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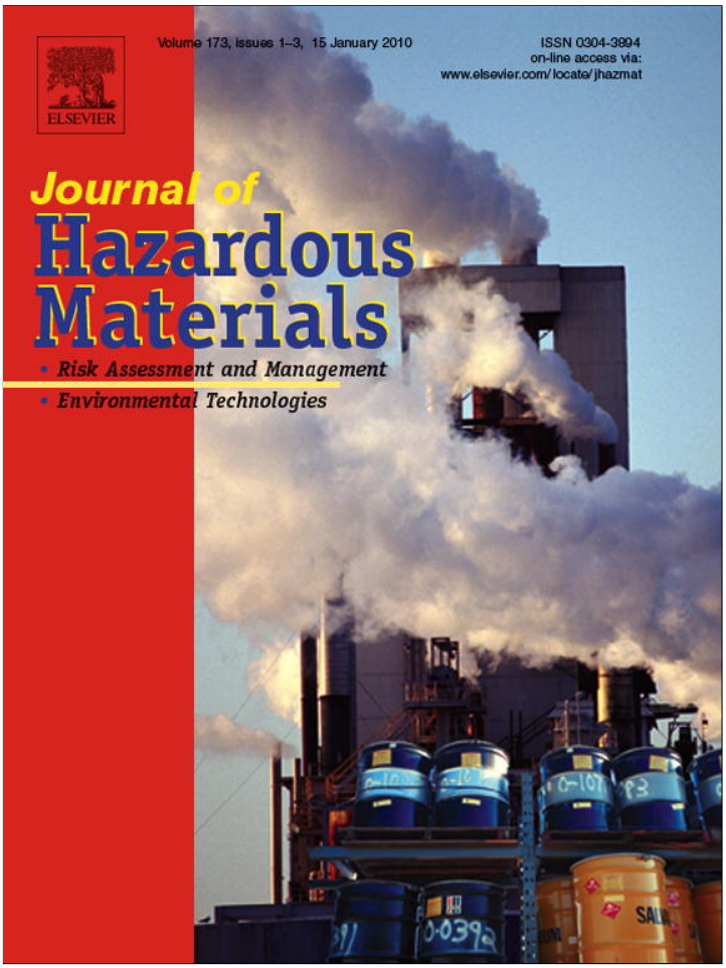

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Energetic residues from field disposal of gun propellants

Michael R. Walsh*, Marianne E. Walsh, Alan D. Hewitt

US Army Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755-1290, USA

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ABSTRACT

Military training with howitzers and mortars produces excess propellant that is burned on the training range and can result in point sources containing high concentrations of unreacted propellant constituents. Propellants contain energetic compounds such as nitroglycerin (NG) and 2,4-dinitrotoluene (2,4-DNT), both of which are found at firing positions and propellant disposal areas. To quantify the mass of residue remaining from the field-expedient disposal of propellants, two mortar propellants and one howitzer propellant were burned under different field conditions. These conditions included burning on a snow pack, at the bottom of a snow pit, and in a pan surrounded by snow for the mortar propellants and on dry and wet sand for the howitzer propellant. For the mortar propellant, the energetics (NG) remaining after burning in the bowl, on frozen ground, and on snow were 0.21%, 5.2% and 18%, respectively. For the howitzer propellant, the difference in energetics (2,4-DNT) remaining after disposal on wet and dry sand was <0.1%, with the overall residue rate of around 1%, similar to that for the mortar propellant burned in an open container. These tests demonstrate that environmental factors, especially in winter, can play a significant role in the effectiveness of field-expedient disposal of propellants.

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1. Introduction

Sustainable use of military training lands requires that adverse impacts to the environment be minimized. The use of munitions will generate energetic compound residues of various types and quantities. This has led to the curtailment of training activities at the Massachusetts Military Reservation after low concentrations of hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX) were detected in the aquifer below the range [1,2]. The discovery of the munition component white phosphorus at the Eagle River Flats impact range on Fort Richardson, Alaska, has led to a long-term cleanup effort and restriction of use of the range since 1990 [3–5]. General impact of training activities on various ranges has been investigated in the past through characterization studies [6–10]. With support from the US Army Garrison, Alaska; the US Department of Defense Strategic Environmental Research and Development Program, and the US Army Environmental Center, research has been conducted on the contributions of specific activities to range energetics loading. Using snow-covered firing positions and snow-and-ice-covered impact ranges [11–13], depositional data has been obtained for several commonly-used small-arms, mortar, and artillery munitions. These studies have provided an insight to the effects of military training, but several sources of energetics residues have not yet been investigated.

When training with howitzers and mortars, the full allotment of propellant charges issued for each round may not be used. Excess propellant at the end of the exercise cannot be returned by the troops. The three common methods of destruction are burning in a disposal structure (burn pan), disposal at an open-burning/open-detonation area, and field-expedient burning at or near the firing point. In this study, we examine the effects of the environment on the disposal in the field of excess mortar and howitzer propellants generated during training exercises. We hypothesized that climatic conditions will affect the efficiency of disposal of propellants. Constituents of interest included 2,4-dinitrotoluene (2,4-DNT) and nitroglycerin (NG).

2. Experimental

2.1. Propellants

Mortar and 105-mm howitzer projectiles are issued with a full complement of propellant increment charges that provide maximum horizontal range for the ordnance. Charges come in a variety of sizes and shapes and may contain different propellants for the same ordnance. Three types of propellant were used in this study (Table 1). The M9 for 81-mm illumination projectiles is a double-base propellant in the form of flakes consisting of 58% nitrocellulose and 40% nitroglycerin. The M45 propellant for 120 mm mortar projectiles is a blend of 100 parts by weight of double-base propellant (86% nitrocellulose and 10% nitroglycerin) in the form of single perforated cylinders and three parts by weight of salt-pellets (77%

* Corresponding author. Tel.: +1 603 646 4363; fax: +1 603 646 4720.
E-mail address: Michael.Walsh@usace.army.mil (M.R. Walsh).

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Table 1
Propellant charges and target analytes for burn experiments.

Ordnance	Propellant charge	Formulation	Mass per charge	Analyte mass per charge
81-mm Illumination	M185	M9	13.3 g	5.31 g NG
120-mm High explosive	M230	M45	130 g	13 g NG
105-mm High explosive	M67	M1	Charge 6: 250 g Charge 7: 405 g	Charge 6: 25 g DNT Charge 7: 41 g DNT

potassium sulfate) (MIL-P-71031). The M1 single-base propellant for 105-mm howitzers is 85% nitrocellulose and 10% DNT. The DNT is primarily 2,4-DNT with a small amount of 2,6-DNT. Nitrocellulose is insoluble in water and is non-toxic. Both nitroglycerin and DNT have sufficient toxicity that preliminary remediation goals have been established by the US Environmental Protection Agency.

2.2. Winter (snow) trials with double-base propellants

Training on military ranges occurs year round. To determine the effect of snow cover on the efficiency of field disposal of excess propellants, we conducted two winter experiments using mortar propellants containing NG. In the first, a small amount of propellant was burned on an undisturbed snow surface. Based on the results of this test, an expanded experiment was conducted involving the disposal of propellants on snow, frozen ground, and in a small stainless steel burn pan. In each of the following experiments, the initial mass of analyte was known, and, following each burn, all of the residues were collected to allow computation of the burn efficiency under different field conditions.

2.2.1. M9 propellant

The first snow surface experiment occurred in January of 2006 at Fort Richardson, Alaska [14]. Following a mortar training exercise, 10 M185 mortar propellant charges containing M9 double-based propellant (5.31 g NG per charge) were piled on the snow and ignited by one of the soldiers. The burned propellant left a bright yellow footprint on the surface of the 30-cm snow cover, with bits of charred charge bag within the area (Fig. 1). Following completion of the burn, all visible residues were collected using a 10-cm by 10-cm scoop from an area encompassing 0.063 m^2. In addition, the snow from a 0.5-m radius annulus surrounding this area was also collected to a depth of 2.5 cm to ensure that all residues were captured. Both snow samples were melted in a nearby field lab where they were vacuum filtered to separate the solids from the aqueous fraction. The 90-mm Ø glass microfiber filters (Whatman grade GF/A) containing the solid residues were stored in refrigerated 120-mL clean amber jars (one sample per jar). A 500-mL aliquot of the aqueous fraction was passed through a solid-phase extraction cartridge (Waters Porpak RDX Sep-Pak, 6 cm^3, 500 mg) to pre-concentrate the energetics. The cartridge was then eluted with 5 mL of acetonitrile (AcN), resulting in a 100:1 concentration of the analytes. The soot samples and a 3.5-mL aliquot of the solid phase extracts were shipped overnight to the analytical chemistry laboratory at the Cold Regions Research and Engineering Laboratory (CRREL) in Hanover, NH, for final processing and analysis. NG was extracted from the solid residues captured on the filters using AcN by shaking each sample with the solvent for 18 h.

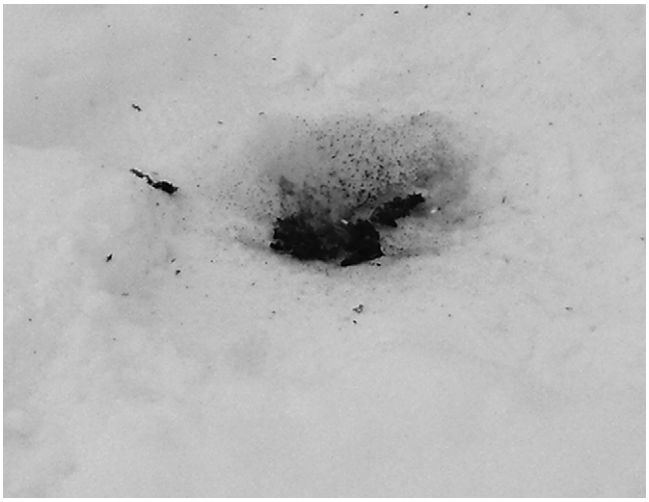

Fig. 1. Residue from the burning of M185 mortar propellant on snow.

2.2.2. M45 propellant

The second experiment was conducted at Fort Richardson in February 2008. A series of tests utilizing 32 M230 propellant charges containing M45 propellant (12.6 ± 0.13 g NG per charge) was performed in a snow-covered, soil-lined basin. Ten charges were placed in a 34-cm Ø by 11-cm deep stainless steel bowl that was placed on the clean snow surface such that the rim was level with the surface. Eleven charges were placed 20 m away on the snow surface, and the final 11 charges placed a further 9 m away on the frozen peaty-loam ground surface at the bottom of a 1-m × 0.5-m excavation through 30 cm of snow (Fig. 2). Ignition of the charges was achieved using an M81 igniter attached to M700 time fuze with the open end of the fuze inserted into a slit made in one of the charges.

2.2.3. Measurement of the mass of NG remaining in the burn bowl

Following the burning of the 10 charges, the bowl and debris within the bowl were placed in clean polyethylene (PE) bags. Both bags were refrigerated before shipment to the laboratory in Hanover, NH. A snow sample was then taken that encompassed the entire area affected by the burn, 0.7 m^2 (Fig. 3), to a depth sufficient to recover all visible residue. This snow residue sample was processed as outlined above. At the analytical lab, the final processing of the burn bowl, burn debris, cartridges, and filters was conducted. The solid residue that was not adhered to the bowl was weighed and placed into a 250-mL wide mouth jar and extracted with 100 mL of AcN after 18 h at 150 rpm on a platform.

The bowl had charred residue adhering to the bottom and sides. To extract the NG from the residue, the following sequential procedure was used. The bowl was rinsed four times with 50-mL aliquots of AcN, which were collected for analysis. The bowl was then scraped and extracted on a shaker table with 20 mL of AcN. The scraped bowl was then rinsed with 50-mL aliquots of AcN, which were collected for analysis. The bowl was next scrubbed several times with glass wool and AcN until 200 mL of AcN was accumulated in a 250-mL jar. The glass wool was added to the jar. A separate final rinse of the bowl with 50-mL aliquots of AcN was done. All samples from these steps were analyzed separately to obtain a total mass of residues adhered to the bowl.

2.2.4. Measurement of the mass of NG remaining from the burns on snow and on frozen ground

The propellant residues from the remaining two burns (snow and frozen ground) were sampled in the spring after snow melt. In

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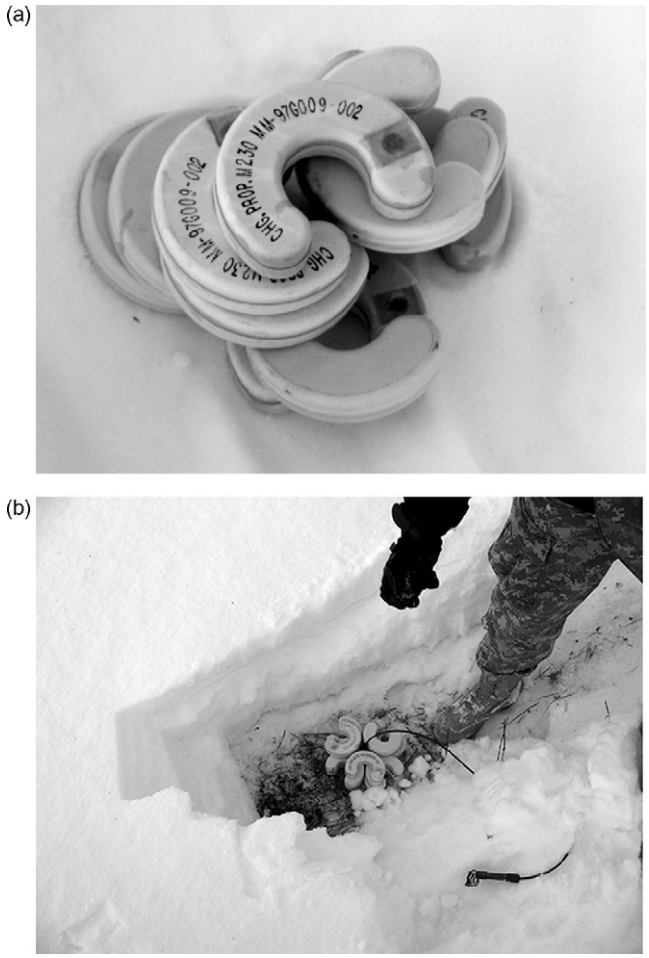

Fig. 2. Setup for snow experiments. (a) Charges on snow. (b) Charges on frozen ground.

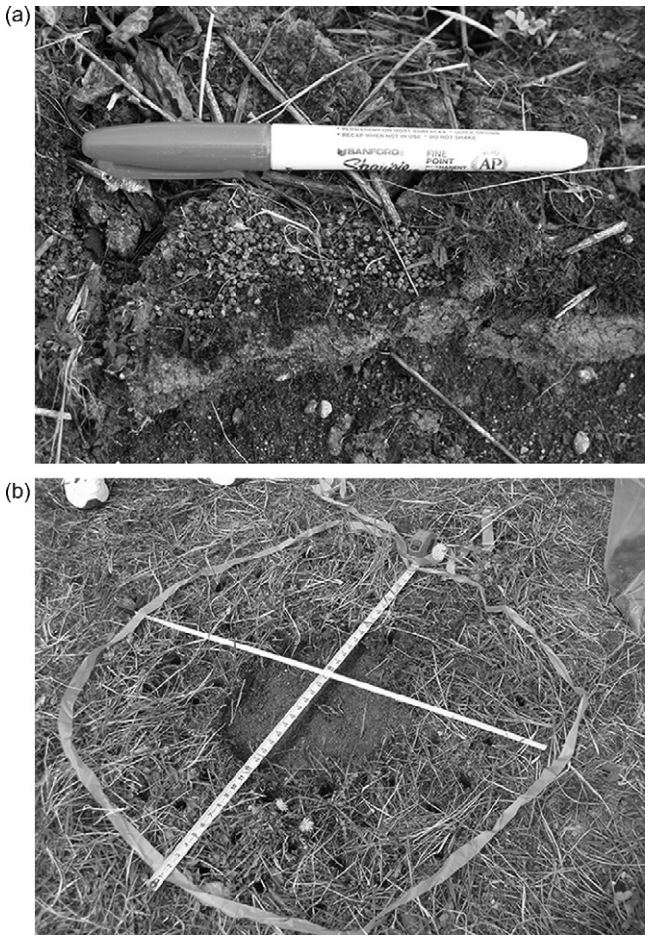

Fig. 4. Snow burn experiment areas in June of 2008. (a) M45 propellant grains on soil surface. (b) June sampling layout.

June, these two burn points were relocated and visually examined. At both locations, intact propellant grains were apparent on the soil surface (Fig. 4a). A series of soil core samples (3-cm Ø × 2.5-cm deep) were collected within the center portion of the two burn points to allow physical and compositional examination of the grains. Then all of the remaining soil within the burn location was collected as a bulk sample with a stainless steel scoop to a depth of 2.5 cm and placed in a polyethylene bag. These bulk samples had a mass of 2600 g (frozen ground burn) and 4600 g (snow burn). In addition, a 0.5-m radius from the center of the these two burn spots were marked using survey tape (Fig. 4b) and replicate 50-increment samples of the surface soils just outside of the excavated area were obtained using a 3-cm corer to a depth of 2.5 cm. The masses of these samples were 830 and 960 g.

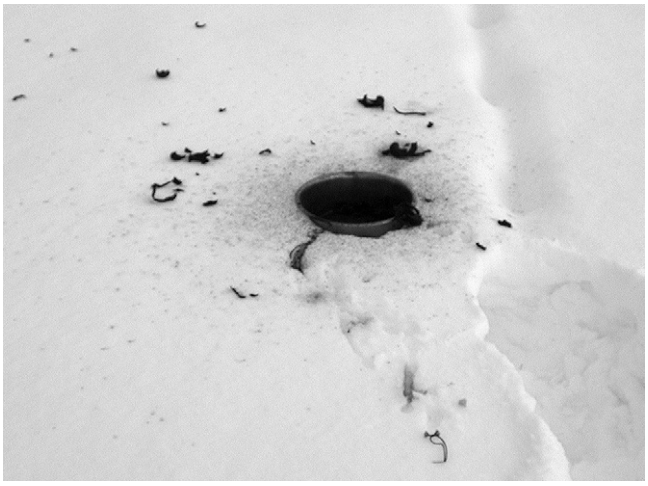

Fig. 3. Aftermath of burn bowl experiment.

Based on the June sampling results, further sampling was conducted in July. At each burn point, annuli of 0.5–1.0 m and 1.0–1.5 m were marked with survey tape (Fig. 5a), and within each annulus duplicate multi-increment samples were taken. Samples were collected using a 4.75-cm diameter corer to a depth of 2.5 cm, the number of increments ranging from 20 to 26. Closer examination of the burn point centers revealed that some grain clusters had been missed at both locations in the June sampling, so these grains and 1.5 cm of the underlying soil were collected. The mass of these samples ranged from 180 to 280 g, grains inclusive. Three soil profile samples were then taken in 2-cm lifts from the surface through the peaty loam, one each in the middle of the burn locations where the top 2.5 cm had been removed in June and one beneath the location where propellant grains were removed in July (Fig. 5b).

2.3. Summer (Soil) trials with single-base propellant

In July of 2008, we evaluated the burning of excess 105-mm howitzer propellant containing 2,4-DNT following a training exercise at Donnelly Training Area outside of Delta Junction, AK. This experiment was performed atop a rectangular bed of clean sand to

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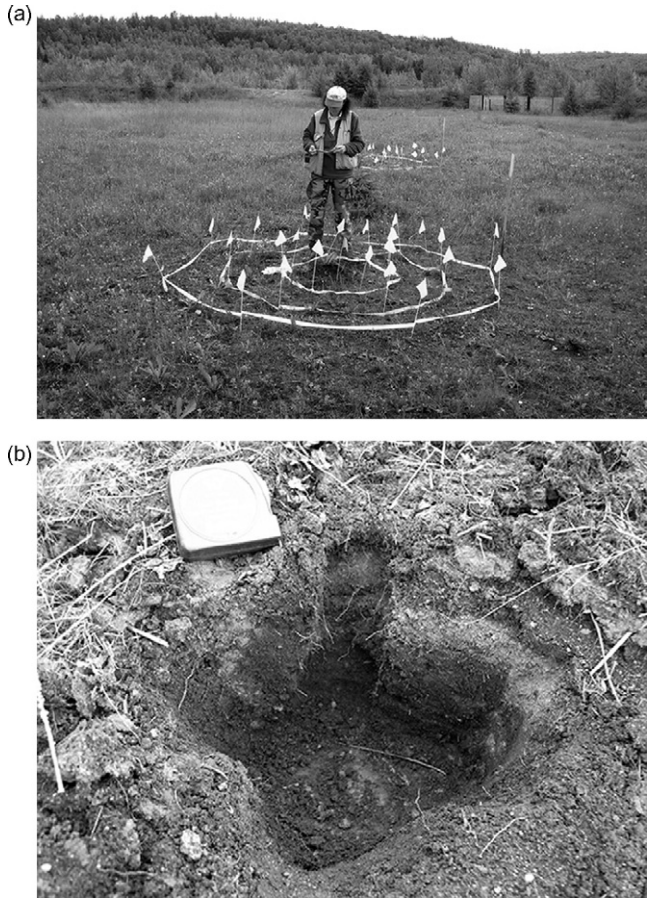

Fig. 5. Sampled burn point where M45 propellant was burned on frozen ground (snow removed). (a) July sampling layout. (b) Soil profile pit below area in Fig. 4.

avoid cross contamination with previous activities. Ten bags of M1 single-based multi-perforated propellant, five bags each of charges 6 and 7 (327.5 g 2,4-DNT total), were overlapped in a line on two separate beds of clean sand. In the first test, the sand was dry. In the second, the sand was wetted with ultra-filtered water prior to setting the bags on the sand bed (Fig. 6a). The sand beds were approximately 1.8-m long × 0.4-m wide by 4-cm deep. To initiate the burn, an artilleryman used a butane lighter to light loose grains from a ruptured bag for the wetted-sand test and an end bag for the dry-sand test. For both test cells, the burn areas were sampled by removing all the discolored sand to a depth of about 1.5 cm (Fig. 6b). A sample was collected around the perimeter of the burn area and a second lift of 1.5 cm was collected beneath the first burn area sample. Each sample was placed in a clean PE bag for later processing and analysis.

At the lab, the >2-mm fraction was sieved out of each sample and retained. The <2-mm fraction was then ground, subsampled, and analyzed according to EPA SW 846 Method 8330B [15]. The >2-mm fraction was extracted using whole sample extraction and analyzed. A 500-g pre-burn sample of the sand used to make the raised beds was also analyzed following grinding, subsampling, and extraction with AcN.

2.4. NG content of M9 and M45 propellant and 2,4-DNT content in M1 propellant

To determine the actual amount of NG in the double base grains of the M9 and M45 propellant and 2,4-DNT in the single-based M1 propellant, approximately 100 mg of unburned grains of each type of propellant were dissolved AcN. The M45 grains that were isolated

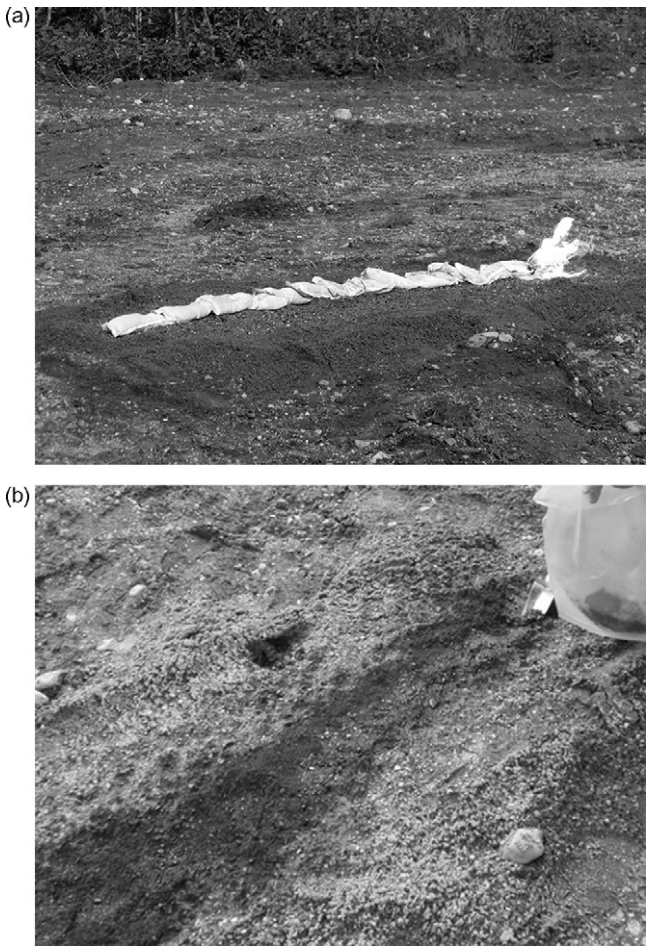

Fig. 6. M1 propellant burn on wetted sand. (a) Start of burn of the 10 bags on wetted sand. (b) Sampling after the burn.

from cores taken in June at the frozen ground and snow-covered burn points were also dissolved in AcN. The masses of NG or 2,4-DNT were determined by HPLC analysis.

2.5. Analytical methods

2.5.1. EXPRAY

An EXPRAY kit (Plexus Scientific Corporation) was used to test for the presence of NG or 2,4-DNT in the AcN extracts and to estimate the dilution needed prior to HPLC analysis [16] (Note this will also respond to NC). One drop of each extract was placed on the paper supplied with the EXPRAY kit. Then the paper was sprayed sequentially with the first two reagents. The first reagent is alkaline and forms a blue–green product if 2,4-DNT is present. The first reagent in combination with the second reagent forms nitrate ions from NG, resulting in a pink colored product as a result of Griess reaction. The color intensity is proportional to the concentration of 2,4-DNT or NG (and other nitroaromatic, nitrate esters, and nitramines, if present).

2.5.2. HPLC

Prior to analysis, each extract was diluted with AcN based on the intensity of the color from the EXPRAY test so that the injected concentration would be less than 10 mg/L. The AcN was then mixed with reagent grade water (1/3, v/v) and filtered through a Millex-FH (Millipore, PTFE, 0.45 μm) filter unit.

Determinations were made on a modular system from Thermo Electron Corporation composed of a Finnigan Spectra SYSTEM

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Table 2
Analysis results for propellant grains prior to burn tests.

Propellant	Actual mass of grains (mg)	Analyte mass (mg)	Analyte mass (%)	Analyte mass specified (%)
M9	117.3	46 (NG)	39.2	40 ± 1.5
M45	114.5	11.9 (NG)	10.4	10 ± 2
M1	115.3 (one grain)	11.2 (DNTs)	9.7	10 ± 2

Model P4000 pump, a Finnigan SpectraSYSTEM UV2000 dual wavelength UV/vis absorbance detector (cell path 1 cm) set at 210 nm (to detect NG) and 254 nm (for other energetics), 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 for NG and 2,4-DNT were prepared from analytical reference materials obtained from Restek Corporation (Bellefonte, PA). The concentration of each analyte was 10 mg/mL in AcN in the solutions used to calibrate the HPLC-UV.

3. Results and discussion

3.1. NG content of M9 and M45 propellant and 2,4-DNT content in M1 propellant

Unfired propellant grains were analyzed to determine if the analytes of interest were present in specified concentrations. Each type of propellant was found to be within military specifications for NG or DNT content (Table 2).

3.2. Winter tests (double-base propellants)

3.2.1. M9 propellant

The results of the analysis of the 81-mm mortar cartridge propellant burn are presented in Table 3. Characterization of the site prior to the test indicated a residue level of <200 μg NG/m^2 from mortar firing during the previous two days. Because of the small quantity involved in the test, the propellant burned only a few centimeters into the snow. Approximately 1.7% of the NG in the original charges remained after disposal. This is equivalent to about 87 mg NG per charge. The background concentration of NG due to the firing exercise was insignificant compared to the results of the burn.

3.2.2. M45 propellant

As discussed earlier, the 120-mm mortar cartridge propellant burn experiment involved several sampling deployments. These included the immediate post-burn sampling and analysis of the burn bowl residues, the initial soil sampling in June 2008, and the follow-up soil sampling in July. The June and July sampling addressed the snow and frozen ground burn residues.

3.2.3. NG remaining in the burn bowl

The burn bowl and loose solid residues were processed as outlined in Section 2. The mass of loose residues within the bowl contained 2.3 mg of NG. Residues that were scraped from the bowl contained 23 mg of NG. The bowl cleaning process yielded an additional 48 mg of NG, with 0.26 mg NG recovered with the final rinse. The snow surrounding the burn bowl contained 200 mg of NG. The total mass recovered was 270 mg, 73% of which was found outside the burn bowl. The per-charge NG residues are thus 27 mg/charge, or 0.21% of the original load.

Table 3
Results of analyses for NG following disposal of M185 propellant charges on snow.

Sample	DU[b] size (m^2)	Recovered mass (mg)	Recovered mass (%)
Background[a]	0.563	0.11	0.01
Burn point	0.063	840	1.6
Annulus	0.50	33	0.06

[a] Background mass estimated from background concentration of 200 μg/m^2.
[b] Decision unit (total area from which sample was taken).

3.2.4. NG remaining from the burns on snow and on frozen ground

The mass of NG remaining after the snow and frozen soil burns indicates that large quantities of propellant remained after both these experiments. The results are divided into three zones. The center encompasses the burn areas and the surrounding area out to 0.5 m. This zone contained the recovered propellant grains. The two annuli surround the central area. The recovered mass per charge and percentage of mass per charge recovered for all three experiments with M45 propellant, including the burn bowl, is shown in Table 4. The residue from the propellant that was burned on the snow pack had 18% of the initial NG mass, indicating a very inefficient burn. The residue from the burn on frozen ground had 5% of the initial NG mass. Both of these unconfined burns left numerous propellant grains on the soil surface. The burn bowl experiment, as stated above, had residues containing 0.21% of the original mass of NG. The relative percent differences (RPDs) for the four annular samples taken around the snow and frozen ground burns averaged 49%, not unusual when trying to measure areas containing a few propellant grains kicked out during the deflagration process.

3.2.5. Soil depth profiles

Propellant grains from the tests conducted in February remained on the ground through June and, for some grains, July. Three soil profile samples were taken to determine if any transport had occurred during the initial snowmelt and summer months. One profile was taken in the center of each burn location that was sam-

Table 4
Results of M45 propellant burn experiments.

Sample description	NG (mg)
Burn bowl	
Within bowl	74
Residue on snow surrounding bowl	200
Total NG mass remaining for bowl burn	270
Initial NG mass in 10 M45 charges	130,000
NG recovered (%)	0.21
Frozen soil burn	
Center 0.5 m radius	7,200
Annulus 0.5–1.0 m	140
Annulus 1.0–1.5 m	<10
Total NG mass remaining for frozen soil burn	7,300
Initial NG mass in 11 M45 charges	140,000
NG recovered (%)	5.2%
Snow burn	
Center 0.5 m radius	22,000
Annulus 0.5–1.0 m	2,100
Annulus 1.0–1.5 m	560
Total NG mass remaining for snow burn	25,000
Initial NG mass in 11 M45 charges	140,000
NG recovered (%)	18

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Table 5
Results of analyses of soil column profiles for M45 propellant burn.

Sample description	NG soil concentration (μg/g)	Total NG recovered (mg)
Frozen soil burn–center of pit		
Original surface sample (top 2.5 cm)	990	16[a]
0–2 cm from new surface	52	2.2
2–4 cm	<0.1	
4–6 cm	<0.1	
6–8 cm	<0.1	
8–10 cm	<0.1	
Total mass for profile samples		2.2
Snow burn–center of pit		
Original surface sample (top 2.5 cm)	3100	50[a]
0–2 cm from new surface	23	0.60
2–4 cm	<0.1	
4–6 cm	<0.1	
6–8 cm	<0.1	
8–10 cm	<0.1	
10–12 cm	<0.1	
12–14 cm	<0.1	
Total mass for profile samples		0.60
Snow burn–below grain mass		
Original surface sample (top 1.5 cm)	2500	24[a]
0–2 cm from new surface	180	5.8
2–4 cm	46	1.3
4–6 cm	9.0	0.30
6–8 cm	<0.1	
8–10 cm	<0.1	
10–12 cm	<0.1	
12–14 cm	<0.1	
Total mass for profile samples		7.4

Note: Original surface samples contained propellant grains.
[a] Estimated for equivalent sample area as taken for profile lifts (2-cm × 2-cm).

pled in June and a third was taken beneath a cluster of grains remaining after the June sampling event. Results are shown in Table 5. The NG concentrations were in the μg/g range for the shallowest soil samples. The mass that is present in these soil samples was small compared to that in the surface 1.5 or 2.5-cm bulk samples that were taken above the profile locations. The profile taken beneath the cluster of grains at the snow burn location gives an extended view of the effect of weathering of the propellant. The mass of NG found below the removed surface grains and soil in July is 7.4 mg, much higher than the 0.60 mg combined mass of NG in the profile below the area where the surface had been removed a month earlier. On a proportional basis, 1.2% of the NG in the surface propellant grains had leached into the soil column by June and 31% of the NG in the surface grains had leached into the soil column by July. Although this is only a rough estimate of the effect of the additional weathering of the surface grains and residues, it indicates that leaching of NG into an organic surface soil will occur.

3.2.6. NG in unconsumed propellant grains

Finally, we looked at the mass of NG in the grains remaining on the soil surface. In June, grains were isolated from three core samples from the snow burn and frozen ground burn tests (3-cm Ø). The grains were counted and analyzed for percent NG remaining. Table 6 shows the results of the analyses. The NG mass in the weathered grains was 58% of the mass expected for unburned grains for the two experiments

It is interesting to note that the mass of NG recovered from a single 3-cm Ø core sample can be quite high. Six 2.5-cm deep core samples were examined for the number of intact grains on the surface, the NG content in the weathered grains, and the NG mass in the soil (Table 7). The recovered NG averaged 95 mg per core sample, with sample concentrations averaging 5300 μg/g, two thirds of which is attributable to the unburned propellant grains on the surface. This average concentration is almost three orders of magnitude higher than the concentrations found on a nearby firing point heavily used by units training with the 120-mm mortar using M45 propellant at Fort Richardson (8.7 μg/g [17]). The effect of a single core or increment containing burn point propellant grains can have a pronounced effect on a multi-increment sample collected to characterize a firing point. The effect on a discrete sample is even greater.

3.3. Summer tests (single-base propellant)

Samples for the two test burns with M1 propellant were processed and analyzed in two steps. The <2-mm fraction was ground, sub-sampled, extracted, and analyzed. The >2-mm fraction was extracted using whole-sample extraction and then analyzed. A summary of the results is given in Table 8. From this table, the total recovered DNT is 3100 mg for the burn on dry sand and 3300 mg for the burn on wet sand. Of these totals, 18–19% of the total recovered DNT mass is from the >2 mm sieved fraction (see "% of total" in last column, Table 8). For the dry burn, 87% of the mass was found in the initial sampling of the plume, 13% was recovered from the subsurface samples (second lift), and <0.5% was recovered from outside the initial sampled area. For the wet burn, the corresponding averages were 73%, 26%, and <0.5%, respectively. These results

Table 6
Results of analyses of propellant grains collected from sample cores.

Sample	# Grains	Theoretical NG mass (mg)[a]	NG mass recovered (mg)	% Mass recovered
Frozen ground	977	391	230	58%
Snow burn	741	300	170	57%

[a] Based on specification that each grain is 10% NG and the grains are 4 mg each.

Table 7
Results of analyses of core samples containing propellant grains.

Core #	Grains in sample	Mass of grains (g)	NG in grains (mg)	Sample soil mass (g)	NG in soils (mg)	Total NG mass: soils + grains (mg)	Total NG concentration: soils + grains (μg/g)
1-Frozen ground	366	1.5	84	17	42	120	6800
2-Frozen ground	351	1.4	84	16	19	100	6000
3-Frozen ground	260	1.0	59	19	22	81	4100
1-Snow burn	330	1.3	64	16	45	110	6200
2-snow burn	140	0.56	37	18	25	62	3400
3-Snow burn	271	1.1	67	16	21	89	5100

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Table 8
Results of analyses of M1 propellant burn tests.

Sample	Fraction	Recovered mass 2,4-DNT (mg)	Recovered mass 2,6-DNT (mg)	Total recovered mass: DNT (mg)	Total % mass recovered: DNT
Background	<2 mm	1.6	0.064	1.7	
	>2 mm	0.37	0.013	0.38	
	Totals	2.0	0.077	2.1	
Dry Burn	<2 mm	2400	103	2500	(81% of total)
	>2 mm	570	28	600	(19% of total)
	Totals	3000	130	3100	0.94% of original mass
Wet Burn	<2 mm	2600	98	2700	(82% of total)
	>2 mm	550	27	580	(18% of total)
	Totals	3100	130	3300	0.99% of original mass

demonstrate the importance of thoroughly sampling the test area. Combined DNT in the residues is 0.94% of the original DNT amount in the propellant tested for the dry burn and 0.99% for the wet burn.

The background sample taken for the 105-mm M1 propellant burn test showed a slight amount of analyte, <2 mg of 2,4-DNT and <0.1 mg 2,6-DNT in a 430-g sample. The source of these analytes was found to be from cross-contamination due to co-storage of the background and residues samples at the analytical laboratory. The background levels for DNT are thus <0.07% for both burns.

3.4. Quality assurance procedures

Over the course of these experiments, many QA procedures were conducted to ensure the quality of the data. Background (baseline) samples were taken where necessary to ensure that levels of background contamination were not significant. Multi-increment sampling was carried out to better characterize larger decision units. Where discrete (whole area or bulk) samples were taken, subsurface samples and samples outside the burn areas were also sometimes obtained. In the processing lab, replicate subsamples of the ground samples and aqueous fractions of the snow samples were analyzed. Whole-sample extraction was done on the >2-mm fraction for the 105 propellant burn tests. In the analytical lab, blanks and spikes were run to verify instrument output. The split samples were run to verify repeatability. All QA procedure results indicate sampling and data fidelity.

4. Discussion

The impact of environmental factors on the efficiency of field-expedient disposal of excess propellants from training exercises is quite significant. The NG mass remaining following burning of M45 propellant on snow and on frozen ground surrounded by snow was much larger than expected, based on the small-quantity test conducted in 2006 with M185 mortar propellant. However, the original test did not generate the heat and violence of burning seen with the larger-quantity tests. There is a phenomenon that occurs that we term the "popcorn effect" in which deflagrating propellant will eject material during the disposal process. This was evident during the burn bowl test in which over 70% of the recovered energetics fell outside the bowl. Ejected unburned propellant grains can constitute an accumulative environmental hazard, especially with propellants that contain DNT, RDX, or heavy metals such as lead. We often find propellant grains scattered about fixed burn points, even those with burn pans and especially when improper disposal methods are employed. The presence of propellant grains can also pose health and security risks. Even a small amount of propellant, when ignited, will burn furiously, posing a risk to the unaware. Larger quantities pose a security risk, as confined propellants when initiated can detonate.

The summer test with single-base propellant containing DNT indicates the surface conditions are not as critical during summer as during winter. The wetted surface had only a minimal effect on the efficiency of the burn. Although the two types of propellants cannot be directly compared because of their physical and compositional differences, it can be noted that both types of propellants burned efficiently (>99% consumption of analyte) when disposed of on a surface not influenced by snow.

The single-base propellant tests were conducted near a badly damaged burn pan. Many propellant grains of different sizes were recovered around the pan that had either been spilled or ejected from the pan during disposal. In the opinion of our unexploded ordnance technician, there was enough propellant recovered to construct a small improvised explosive device.

5. Conclusions

This set of experiments demonstrates that environmental factors can have a strong effect on the efficacy of the field-expedient disposal of excess propellants. The difference in recovery rates from double-base mortar propellant disposed of in a burn pan, on frozen soil surrounded by snow, and on snow is 0.21%, 5%, and 18% of the original NG mass, an order of magnitude between each condition. The effect of wetted soils beneath burning single-base howitzer propellant in summer is not significant, with residues of 0.94% of the original DNT mass recovered after the burn on dry soil versus 0.99% recovered following burning on wetted soil. The use of a functional burn pan is critical in the disposal of propellants in winter and will help contain ejected propellant grains in all seasons. The presence of large quantities of unburned propellants at disposal sites can constitute an environmental hazard from the leaching of energetics into the groundwater over time. In addition, the accumulation of unburned grains at disposal sites will constitute a security risk.

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