eagle River Flats (ERF) impact area in June 2007 to determine physical disturbance of the mudflat when it is not covered by ice. Currently, ERF is used only when it is covered by ice that prevents disturbance of the underlying sediment. Thirteen of the projectiles functioned normally and produced high-order detonations. The high-order detonation craters averaged 2.7 m in diameter and 0.7 m in depth, and no high-explosives residues from the Comp B filler were detected in the sediments in and around the craters. One projectile partially detonated. The crater was 1.7 m in diameter and 0.7 m in depth. Residues of TNT, RDX, and HMX were detected at tens of parts per million concentrations on the day of the detonation. None of the detonations exposed white-phosphorus-contaminated sediments or unexploded ordnance. Water draining off the mudflats immediately adjacent to areas with explosives residues on the surface had detectable concentrations of RDX, but water within the gully system had energetic concentrations of $\leq$ 0.06 µg/L. At the firing points, the propellant residue expelled from the mortar consisted of partially consumed grains that had nearly the same proportion of nitroglycerin as in the unfired propellant. Surface soils at the firing points had NG concentrations (around 10 µg/g) similar to those observed during previous sampling events.

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Nomenclature

2,4-DNT	2,4-dinitrotoluene
Am-DNT	Amino-dinitrotoluene
CRREL	Cold Regions Research and Engineering Laboratory
DAC	Defense Ammunition Center
ECD	Electron Capture Detector
EIS	Environmental Impact Area
ERF	Eagle River Flats
ESTCP	Environmental Security Technology Certification Program
FP	Firing Point
FRA	Fort Richardson, Alaska
GC	Gas Chromatography
HE	High Explosives
HMX	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
HPLC	High-Performance Liquid Chromatography
LO	Low-Order (partial) Detonation
NAD	North American Datum
NC	Nitrocellulose
NG	Nitroglycerin
OP	Observation Point
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine
Rep	Replicate

RSD	Relative Standard Deviation
TNT	2,4,6-trinitrotoluene
UCL	Upper Confidence Limit
USAARK	US Army Alaska
USAGAK	US Army Garrison, Alaska
UTM	Universal Transverse Mercator
UXO	Unexploded Ordnance
WP	White Phosphorus

Preface

This report was prepared by Marianne E. Walsh, Biogeochemical Sciences Branch (BSB), US Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire; Charles M. Collins, BSB, CRREL; Michael R. Walsh, Engineering Resources Branch (ERB), CRREL; Charles A. Ramsey, EnviroStat, Fort Collins, Colorado; Susan Taylor, BSB, CRREL; Susan R. Bigl, BSB, CRREL; Ronald N. Bailey, BSB, CRREL; Alan D. Hewitt, BSB, CRREL; and Mark Prieksat, Colorado State University.

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This report was prepared under the general supervision of Dr. Justin B. Berman, Chief, Research and Engineering Division, CRREL; Dr. Lance D. Hansen, Deputy Director, CRREL; and Dr. Robert E. Davis, Director, CRREL.

At the time this work was performed, Colonel Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

1 Introduction

Eagle River Flats (ERF) is the mortar and artillery impact area for Fort Richardson, Alaska. In the early 1990s, use of ERF as an impact area was suspended because of the suspicion that residues from high explosives (HE) were poisoning waterfowl that use the wetland impact area as a migratory staging area (Racine et al. 1992a, b). Sampling and analysis of the sediments at ERF did not detect HE residues, but did reveal the presence of another munition, white phosphorus (WP). Subsequent investigations proved that WP was the cause of the waterfowl deaths (Racine et al. 1993). After the cause of the waterfowl mortality was identified, the ERF impact area was reopened for training with HE and illumination ordnance during the winter months when ice cover prevents disturbance of the underlying sediment (US Army AK 2002). Investigations of the extent and persistence of the WP contamination and remediation activities took place during the summer (M.E. Walsh 1996, M.R. Walsh 1999, 2000). As of the summer of 2007, the surface sediments of all the major waterfowl feeding ponds were remediated by temporary pond pumping. Residual WP remains in a bulrush marsh complex in the buffer zone of the impact area and potentially deep within the pond sediments that were not desaturated.

The US Army Garrison Alaska has proposed that live-fire training should no longer be limited to firing on an ice cover and that the impact area be opened during all seasons for required training. Some restrictions would remain. White phosphorus would continue to be banned and firing would not occur during the waterfowl migrations in the spring and fall. Waterfowl mortality monitoring would continue during the fall waterfowl migration. Recognizing that the detonations of HE-filled projectiles when ERF is not ice-covered have the potential to reintroduce WP to the surface sediments either by exposing underlying contaminated sediments or by rupturing buried WP-filled ordnance, the impact zone within ERF will be confined to the mudflats that are not waterfowl habitat and that intermittently desaturate. An Environmental Impact Statement (EIS) is required for this change of use of the impact area.

This report summarizes the results from a study of some of the potential consequences of the use of the ERF impact area when it is not covered

with ice. A live-fire training exercise was conducted in June 2007 with 120-mm mortar projectiles, the largest ordnance that would be fired at Fort Richardson under the current training requirements. The crater dimensions were obtained, and the sediments within and ejecta from the craters were analyzed for both WP and HE residues. Also, water leaving the flats on an outgoing tide was sampled and analyzed for HE residues.

Increased use of the ERF impact area will necessarily require increased use of firing points. Firing of ordnance and burning of excess propellant are two activities that will increase in frequency. To determine the potential for the accumulation of propellant residues, firing point soils were collected and analyzed for nitroglycerin after the test firing. Also, trays were placed in front of the mortars to collect propellant residue for microscopic examination.

2 Methods

Field Test: 120-mm and 81-mm Mortars

The 1-24th Infantry Battalion of the 4-25th Stryker Brigade Combat Team fired mortar projectiles from FP Perry and FP Lower Fox on 5–7 June 2007. For FP Perry, the target location was on the east side of the Eagle River at grid coordinate UP544018. The full UTM coordinate for this target point is 354,400E and 6,801,800N (NAD83 UTM Zone 6N). This grid point is in the southwest quadrant of the former Bread Truck pond (Fig. 1 and 2), and was the target for fourteen 120-mm HE projectiles. For FP Lower Fox, the target was on the west side of the river at grid coordinate UP540014. The full UTM coordinate is 354,000E and 6,801,400N (NAD83 UTM Zone 6N) and is located on the mudflat of Area A (Fig. 1). Approximately 400 practice rounds were fired at this target location.

Figure 1. Aerial image (Aero-Metric 2006) showing target points on the east and west sides of the Eagle River, FP Lower Fox, FP Perry, FP Upper Cole, and OP Eagle.

Figure 2. View from FP Upper Cole Point looking north to the targeted area on the east side of the Eagle River. Point of arrow is the target point.

Live ordnance was fired from FP Perry (Fig. 1). The ordnance was the 120-mm HE M933 cartridge with an M745 point detonating fuze. The high explosive filler was 2.99 kg of Comp B (60/40 RDX/TNT). Each cartridge has four M230 doughnut-shaped charges, each of which contains 130 g of M45 propellant (Table 1). Two charges were used to fire the projectiles and the excess charges were burned at the firing point (Fig. 3) after the firing mission.

Two types of training rounds were fired from FP Lower Fox. One was the 81-mm M879 cartridge full-range training round. These cartridges are ballistically similar to the 81-mm M821 HE cartridge, but have an inert filler (Table 1). The M751 fuze contains a pyrotechnic smoke charge that is supposed to produce an audible sound and smoke cloud (US Army 1994). Each cartridge has four M220 propelling charges that contain M38 propellant. M38 propellant is 98% NC (nitrocellulose) and has a maximum of 2% NG (DAC 2006). The ignition cartridge contains M9 propellant, which is 40% NG. The second training round was the 120-mm full-range practice M931 cartridge (Fig. 4) that has a hollow body with a vent tube and plug. When the projectile hits the ground, a pyrotechnic smoke cartridge in the fuze functions and vents through the holes in the fin boom of the projectile

(US Army 1994). Each M233 charge contains 115 g of M47 propellant that is 10% NG. Both types of training rounds were supplied with four propellant charges per cartridge. The excess propellant from the 120-mm mortars was burned (Fig. 4) in three piles and the excess 81-mm propellant (222 charges) was burned in one pile.

Table 1. Ammunition fired in Eagle River Flats impact area in June 2007.

Nomenclature[a]	Firing point	Propellant	Ignition cartridge	Filler	Other
120-mm Comp B M933 w/fuze M745 for mortars M120/M121 Lot MM-97K025-002 NSN 1315 01 343 1941 DODIC C623	Perry	CHG Prop M230 MM-97G009-002 containing M45 (86% NC, 10% NG)[b] 130 g/charge Drawing #12577522[c]	M981[d] containing M44 (52% NC, 44% NG)[b] 68 g Drawing # 12577526[e]	Comp B 6.59 lbs (2.99 kg)[d]	
120-mm full-range practice M931 w/fuze M781 for mortars M120/121 Lot SDP00F002H001 NSN 1315-01-467-0993 DODIC CA09	Lower Fox	CHG Prop M233 VSR99H040-004 containing M47 (82% NC, 10% NG)[b] 115 g/charge Drawing 12977282[f]	M1005[d] containing M44 (52% NC, 44% NG)[b] or M1020 containing M48 (34% NG, 0.5% DNT)[g] 3.89 g	None (hollow body)	Charge pyrotechnic 16 grams (36 % potassium perchlorate, 36% aluminum, 28% zinc dust)[g]
CTG 81-mm prac M879 w/PD fuze M751 for mortar M252 CZE95B004-017 Lot MA-97H020-006 NSN 1315-01-354-4916 DODIC C875	Lower Fox	M220[g] containing M38 (98% NC) 34.7 g/charge[g]	M299[d] containing M9 (57.8% NC, 40% NG)[g]	Hydrocal (inert: (calcium sulfate hemihydrate) 2.05 lb[d]	Charge pyrotechnic 16 grams (36 % potassium perchlorate, 36% aluminum, 28% zinc dust)[g]

[a] Nomenclature obtained at the firing points from the ammunition packaging
[b] DAC 2006
[c] ARDEC 2005a
[d] US Army 1994
[e] ARDEC 2005b
[f] ARDEC 1996
[g] DAC 2008

a. Loading.

b. Firing.

Figure 3. Live fire of 120-mm HE mortar cartridges from FP Perry.

c. M230 propellant charges (containing M45 propellant) for 120-mm HE mortar cartridge.

d. Burn pile.

Figure 3 (cont'd).

e. Burn residue.

Figure 3 (cont'd). Live-fire of 120-mm HE mortar cartridges from FP Perry.

a. Firing.

Figure 4. Firing of 120-mm target practice cartridges from FP Lower Fox.

b. Preparing to burn.

c. Propellant burn.

Figure 4 (cont'd).

On 5 June 2007, we observed from FP Upper Cole (Fig. 1). At 1625 hours, the range was opened and the officer in charge at FP Lower Fox radioed the following nomenclature: M250, C875, and M879, which indicated that their ammunition was the 81-mm cartridge full-range training round. We observed for approximately 30 minutes while the practice rounds were fired. The only indication that the rounds were landing was a small amount of wet sediment thrown up from the impact points and the movement of birds (Sandhill Cranes and gulls) away from the target area. We did not observe any smoke from the pyrotechnic smoke charge.

On 6 June 2007 we had observers at FP Upper Cole and FP Perry. The forward observers were at FP Eagle (Fig. 1). Firing of fourteen 120-mm HE projectiles from FP Perry took place between 1143 and 1310 hours. Thirteen detonations were high order and one was low order. The range was closed at 1319 hrs to allow us to collect samples as described below. The excess propellant, consisting of 28 charges, was burned at the firing point (Fig. 3) at 1340 hrs. Nomenclature for the ammunition and UTM coordinates were obtained for the Stryker positions and the burn point.

On the evening of 7 June 2007, we had observers visit FP Lower Fox. Two Strykers, one on the north side and one south side of the firing point (Fig. 4), were firing 120-mm mortars, and three 81-mm mortars were set up between the two Strykers. We were told that by 2030 hours, 222 81-mm target practice rounds and 106 120-mm full range practice rounds had been fired out of a total of 400 practice rounds drawn. Nomenclature for the ammunition and UTM coordinates were obtained for the mortars and the burn points.

Sampling within the Impact Area

Sediment Sampling of the Targeted Area Before and After Live-Fire Exercise

To determine whether the firing of 120-mm HE projectiles left energetic residues or exposed buried WP-contaminated sediments, samples of sediment were obtained before and after the live-fire exercise. On 4 June 2007, a 200-m × 200-m area centered on the east target point was marked and the perimeter cleared by our UXO technician (Fig. 1). Then triplicate 100-increment samples were collected by three sampling teams, each using a 3-cm-diameter corer to a depth of 2.5 cm (Fig. 5). The starting point

for the first increment for each 100-increment sample was chosen randomly within the first 20-m × 20-m cell, then subsequent points were taken at approximately 20-m intervals, measured by pacing, on a square grid pattern. Each point was checked with a magnetic locator by our UXO technician prior to obtaining a sediment core (Fig. 5). Post-firing sampling took place on 6 June 2007 from the same area and using the same method, but with three new randomly chosen starting points.

Figure 5. Sampling of 200 m × 200 m cell. Each point was cleared with a metal detector for potential UXO prior to taking a core.

Sampling of Craters

Immediately after the live fire from FP Perry into the east side of ERF, the fourteen craters produced by the detonations of the 120-mm HE projectiles were photographed (Appendix A), measured to obtain maximum and minimum diameters and depth, and mapped using a Trimble GPS Pathfinder Pro XR system. Then, multi-increment sediment samples were collected by hand from within the crater (~30 to ~40 increments) and from the sediment that was ejected from the crater (~50 to ~90 increments).

In August 2007, another set of sediment samples was collected from the one crater where HE residues were detected in June (as described in the Results, page 23). Duplicate field samples were collected from within the crater and one field sample was collected from the ejecta. Subsurface samples were obtained using an Oakfield corer to collect samples co-located with the fin of the mortar cartridge, which was buried in the mud at the crater bottom. Also, a 10-m × 10-m area (Fig. 6) was established around the crater and triplicate 100-increment samples collected with a 3-cm-diameter corer to a depth of 3 cm. The multi-increment samples contained sediment from the ejecta, crater, and surrounding undisturbed sediment.

Water Sampling Within the Impact Area

The first series of flooding tides after the June live-fire training exercise occurred at the end of August. To determine whether explosives residues are being transported by flooding tides from the flats to the Eagle River, we collected a series of sediment and water samples within the distributary gully located nearest a cluster of low-order detonations (Fig. 7) from previous winter firing exercises. The low-order detonation labeled as LO3 in Figure 7 occurred in March 2006. Chunks of Comp B were scattered over a 378-m^2 area. A total of 133 chunks were found. Estimates of the mean concentration of RDX and TNT in the surface sediments remaining in June 2007 ranged from 7.3 to 82 μg/g for RDX, 0.6 to 26 μg/g for TNT, and 1.8 to 11 μg/g for HMX based on 100-increment samples (Hewitt et al. 2008). The low-order detonation labeled LO6 in Figure 7 is just above the bank of the gully near the Eagle River. Chunks of Comp B were found immediately adjacent to the crater in May 2007, and sediment from the thalweg (bottom) of a shallow drainage channel downslope of the crater was sampled. RDX and TNT concentrations were 12 and 2.0 μg/g, respectively, and the HMX concentration was 2.9 μg/g.

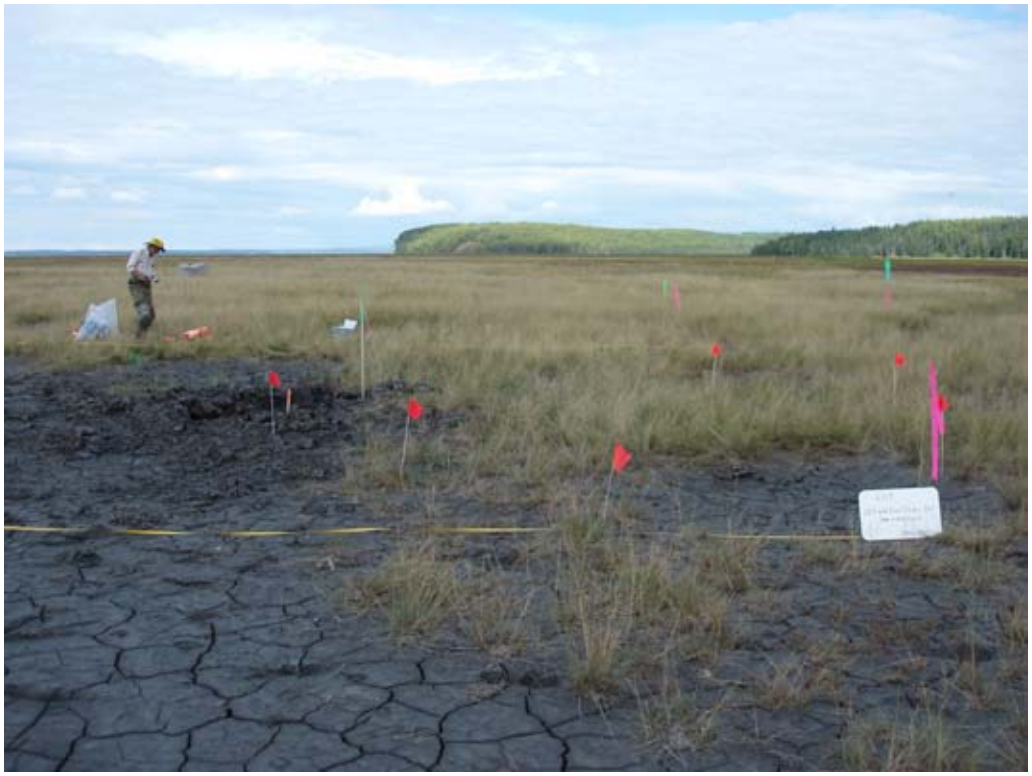
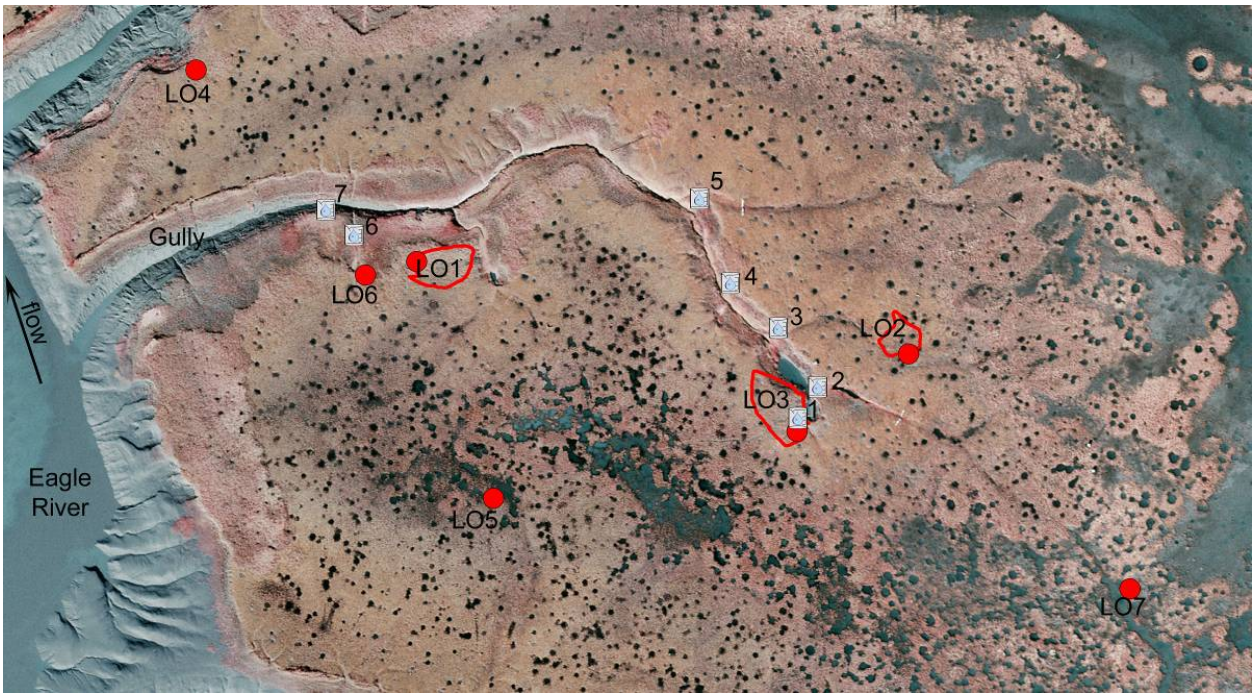


Figure 6. A 10-m × 10-m area centered on the low-order detonation crater from which multi-increment samples were collected in August 2007 to determine explosives residues. Mean concentrations were 8.8, 4.3, and 1.3 µg/g for RDX, TNT, and HMX.

To determine whether HE residues from these low-order detonations are migrating toward the Eagle River, discrete sediment samples were collected at six points as shown in Figure 7. Multi-increment sediment samples were collected between the points (Fig. 7b) near LO3. Water moving off the flats on 29 August 2007 was sampled using an US DH-48 isokinetic sampler (Fig. 7c) at the same six points plus an additional point in the gully below LO6.

Firing Points

Two sample collection activities took place at the firing points that were directly related to the June 2007 live-fire training. The first was the collection of propellant residues on trays that were placed in front of the mortars (Fig. 8). The purpose of the collection was to examine the residue with a microscope to elucidate its structure and to estimate the mass of NG in the solid propellant residue that would be deposited on the ground.



a. Red circles indicate the locations of low-order detonations. Water and sediment samples were collected starting near LO3 at the points numbered 1 to 7.

b. Multi-increment sampling of sediment within the drainage gully.

Figure 7. Gully samples.

c. US DH-48 isokinetic sampler.

Figure 7 (cont'd).

The second activity was the collection of soil at the locations where excess 120-mm propellant was burned. At FP Perry, we went to the UTM coordinate for the burn point, but no physical evidence of the propellant burn was visible (despite the blackened surface produced by the June burn (Fig. 3e). Because of the uncertainty of the exact location of the burn point, only one soil sample, mostly gravel, was collected using a scoop at the UTM coordinate. Two burn points were sampled at FP Lower Fox in August 2007. Both corresponded to the locations where M233 propellant charges were burned. These charges are different from the M230 burned at FP Perry. We located the burn points from the GPS coordinates and a stake that had been placed on the night that the propellant was burned. At one burn point, we took nine discrete cores with the 3-cm corer, one in the center and eight around the compass points N, NE, E…NW at 50 cm from the center (Fig. 9). We analyzed each core separately to determine the spatial heterogeneity of the NG residue. To obtain a mean concentration at the burn point, we took two multi-increment samples within 50 cm of the center with 20 increments each, and also two samples at 50 to 90 cm from the

center, one where the ground was black and the other from where it was not black. We sampled the second 120-mm burn point at FP Lower Fox (marked with an orange stake in the left of Fig. 9) by collecting three ~30 increment samples within 1.5 m from the center and three 30-increment samples 1.5 to 2.5 m from the center. Each multi-increment sample was collected with the 3-cm-diameter corer to a depth of 2.5 cm.

Figure 8. Trays used to collect propellant residue.

Soils from FP Lower Fox were collected in May (before the live-fire exercise) and in August 2007 for projects not related to the EIS, but the results are pertinent to the EIS. The projects were "Soil and Water Monitoring for Fort Richardson" and the ESTCP project "Validation of Sampling Protocol and the Promulgation of Method Modifications for the Characterization of Energetic Residues on Military Testing and Training Ranges."

Figure 9. Burn point samples at FP Lower Fox.

The north side of FP Lower Fox has been sampled annually since 2005 (Walsh et al. 2007) as part of a monitoring study of the accumulation of nitroglycerin from propellant residue. The area sampled was 22-m × 36-m (Fig. 10) and corresponded to the snow surface in front of a Stryker-mounted 120-mm mortar in February 2005 (Walsh et al. 2005). The concentration of NG in the surface soil in the same area the following summer was 8.7 µg/g and was 10 µg/g in 2006 (Walsh et al. 2007). Surface soil from the same area was resampled in May and in August 2007, before and after the live-fire training in June 2007. Triplicate multi-increment samples were collected with a 3-cm-diameter corer to a depth of 2.5 cm.

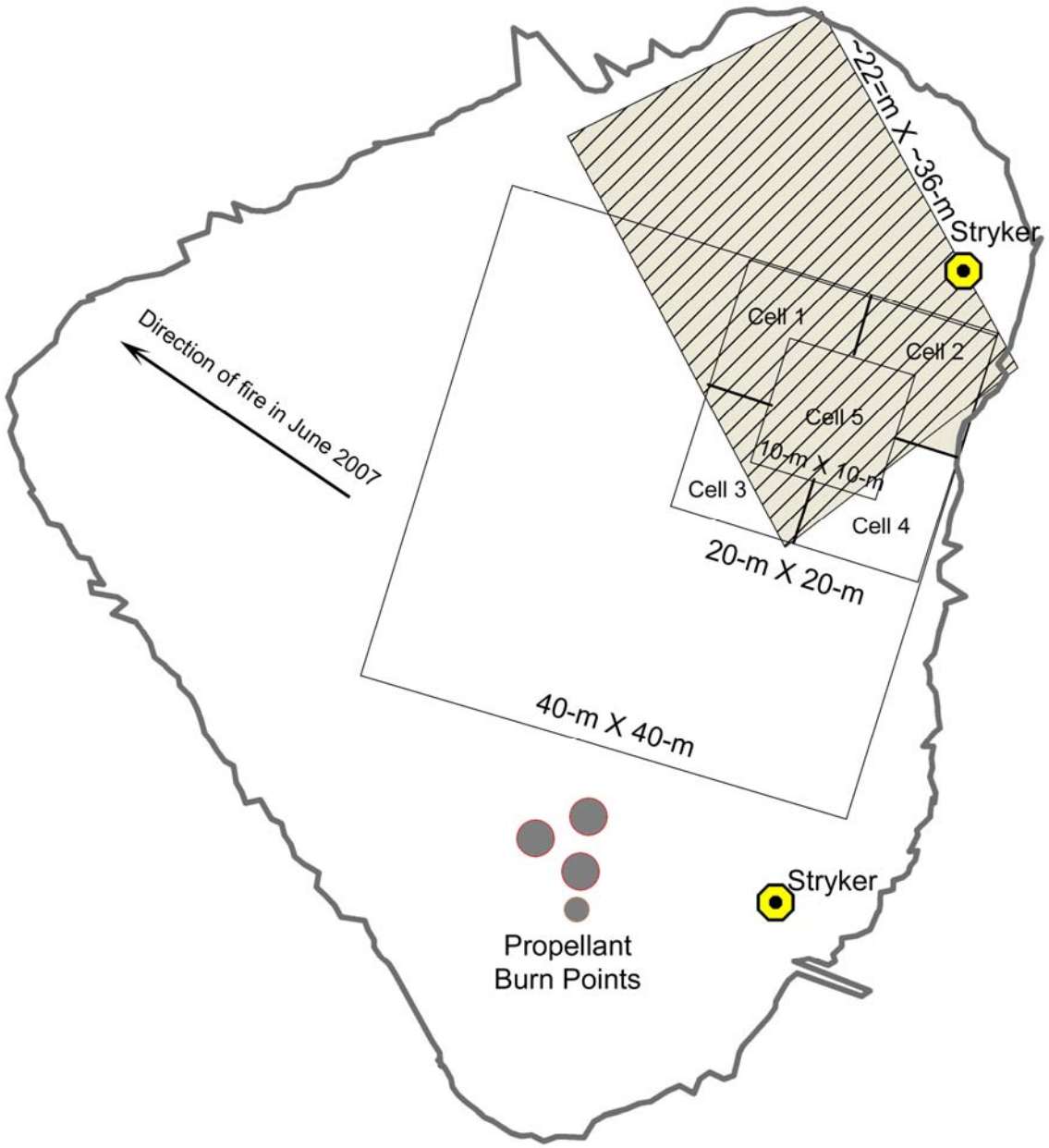


Figure 10. Map of FP Lower Fox showing areas sampled for NG. The yellow circles correspond to the locations of the Stryker-mounted 120-mm mortars fired in June 2007.

Also, immediately before the June 2007 live-fire training, an extensive sampling effort took place at FP Lower Fox in May 2007 to compare the uncertainty associated with various soil sampling protocols (Hewitt et al. 2008). FP Lower Fox was used for the study because we knew that the NG concentrations in the surface soils were sufficiently above the analytical detection limits to allow a meaningful comparison of the sampling proto-

cols. A 40-m × 40-m area was chosen (Fig. 10) and flags were placed at 4-m intervals around the perimeter, marking the bounds of 4-m × 4-m cells. More than 100 discrete samples were collected from random cells. Also, ten 100-increment samples were collected with a 3-cm-diameter corer every 4 m to a depth of 2.5 cm. For each of these samples, the first increment was from a random location within the first 4-m × 4-m cell, then subsequent increments were spaced at 4-m intervals. The intervals were determined by pacing and visual confirmation from the perimeter flags. On the evening of June 7, when the training exercise was almost over, one 100-increment sample was collected, and on June 21, three more 100-increment samples were collected from the same 40-m × 40-m area using the same procedure as the pre-firing samples.

Based on the results from May and June, part of the overlapping zone between the two areas described above at FP Lower Fox was sampled in August 2007 in an attempt to determine whether there was a zone of very high NG concentration. A 20-m × 20-m area was positioned as shown in Figure 10 and five individual cells were sampled by the collection of multi-increment samples. The spacing of the cores was 1.67 m; this sampling distance yielded 144 increments from the 20-m × 20-m area.

3 Sample Processing and Analytical Methods

Energetic Residues

Soils and Sediments

Soil and sediment samples were processed according to SW846 Method 8330B (USEPA 2006). First, sediment samples from the impact area were subsampled for white phosphorus as described below. Then, firing point soils and impact area sediments were air-dried, and the soils from the firing points were sieved using a 10-mesh (2-mm) sieve. The sediments from ERF were not sieved because of their fine grain size. Soils and sediments were ground on a ring mill in 500-g increments. The ring mill was a Lab-Tech Essa (Belmont, Western Australia) LM-2 equipped with a B800 bowl. Firing point samples were ground for five 60-s cycles and impact area samples were ground for one 60-s cycle. Ground multi-increment samples were manually subsampled. For each sample, the 500-g ground portions were combined and then spread over a flat surface. Duplicate 10.0-g subsamples were formed from several small increments taken from random locations. Many increments were used to form each subsample because the multi-increment samples were ground in 500-g portions and each portion would not be expected to have the same analyte concentrations. Each 10-g sample was extracted with acetonitrile by shaking for 18 hours.

Water Samples

Water samples from the distributary gully were preconcentrated using solid phase extraction. Each Waters PoraPak RDX Sep-Pak Vac cartridge was preconditioned with 15 mL of acetonitrile (gravity flow), then with 30 mL of reagent-grade water (Milli-Q) at less than 10 mL/min. A 500-mL (or less) water sample was passed through each cartridge at less than 10 mL/ min, then each cartridge was dried under vacuum for at least 20 minutes to remove residual water. The dried cartridges were eluted with 5 mL of acetonitrile. Generally, 4.5 mL were recovered, so the final volume was made up to 5.0 mL with acetonitrile to yield a hundredfold concentration factor.

Analytical Methods

Prior to HPLC analysis, a 1.00-mL aliquot of each acetonitrile soil or solid phase extract was mixed with 3.00 mL of Milli-Q (reagent-grade) water and filtered through a Millex-FH (Millipore, PTFE, 0.45 µm) filter unit. Determinations were made on a modular system from Thermo Electron Corporations composed of a Finnigan SpectraSYSTEM Model P4000 pump, a Finnigan SpectraSYSTEM UV2000 dual wavelength UV/VS absorbance detector set at 210 (to detect NG) 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).

Calibration standards were prepared from analytical reference materials obtained from Restek Corporation (Bellefonte, Pennsylvania). The analytical reference materials were 8095 Calibration Mix A (HMX, RDX, TNT, 2,4-DNT, 2,6-DNT, 1,3-DNB, 1,3,5-TNB, 2-Am-4,6-DNT, 4-Am-2,6-DNT, and tetryl) and a single-component solution of NG; the concentration of each analyte was 1 mg/mL in acetonitrile. A 1- and a 10-mg/L solution were used to calibrate the HPLC-UV. Soil concentrations were obtained by first calculating the extract concentrations. Extract concentrations were then multiplied by the volume of solvent used to extract each sample or subsample and divided by the mass of extracted soil. Extracts that had concentrations greater than 20 mg/L were diluted with acetonitrile prior to mixing with water and HPLC analysis.

Water sample solid phase extracts were also analyzed by GC-µECD (USEPA 2000), which provides lower detection limits. 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. Separation was conducted on a 6-m- × 0.53-mm-ID RTX-TNT fused-silica column that has a 1.5-µm-thick film of a proprietary Crossbond phase. 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 1.28 psi inlet pressure. The µECD

detector temperature was 280°C; the makeup gas was nitrogen at 45 mL/min.

White Phosphorus

Sediments from the 200-m × 200-m target area that were collected before and after the live-fire exercise and sediments from the impact craters were subsampled for white phosphorus while the sediments were still wet. For multi-increment sediment samples from the target area, a 200-g subsample was formed from at least 30 increments of the field sample. Crater samples were subsampled by taking a 40-g sediment aliquot. Samples were analyzed for white phosphorus by EPA SW-846 Method 7580 White Phosphorus (P_4) by Solvent Extraction and Gas Chromatography (USEPA 1995). The method detection limit is estimated to be 0.0002 μg/g.

4 Results

Live Fire of 120-mm Mortars from FP Perry

The first detonation (number 1 in Fig. 11) was 500 m southeast of the target point on the east side of ERF. The next four detonations (numbers 2 to 5 in Fig. 11) were even farther south. We contacted FP Perry to have firing suspended and M.R. Walsh went to OP Eagle to find out whether the forward observers knew the correct location of the target point. Once the forward observers were directed to the correct target location, firing recommenced and the next six detonations were progressively closer to the targeted area, and the final three detonations were within the 200- × 200-m targeted area.

Based on our observations from FP Upper Cole, 13 of the 14 HE projectiles functioned as designed and produced high-order detonations (Fig. 12). One projectile (the second one fired) detonated, but the detonation was incomplete or low order (Fig. 12b). No chunks of HE were visible on the sediment surface. An abnormally large section of the projectile body was found in the crater wall (Fig. 13). In a high-order detonation, only the tail section of the projectile remains after the detonation.

Crater Analysis

The maximum and minimum diameter and the depth of each of the apparent craters are listed in Table 2. The apparent crater is the crater visible to an observer and is smaller than the true crater. The true crater would also include the volume of ejecta material that has fallen back into the crater and the volume of the zone of fractured material at the bottom and along the sides of the crater. The 13 high-order detonations formed craters with an average apparent diameter of 2.69 m (radius of 1.35 m) and an average apparent depth of 0.72 m (Table 2a). The one projectile that produced a low-order or incomplete explosion made a smaller apparent crater with a mean diameter of 1.65 m (Table 2b).

The radius and depth of an apparent crater can be predicted by cube-root scaling given the weight of the explosive charge and the location of the charge relative to the ground surface. For point-detonating projectiles, we

assume that the explosive charge is at the surface. Constants have been developed for explosions in various types of ground media (Table 3).

a. Aerial image (Aero-Metric 2006) with locations of craters and target area.

b. Ground view of craters 9, 10, and 11.

Figure 11. 120-mm detonation craters.

a. High-order detonation.

b. Low-order detonation.

Figure 12. Images showing the visual difference between a high-order and low-order detonation of a 120-mm projectile.

a. With a large fragment from the projectile body.

b. Collection of subsurface samples from the same crater after a flooding tide.

Figure 13. Low-order detonation crater (#2) in Figure 12.

Table 2. Dimensions of apparent craters from 120-mm HE mortar projectiles fired into ERF.

Crater #	UTM Coordinates (6 North, WGS 84) Easting (m)	Northing (m)	Diameter (m) Minimum	Maximum	Mean	Depth (m)
a. Of the 13 normally functioning projectiles.						
1	354,729	6,801,434	3.00	3.10	3.05	0.67
3	354,740	6,801,308	2.45	2.80	2.63	0.71
4	354,795	6,801,285	2.50	2.80	2.65	0.66
5	354,698	6,801,397	2.70	2.80	2.75	0.75
6	354,655	6,801,471	2.40	2.70	2.55	0.70
7	354,661	6,801,581	2.80	3.00	2.90	0.68
8	354,433	6,801,685	3.00	3.20	3.10	0.77
9	354,398	6,801,671	2.40	2.50	2.45	0.64
10	354,387	6,801,674	2.60	2.60	2.60	0.76
11	354,395	6,801,684	2.30	2.40	2.35	0.67
12	354,388	6,801,757	2.30	2.60	2.45	0.79
13	354,420	6,801,763	2.70	3.00	2.85	0.72
14	354,418	6,801,783	2.60	2.70	2.65	0.90
Mean			2.60	2.78	2.69	0.72
b. Of the one low-order detonation.						
2	354,765	6,801,345	1.50	1.80	1.65	0.68

Table 3. Predicted apparent scaled radius and depth of crater by cube-root scaling for explosive charge at surface in various media.

	Snow	Ice	Frozen silt	Unfrozen soil
R_a	0.87 $M_c^{1/3}$	0.71 $M_c^{1/3}$	0.56 $M_c^{1/3}$	0.5 to 0.6 $M_c^{1/3}$
D_a	0.3 to 0.5 $M_c^{1/3}$	0.24 $M_c^{1/3}$	0.28 $M_c^{1/3}$	0.3 $M_c^{1/3}$

R_a Apparent radius of the crater in meters
M_c Mass of the explosive charge in kilograms
D_a Apparent depth of the crater in meters

The apparent depth and radius of a crater will increase with the depth of explosive charge below the surface down to a maximum depth called the optimum depth. This depth varies with the size of the explosive charge (Table 4).

Table 4. Predicted apparent scaled radius of crater at optimum charge depth.

	Moist clayey soil[a]	Frozen silt[a]	Ice[b]
R_a	0.9 $M_c^{1/3}$	0.9 to 1.1 $M_c^{1/3}$	0.71 $M_c^{1/3}$
Opt. Depth	0.5 $M_c^{1/3}$	0.7 to 0.8 $M_c^{1/3}$	

[a] Mellor (1989)
[b] Mellor (1986)

The 120-mm HE mortar projectile fired during the test has 2.99 kg of Comp B explosive filler. If we assume that the charge detonated at the surface, and based on the equations in Table 3, the apparent radius (R_a) in unfrozen silt should be 0.87 m and the apparent depth should be 0.43 m. The average apparent radius of the 13 craters (Table 2a) is 1.35 m, 55% larger than predicted. The average apparent depth is 0.72 m, 66% deeper than predicted. The likely explanation for the difference is that the 120-mm mortar projectiles penetrated to some depth into the unfrozen sediment prior to detonating. Using the equations from Table 4, the optimum depth of the 3-kg explosive charge in the 120-mm projectile would be 0.72 m and the apparent radius for the projectile detonated at the optimum depth would be 1.3 m, within 4% of our average measured 1.35-m radius. This indicates that there was probably about 0.7 m of penetration of the mortar projectiles into the unfrozen ground prior to detonation.

The 120-mm practice mortar projectiles do not produce a crater, but they do form holes. Appendix Figure A-2 shows one of these holes that was located on the mudflats on the west side of the river. The diameter of the hole was approximately 30 cm and the depth was greater than 2 m. Our UXO technician inserted the entire length of his Schonstedt Magnetic Locator and his arm into the hole formed by the round and did not detect a metallic signal, indicating that the projectile penetrated several meters.

Analysis for Comp B Residue

No high-explosives residues were detected in the 200-m × 200-m targeted area before or after the firing of the 120-mm mortars (Table 5a). Nor were HE residues detected in and around the 13 high-order detonation craters (Craters 1 and 3–14 in Table 5b).

Energetic residues were detectable in the two field samples from the low-order detonation crater (#2) (Fig. 13a). Comp B residues, consisting of

RDX and TNT (the HE filler) and HMX (present as an impurity in RDX) were present at tens of parts per million concentrations (Table 5b). 2,4-DNT (present as an impurity in TNT) and the isomers of Amino-DNT (reduction products of TNT) were detectable (Table 5b) at sub-part-per-million concentrations. Samples of the surface sediment within Crater 2 in August 2007 (82 days after the detonation) had mean concentrations of 24, 3.5, and 2.9 µg/g of RDX, TNT, and HMX (Table 6). TNT appears to be declining because it is much less persistent than RDX or HMX. The reduction products of TNT were also detectable, just above the method detection limit (0.1 µg/g) for these two compounds.

Sediment that was thrown from the crater up to 20 m away, referred to as ejecta, had 105, 64, and 15 µg/g of RDX, TNT, and HMX on the day of the detonation and had 13, 5.2, and 2.0 µg/g in the subsequent sample 82 days after the detonation (Tables 5b and 6).

A 10- × 10-m area around the crater was established to monitor the persistence of the energetic residues (Fig. 6). Multi-increment samples collected in August 2007 had mean concentrations of 8.8, 4.3, and 1.3 µg/g of RDX, TNT, and HMX (Table 6).

This low-order detonation is the seventh, all from 120-mm projectiles, that we have sampled at ERF. Unlike the previous low-order detonations, each of which occurred in the winter on top of an ice cover, this detonation took place subsurface and no chunks of Comp B were found in or around the crater. The concentrations of RDX, TNT, and HMX in the surface sediment of this crater were much less than those found in the craters that had surface detonations, where energetic residues were present up to thousands of parts per million. We suspected that higher concentrations might be co-located with the fin. When we sampled the crater in August, we found that the fin was 68 cm in the mud below the bottom of the crater. We used an Oakfield corer to attempt to collect sediment samples adjacent to the fin. Unfortunately, the crater had been flooded so sampling was difficult (Fig. 13b). We took six sediment cores around the fin and combined them to form one sample. We detected RDX, TNT, and HMX at 18, 9.6, and 2.3 µg/g, which are similar concentrations to those found in the August surface sediment crater samples. Two cores were analyzed individually (Table 7), each of which was divided into two lengths corresponding to 0 to 25 cm and 25 cm to the same depth as the fin. There was no indication

of increased concentration at depth (Table 7) for the six combined cores; however, the two cores that were divided both show an increase at depth for HMX and RDX, but not for TNT.

Gully Samples

Water and sediment were collected during the series of flooding tides at the end of August. Samples were collected in the drainage gully near two older low-order detonations, LO3 and LO6 in Figure 7. Energetic residues were not detectable in the sediment samples from within the gully near LO3 (Table 8). Water flowing into the head of the gully near the low-order crater had detectable concentrations of RDX (6.47 μg/L) and HMX (1.2 μg/L) (Fig. 7c). TNT was just barely detectable (0.04 μg/L), and the two reduction products of TNT were present at low concentrations (Table 8). Concentrations were considerably lower in the water from the next four points downstream within the gully. Only RDX was detectable at points 2 (Fig. 14) and 3, then was undetectable at points 4 and 5 (Table 8).

Points 6 and 7 were farther downstream near another low-order detonation (LO6) (Fig. 7 and 15). Point 6 was at the mouth of a shallow drainage channel running downslope from the crater. Duplicate multi-increment samples of the sediment were collected along the length of the thalweg (bottom) of this channel (Fig. 15b) in May and in August 2007. TNT and HMX were detected in the sediment at part-per-million concentrations and RDX was detected at tens of part-per-million concentrations. RDX and HMX were detected by HPLC in the water flowing out of the shallow drainage (21 μg/L for RDX and 4.5 μg/L for HMX). RDX was just barely detectable (0.06 μg/L) in the sample collected 10 m downstream in the water flowing in the main gully; HMX was not detected.

Analysis for WP

White phosphorus was not detected in any of the samples collected from the 200-m × 200-m targeted area, nor was it detected from within the craters or the ejecta from the craters.

Table 5. Results of the analysis for Comp B and WP residues in ERF sediments collected before and after the live-fire of 120-mm mortars in June 2007. Concentrations are expressed as µg/g.

a. 200-m × 200-m grid samples: Sample tool was the 3.0-cm-diameter corer set to 2.5-cm depth.											
Grid location	Samplers	Number of increments	Sample mass* (g)	Lab replicate	HMX	RDX	TNT	2,4-DNT	2-Am-DNT	4-Am-DNT	White phosphorus
Before firing (4 June 2007) concentration (µg/g)											
N8, W13	CAR/MC	100	1475	a	<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
				b	<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	
N18, W6	CAR/RB	100	1477	a	<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
				b	<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	
N17, W4	CAR/SB	100	1511	a	<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
				b	<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	
Post firing (6 June 2007)											
N7, W19	SB/RR	100	1883	a	<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
				b	<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	
N11, W9	CAR/MP	100	1699	a	<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
				b	<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	
N16, W12	MRW/CMC	100	1737	a	<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
				b	<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	
* Air-dried mass after removing 200 g of wet sediment for analysis of WP.											

b. Crater samples (concentrations are expressed as µg/g.).												
Crater number	Location	Sampler	Number of increments	Sample mass (g)	Lab replicate	HMX	RDX	TNT	2,4-DNT	2-Am-DNT	4-Am-DNT	White phosphorus
1	Inside	CAR	~40	274		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
2	Inside (Field Rep 1)	CAR	35	300	a	4.44	30.8	19.0	0.08	0.25	0.39	<0.0002
					b	4.44	30.4	19.1	0.07	0.22	0.39	
	Inside (Field Rep 2)	CAR	36	417	a	10.4	72.2	51.0	0.15	0.31	0.36	<0.0002
					b	10.0	74.4	51.0	0.15	0.31	0.41	

Table 5b (cont'd). Crater samples (concentrations are expressed as µg/g.).												
Crater Number	Location	Sampler	Number of increments	Sample mass (g)	Lab replicate	HMX	RDX	TNT	2,4-DNT	2-Am-DNT	4-Am-DNT	White phosphorus
3	Inside	CAR	47	390		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
4	Inside	CAR	40	337		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
5	Inside	CAR	38	330		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
6	Inside	MEW	40	202		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
7	Inside	MEW	38	267		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
8	Inside	MEW	36	279		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
9	Inside	MEW	31	252		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
10	Inside	MEW	35	288		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
11	Inside	MEW	36	318		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
12	Inside	MEW	32	306		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
13	Inside	MEW	35	213		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
14	Inside	MEW	36	302		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
1	Ejecta	CAR	51	324		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
2	Ejecta	MEW	58	430	a	14.6	105	64.1	0.15	1.01	1.16	<0.0002
					b	14.5	104	63.2	0.15	1.00	1.14	
3	Ejecta	CB	71	314		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
4	Ejecta	MEW	69	437		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
5	Ejecta	MEW	60	457		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
6	Ejecta	CB	51	390		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
7	Ejecta	MEW	64	647		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
8	Ejecta	CB	65	629		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
Cluster 9, 10, 11	Ejecta	CB	93	997		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
12	Ejecta	CB	68	589		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002
Cluster 13, 14	Ejecta	CB	74	715		<0.02	<0.02	<0.02	<0.02	<0.1	<0.1	<0.0002

Table 6. Concentrations (µg/g) of HE residues in samples from crater #2 produced by the low-order detonation on 6 June 2007. Samples were collected on 27 August 2007.

Crater number	Sampler	Number of increments	Sample mass (Air-dried)	Lab replicate	HMX	RDX	TNT	2,4-DNT	2-Am-DNT	4-Am-DNT
Inside crater (Field Rep 1)	RNB	30	166	a	3.40	27.6	4.64	0.07	0.18	0.16
				b	3.33	27.5	4.54	0.07	0.18	0.18
Inside crater (Field Rep 2)	RNB	30	164	a	2.40	17.8	2.41	0.05	0.12	<0.1
				b	2.38	17.7	2.40	0.04	0.13	0.15
Ejecta around crater	MEW	53	526	a	1.98	12.6	5.11	<0.02	<0.1	<0.1
				b	1.87	12.7	5.30	<0.02	<0.1	<0.1
10-m × 10-m area around crater (Field Rep 1)	RNB/MEW	100	2445	a	0.91	5.99	2.33	<0.02	<0.1	<0.1
				b	1.00	5.60	2.14	<0.02	<0.1	<0.1
10-m × 10-m area around crater (Field Rep 2)	MEW/RNB	100	2703	a	0.87	5.87	2.82	<0.02	<0.1	<0.1
				b	1.13	5.93	2.73	<0.02	<0.1	<0.1
10-m × 10-m area around crater (Field Rep 3)	RNB/MEW	100	2475	a	2.20	14.7	7.74	<0.02	<0.1	<0.1
				b	1.87	14.6	7.91	<0.02	<0.1	<0.1

Table 7. Concentrations (µg/g) in core samples collected on 30 August 2007 from the low-order detonation.

Sample	Sample depth (cm)	Air-dry sample mass (g)	HMX	RDX	TNT	2,4-DNT	2-Am-DNT	4-Am-DNT
Six cores combined	68 (at fin)	343	2.24	17.8	9.61	<0.02	<0.1	<0.1
			2.38	17.9	9.62	<0.02	<0.1	<0.1
Core 1	0 to 25	101.5	3.33	25.2	8.20	<0.02	0.26	0.21
Core 2	0 to 25	44.5	0.56	6.93	0.28	<0.02	0.04	<0.1
Core 1	25 to fin	52.4	7.55	58.8	7.56	<0.02	0.26	0.23
Core 2	25 to fin	65.0	1.63	14.4	2.12	<0.02	0.15	0.13

Table 8. Comp B residues in water and sediment from a gully near low-order detonations. Samples were collected on 29–30 August 2007.

Sample	# Incs	Air-dry sample mass (g)	HMX	RDX	TNT	2-Am-DNT	4-Am-DNT
Sediment samples near LO3			Conc. (µg/g)				
Point 1 to 2	12	232	<0.02	<0.02	<0.02	<0.1	<0.1
			<0.02	<0.02	<0.02	<0.1	<0.1
Point 2 to 3	16	279	<0.02	<0.02	<0.02	<0.1	<0.1
			<0.02	<0.02	<0.02	<0.1	<0.1
Point 3 to 4	19	350	<0.02	<0.02	<0.02	<0.1	<0.1
			<0.02	<0.02	<0.02	<0.1	<0.1
Point 4 to 5	25	516	<0.02	<0.02	<0.02	<0.1	<0.1
Point 1	discrete	171	<0.02	<0.02	<0.02	<0.1	<0.1
			<0.02	<0.02	<0.02	<0.1	<0.1
Point 2	discrete	240	<0.02	<0.02	<0.02	<0.1	<0.1
			<0.02	<0.02	<0.02	<0.1	<0.1
Point 3	discrete	165	<0.02	<0.02	<0.02	<0.1	<0.1
			<0.02	<0.02	<0.02	<0.1	<0.1
Point 4	discrete	157	<0.02	<0.02	<0.02	<0.1	<0.1
			<0.02	<0.02	<0.02	<0.1	<0.1
Point 5	discrete	233	<0.02	<0.02	<0.02	<0.1	<0.1
			<0.02	<0.02	<0.02	<0.1	<0.1
Water samples near LO3		Volume (mL)	Conc. (µg/L)				
Point 1	3 dips†	461	1.19	6.47	0.04	0.09	0.15
Point 2	3 dips	356	<0.05	0.11	<0.04	<0.04	<0.04
Point 3	3 dips	439	<0.05	0.06	<0.04	<0.04	<0.04
Point 4	3 dips	424	<0.05	<0.04	<0.04	<0.04	<0.04
Point 5	3 dips	434	<0.05	<0.04	<0.04	<0.04	<0.04

Table 8 (cont'd).

Sample	# Incs	Air-dry sample mass (g)	HMX	RDX	TNT	2-Am-DNT	4-Am-DNT
Sediment samples near LO6			Conc. (µg/g)				
Thalweg of shallow drainage†† Rep 1	27 Incs	399	8.36	42.5	5.40	0.24	0.22
			7.68	43.3	5.70	0.25	0.22
Thalweg of shallow drainage†† Rep 2	27 Incs	419	3.03	13.4	1.71	ND	ND
			3.28	13.7	1.76	ND	ND
Water samples near LO6		Volume (mL)	Conc. (µg/L)				
Mouth of shallow drainage	Isokinetic Sampler	441	4.54	21.3	<0.09*	<0.2*	<0.2*
Main Gully	Isokinetic Sampler	441	<0.05	0.06	<0.04	<0.04	<0.04

† With isokinetic sampler.

†† Results from May 2007: RDX and TNT concentrations were 12 and 2.0 µg/g, respectively, and the HMX concentration was 2.9 µg/g.

* Not analyzed by GC-ECD because of detection of RDX and HMX by HPLC.

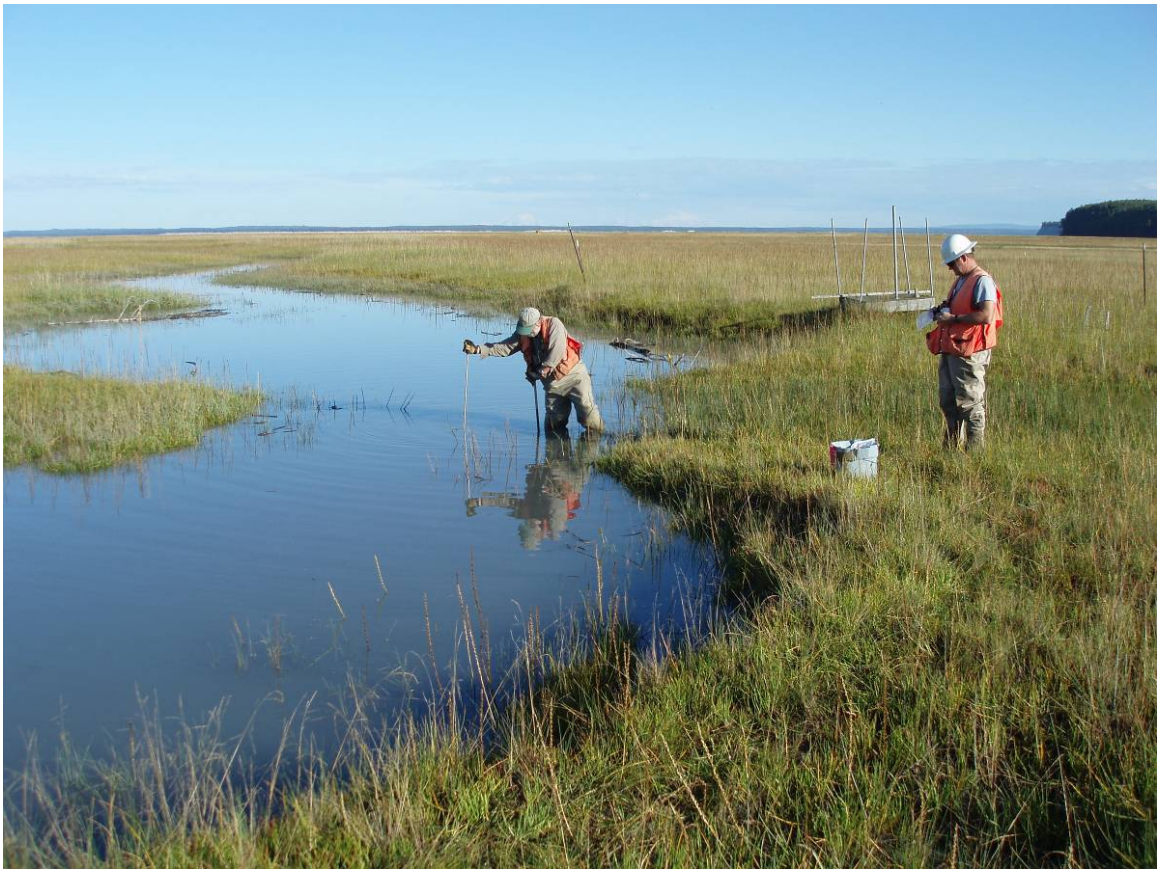


Figure 14. Sampling downstream in gully at Point 2 in Figure 7.

a. View downslope into the gully (August 2007).

b. View upslope showing shallow drainage channel (June 2007).

Figure 15. Ground views from L06 in Figure 7.

c. Sampling of water flowing in the above shallow drainage channel following a flooding tide on 29 August 2007.

d. Sampling the water flowing toward the Eagle River at point 7 in Figure 7.

Figure 15 (cont'd).

Analysis for Nitroglycerin at Firing Points

Propellant Structure and Composition: Unfired and Fired

Twenty individual unfired grains (1 mm long and 1.5 mm in diameter) of M45 propellant (Fig. 3 and 16) from FP Perry were weighed and the masses ranged from 3.2 to 4.3 mg. The mean mass was 3.8 mg, and according to the formulation specifications in which NG is 10 ± 2% of the formulation, the approximate mass of NG per grain would be 0.38 mg.

The propellant residue collected in front of the mortar consisted of rings and crescent-shaped pieces. To determine the proportion of NG in the fired residue, 4.1 mg of the residue was shaken in a vial with acetonitrile to extract the NG from the nitrocellulose matrix. The mass of NG recovered was 0.36 mg, which is essentially the same amount of NG that would be in the same mass of unfired propellant. Therefore, the propellant residue consists primarily of unconsumed propellant with approximately the same amount of NG as the unfired propellant.

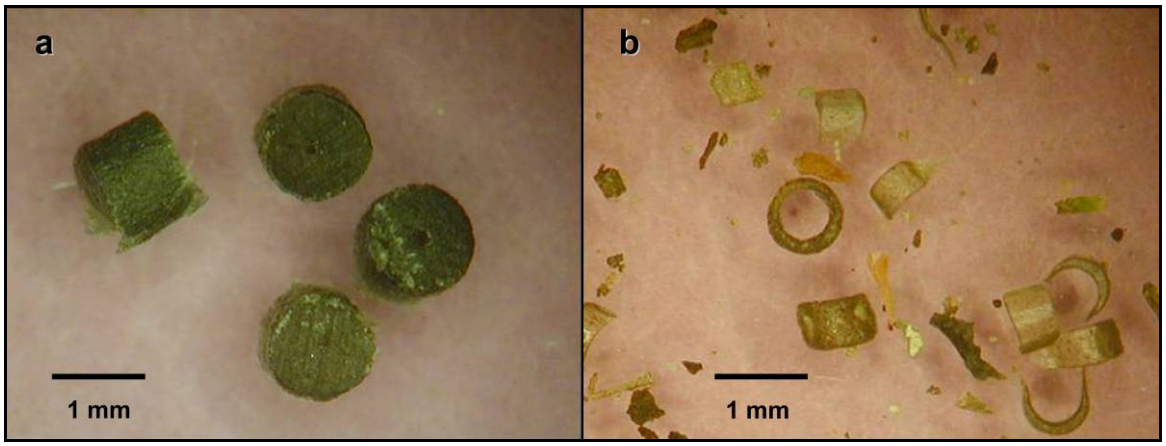


Figure 16. M45 propellant a) unfired and b) residues collected on trays in front of the 120-mm mortar at FP Perry on 6 June 2007.

Analysis for NG in Soils from Propellant Burn Points

The 28 excess M230 propellant charges were burned in one pile at FP Perry. In June, the charred residue on the gravel surface was obvious (Fig. 3e). A UTM coordinate was obtained. When we navigated to the same UTM coordinate in August 2007, there was no visual evidence of the burn point at the coordinate or anywhere near the coordinate. One soil sample was collected at the UTM coordinate and the NG concentration was 18 µg/g.

At FP Lower Fox, the excess propellant from the 120-mm practice rounds was burned in three piles (Fig. 4 and 10). The propellant charges were M233, each of which contains 115 g of M47 propellant (10% NG). We determined NG concentrations in nine individual soil cores from the first M233 burn point at FP Lower Fox (Fig. 9). The NG concentration in the center was 15 µg/g and ranged from 0.11 to 41 µg/g in eight equally spaced samples located 50 cm from the center (Table 9a). The total mass of NG in these nine samples was 1,020 µg and the total mass of soil was 150 g, yielding a concentration of 6.8 µg/g if the increments had been combined in one sample. The mean NG concentration was slightly higher (9.8 µg/g) in the two multi-increment samples composed of 20 surface cores from random locations within 50 cm of the center. In the soil located between 50 and 90 cm from the center, the NG concentrations were 11 µg/g in the soil with a blackened surface and 12 µg/g in the soil that was not blackened (Table 9b). These concentrations are all very similar to each other and to the concentrations found elsewhere in the firing point.

The second M233 burn point had a mean NG concentration of 6.7 µg/g in multi-increment samples composed of 31 or 32 cores from random locations within 1.5 m of the center (Table 10). The mean NG concentration between 1.5 and 2.5 m of the burn point was 2.1 µg/g.

Table 9. NG concentrations from the first burn point of propellant charges (M233) from 120-mm full range practice rounds at FP Lower Fox. The propellant charges were burned on 7 June 2007 and the soil samples were collected on 21 August 2007.

a. In individual cores.		
Position	Sample mass < 2 mm	NG (µg/g)
North	16.32	1.91
Northeast	20.55	4.11
East	16.97	5.79
Southeast	11.25	0.11
South	11.26	41.0
Southwest	15.67	4.54
West	19.03	0.13
Northwest	21.55	0.19
Center	17.17	15.2

Table 9 (cont'd).

b. In multi-increment samples.					
Position	Increments	Sample mass < 2 mm	Lab duplicate	NG (µg/g)	Mean of lab duplicates
Center: 0 to 50 cm	20	311	a	8.73	8.11
			b	8.35	
	20	323	a	11.3	11.1
			b	10.9	
				Mean	9.81
Annulus: 50 to 90 cm black surface	15	217	a b	11.2 11.0	11.1
Annulus: 50 to 90 cm excluding black surface	20	279	a b	12.0 12.3	12.15

Table 10. NG concentrations from the second burn point of propellant charges (M233) from 120-mm full-range practice rounds at FP Lower Fox. The propellant charges were burned on 7 June 2007 and the soil samples were collected on 30 August 2007.

Position	Increments	Sample mass < 2 mm	Lab duplicate	NG (µg/g)	Mean of lab duplicates
120-mm Burn Point #2					
Center: 0 to 1.5 m	32	349	a	9.01	9.44
			b	9.88	
	32	446	a	5.49	5.66
			b	5.83	
	31	393	a	5.10	4.84
			b	4.58	
				mean	6.65
Annulus: 1.5 to 2.5 m	30	426	a	1.31	1.19
			b	1.08	
	30	384	a	3.21	3.41
			b	3.60	
	30	409	a	1.36	1.58
			b	1.79	
				mean	2.06

Other Sampling Activities at FP Lower Fox

Soil samples were collected at FP Lower Fox for two other projects. The first was for the ongoing monitoring of Fort Richardson training lands. A ~22-m × ~36-m area on the north side of FP Lower Fox (Fig. 10) has been

sampled repeatedly to monitor the persistence of NG. This area corresponded to the area in front of a Stryker-mounted 120-mm mortar fired in February 2005. There have been four sampling events, each with triplicate multi-increment samples. The mean NG concentrations have been 8.7, 10.0, 13.1, and 8.4 µg/g (Table 11). Given the uncertainty associated with the mean for each sampling event, there is no evidence for accumulation of NG within this sampling area.

A larger, more centrally located 40-m × 40-m area was sampled extensively in May 2007 for the ESTCP project "Validation of Sampling Protocol and the Promulgation of Method Modifications for the Characterization of Energetic Residues on Military Testing and Training Ranges" (Hewitt et al. in prep). The same area was sampled again, once on the night of the live-fire training, 7 June 2007, and in triplicate two weeks later, even though the area was not located in front of either Stryker (Fig. 10). The results for the 100-increment samples are given in Table 12. Before the live fire, most of the multi-increment samples yielded estimates of NG around 5 µg/g. On the last night of the live-fire training, the one sample collected had 5.4 µg/g, and two weeks later, the mean of the triplicate multi-increment samples was 3.8 µg/g, indicating that NG did not accumulate in this area as a result of the training event.

Table 11. Concentration of NG at FP Lower Fox. Area sampled was ~22- m × ~36 m and corresponds to the area in front of a Stryker-mounted 120-mm mortar fired in February 2005. The sampling tool was a 4.75-cm-diameter corer in 2005 and 2006 and was 3.0-cm diameter in 2007. Depth was set to 2.5 cm.

Sample ID†	Samplers	Actual number of increments	Sample mass (kg) (< 2 mm)	Lab duplicate	NG concentration (µg/g)	Mean of lab duplicates
7 Sept. 2005						
Field Rep 1	RNB/MEW	100	2.39	a	11.1	10.3
				b	9.58	
Field Rep 2	RNB/MEW	105	2.27	a	6.59	7.57
				b	8.54	
Field Rep 3	RNB/MEW	104	2.57	a	8.23	8.16
				b	8.09	
					Mean	*8.68*
					Variance	*2.06*
					RSD	*17%*
					95% UCL	*11.1*

Table 11 (cont'd).

Sample ID†	Samplers	Actual number of increments	Sample mass (kg) (< 2 mm)	Lab duplicate	NG concentration (µg/g)	Mean of lab duplicates
2 Sept. 2006						
Field Rep 1	MRW/AG	44	1.48	a	9.00	9.73
				b	10.5	
Field Rep 2	MRW/AG	44	1.54	a	13.0	13.5
				b	14.1	
Field Rep 3	MRW/AG	44	1.63	a	7.45	6.88
				b	6.31	
					Mean	*10.0*
					Variance	*11.0*
					RSD	*33%*
					95% UCL	*15.6*
30 May 2007						
Field Rep 1	RNB/MEW	74	1.16	a	22.9	23.7
				b	24.6	
Field Rep 2	RNB/MEW	77	1.11	a	10.3	10.0
				b	9.61	
Field Rep 3	JJ/MEW	76	1.08	a	5.33	5.52
				b	5.72	
					Mean	*13.1*
					Variance	*89.7*
					RSD	*72%*
					95% UCL	*29.0*
30 Aug 2007						
Field Rep 1	RNB/MEW	88	1.24	a	9.35	8.51
				b	7.67	
Field Rep 2	MEW/RNB	88	1.07	a	5.61	5.35
				b	5.09	
Field Rep 3	RNB/JJ	88	1.38	a	11.3	11.4
				b	11.6	
					Mean	*8.42*
					Variance	*9.16*
					RSD	*36%*
					95% UCL	*13.5*

† Field samples were air-dried and machine-ground for five one-minute cycles, and duplicate 10-g subsamples taken for solvent extraction.

Table 12. NG concentrations in 100-increment surface soils samples from a 40-m × 40-m area at FP Lower Fox (Hewitt et al. in prep).

	Sample mass (kg) (< 2 mm)	NG (µg/g)
May 2007		
Field Rep 1	1.21	4.54
Field Rep 2	1.31	4.94
Field Rep 3	1.37	5.22
Field Rep 4	1.24	7.00
Field Rep 5	1.55	62.8
Field Rep 6	1.26	3.98
Field Rep 7	1.28	4.44
Field Rep 8	1.48	10.68
Field Rep 9	1.34	4.94
Field Rep 10	1.38	4.99
	mean	11.4
	median	4.97
7 June 2007		
Field Sample	1.23	5.43
21 June 2007		
Field Rep 1	1.18	4.54
Field Rep 2	0.87	3.38
Field Rep 3	1.22	3.55
	mean	3.82

One of the multi-increment samples taken from the 40-m × 40-m area had an NG concentration of 63 µg/g, one order of magnitude higher than almost all of the other samples (Table 12). Also, one of the triplicate samples from the ~22-m × ~36-m collected on 30 May 2007 had a concentration of 24 µg/g, which was two to three times more than most of the other estimates. Based on these results, we hypothesized that a localized zone of high NG concentration may be located in the overlapping area. To test this hypothesis, we sampled the 20-m × 20-m area in the northeast quadrant of the 40-m × 40-m area (Fig. 10). We divided the area into five cells. Estimated NG concentrations in the multi-increment samples from the cells ranged from 2.7 to 12.3 and the overall mean for the 20-m × 20-m quadrant was 7.2 µg/g (Table 13). Again, this concentration falls within the range of concentrations detected in the larger areas, indicating that we did not find a localized area of high concentration.

Table 13. NG concentrations determined in the surface soils of five cells of a 20-m × 20-m area at FP Lower Fox. Soils were collected on 31 August 2007.

Location	Increments	Sample mass (kg) (<2-mm)	NG (µg/g)	NG (µg/g)	NG mass (µg)
Cell 1	27	0.386	6.77	6.79	2,620
			6.81		
Cell 2	27	0.323	12.2	12.3	3,990
			12.4		
Cell 3	27	0.402	2.47	2.70	1,090
			2.93		
Cell 4	27	0.375	7.85	7.91	2,970
			7.97		
Cell 5	36	0.468	8.01	7.25	3,390
			6.49		
	Total increments	Total soil mass (g)	Overall NG (µg/g)		Total NG mass (µg)
Cells 1–5	144	1954	7.2		14,100

5 Conclusions and Recommendations

This study measured the physical disturbance and energetic residues resulting from the live fire of 120-mm mortars into ERF when it is not covered with ice. The physical disturbance was the formation of craters 0.7 m deep and 2.7 m wide. These crater dimensions are consistent with a detonation 0.7 m below the surface. No explosives residues were detected from the ordnance that functioned properly and produced high-order detonations. TNT, RDX, HMX, and the biological transformation products of TNT were detected in and around the crater produced by the one projectile that did not completely detonate. No solid pieces of Comp B were visible in the surface of the sediment around this crater; however, pieces of energetic residue could be in the mud where the detonation occurred.

Water draining off the mudflats immediately adjacent to areas with explosives residues on the surface had detectable concentrations of RDX and HMX. Within the gully system, RDX was the only detectable analyte in the samples nearest the source. RDX concentrations in water from the gully were 0.1, 0.06 (two samples), and <0.04 µg/L (two samples). Comp B residues were not detectable in the sediments from the drainage gully.

None of the detonations exposed white-phosphorus-contaminated sediments or unexploded ordnance.

The propellant residue expelled from the mortar consisted of partially consumed grains that had nearly the same proportion of nitroglycerin as in the unfired propellant. Surface soil from locations where propellant was burned at the firing points had NG concentrations similar to that observed over larger areas of the firing point (around 10 µg/g).

Based on the results of these studies, live-fire exercises can occur when ERF is not ice-covered, but monitoring of the craters is recommended. This monitoring would include observations of the detonations for the unlikely event that a buried WP round is hit and detonated, producing a smoke cloud. The monitoring should also document, when possible, the occurrence and location of duds and low-order detonations.

Further studies at the firing points to confirm that NG is not accumulating in the surface soil should include sampling of the entire firing point to capture propellant residue no matter where the mortars are positioned. Also, water percolating down through the surface soils should be sampled using lysimeters to monitor the potential migration of NG.

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Appendix A: Crater Photographs

Crater 1

Crater 2 (low order)

Crater 3

Crater 4

Figure A-1. Images of the craters produced by fourteen 120-mm HE mortar projectiles on 6 June 2007. Crater dimensions and UTM coordinates are given in Table 2 and locations are shown on an aerial photograph in Figure 11.

Crater 5

Crater 6

Crater 7

Crater 8

Crater 9

Crater 10

Figure A-1 (cont'd). Images of the craters produced by fourteen 120-mm HE mortar projectiles on 6 June 2007. Crater dimensions and UTM coordinates are given in Table 2 and locations are shown on an aerial photograph in Figure 11.

Crater 11

Crater 12

Crater 13

Crater 14

Figure A-1 (cont'd).

Figure A-2. Hole from 120-mm practice mortar projectile fired into the mudflat on the west side of ERF.

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14. ABSTRACT

Fourteen 120-mm high-explosive mortar projectiles were fired into the Eagle River Flats (ERF) impact area in June 2007 to determine physical disturbance of the mudflat when it is not covered by ice. Currently, ERF is used only when it is covered by ice that prevents disturbance of the underlying sediment. Thirteen of the projectiles functioned normally and produced high-order detonations. The high-order detonation craters averaged 2.7 m in diameter and 0.7 m in depth, and no high-explosives residues from the Comp B filler were detected in the sediments in and around the craters. One projectile partially detonated. The crater was 1.7 m in diameter and 0.7 m in depth. Residues of TNT, RDX, and HMX were detected at tens of parts per million concentrations on the day of the detonation. None of the detonations exposed white-phosphorus-contaminated sediments or unexploded ordnance. Water draining off the mudflats immediately adjacent to areas with explosives residues on the surface had detectable concentrations of RDX, but water within the gully system had energetic concentrations of ≤ 0.06 µg/L. At the firing points, the propellant residue expelled from the mortar consisted of partially consumed grains that had nearly the same proportion of nitroglycerin as in the unfired propellant. Surface soils at the firing points had NG concentrations (around 10 µg/g) similar to those observed during previous sampling events.

15. SUBJECT TERMS

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