ERDC/CRREL TR-07-17

Cold Regions Research
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Development Center

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Prepared for Strategic Environmental Research and Development Program (SERDP)
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**Abstract:** Military live-fire training missions utilize a variety of energetic materials that are never completely consumed during firing. In February 2007, the U.S. Army Cold Regions Research and Engineering Laboratory teamed with the Vermont National Guard at Camp Ethan Allen to conduct tests to determine the propellant residues deposition related to the firing of small arms. Samples were collected from the snow surface at the firing points for 5.56-, 7.62-, 9-, and 12.7-mm (0.50-cal.) weapons, as well as from areas up to 40 m downrange. Six tests were conducted utilizing five weapon systems. Samples were analyzed to derive an estimate of the mass of unreacted energetics deposited from each activity. The areas sampled at the 5.56-mm firing points contained 1.8 and 1.3 mg NG (1.1% and 0.80% original mass) per round, the 7.62-mm firing point contained 1.5 mg NG and 0.0018-mg DNT (0.56% and 0.048% original mass) per round, the 9-mm firing point contained 2.1-mg NG (5.4% original mass) per round, and the 12.7-mm firing points averaged 11 mg NG (0.73% original mass) per round. These results indicate that although consumption rates for this class of ammunition are high, accumulation of energetic residues should be considered for range sustainment programs.

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# Preface

This report was prepared by Michael R. Walsh, Engineering Resources Branch (ERB), U.S. Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire; Marianne E. Walsh, Susan R. Bigl, Nancy M. Perron, and Alan D. Hewitt, Environmental Sciences Branch (ESB), CRREL; and Dennis J. Lambert, ERB, CRREL.

Fieldwork on active ranges is a difficult and complicated matter and requires the cooperation and assistance of many people. The authors thank the soldiers and officers of the Vermont National Guard for access to their ranges, help with ammunition coordination, and field assistance with the weapons, enabling the gathering of valuable samples upon which this research is based. They especially thank LTC Thomas Cahalan for his interest and support of their field work in Vermont. The authors also thank Nick Collins for setting up the initial contacts at Camp Ethan Allen, Vermont, as well as coordinating the transfer of ammunition. Internal manuscript review was provided by Dr. Clarence Grant and Dr. Thomas Jenkins. Editing was done by David Cate. Funding was provided by Dr. Thomas Jenkins through SERDP Project ER-1481.

This report was prepared under the general supervision of Thomas J. Tantillo, Chief, Engineering Resources Branch; Dr. Lance Hansen, Acting Deputy Director; and Dr. Robert E. Davis, Director, CRREL.

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

# 1 Introduction

Military live-fire training missions utilize a variety of energetic materials. In the case of small arms, cartridges are issued with various types and configurations of propellants, depending on the type and age of the round. These energetic materials are never completely consumed during firing and have the potential to accumulate on military training ranges where they are used (Pennington et al. 2002, Hewitt et al. 2003, Jenkins et al. 2005). In February 2007, CRREL teamed with the Vermont National Guard to conduct two series of tests utilizing small arms. The objective of this field work was to determine mass loadings at firing points for the 5.56-mm automatic rifle and machine gun, the 7.62-mm machine gun, the 9-mm pistol, and the 12.7-mm (0.50-cal.) machine gun, all standard weapon systems of the U.S. Army and many foreign military inventories. The results of these live-fire tests will enable us to obtain controlled baseline data on a per-round basis for commonly used ammunition expended at firing ranges during training exercises. These data can be used by the military in general and range managers in particular in planning range use and maintenance while considering the environmental impact of this type of activity.

# 2 Background

The examination of firing points as a source of energetic residues is a recent thrust in range sustainability research. Studies funded by U.S. Army Alaska (Soil and Water Quality Monitoring Fund) at Fort Wainwright's Donnelly Training Area (DTA) starting in 2000 (Walsh et al. 2001) indicated that propellant-related energetic compounds were accumulating at heavily used indirect- and direct-fire firing points. Further research in 2001 and 2002 (Walsh et al. 2004) reinforced the original indications, with the propellant constituents nitroglycerin (NG) and 2,4-dinitrotoluene (DNT) recovered at several firing points. The State of Alaska lists DNT as a hazardous substance.

In 2002, SERDP funded research at Fort Richardson in Alaska to estimate residue deposition from the live-fire detonation of 105-mm and 81-mm high-explosive (Composition B) projectiles. Following the firing of the 105-mm howitzers, residues were collected from the snow-covered area in front of one of the guns. The results indicated concentrations of propellant residues much higher than found at the impact areas (Hewitt et al. 2003, Walsh et al. 2004, 2005b, 2007, Ramsey et al. in prep).

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

The accumulated information led to the submission of a proposal to SERDP (ER-1481) to formally investigate military range firing points. In January 2006, tests were conducted in Alaska utilizing 60-mm and 81-mm mortars (Walsh et al. 2006). This completed a series of tests on energetics residues deposition on a per-round basis for various indirect-fire weapon systems. Residues accumulation data for several types of firing points have also been reported by Jenkins et al. (2007). Our attention has now shifted to small arms ranges, where firing points are more defined, concentrated, and heavily used. This study examines the deposition rates for common small arms ammunition.

# 3 Field Tests

## Field Site

The tests were conducted at Camp Ethan Allen (CEA), Jericho, Vermont. Two ranges were utilized. Range 6-2 is a small range sheltered on three sides by trees and berms, affording some protection from the winds that frequent the base (Fig. 1). The 5.56-, 7.62-, and 9-mm weapon systems were fired on this range. Range 6-5 is located in a large open area with a long, cleared downrange area. The 12.7-mm machine gun was fired on this range. The 6-5 range was a more difficult area to conduct tests as it is exposed to the wind, but it is the only available range at CEA for the large machine gun.

Figure 1. Looking downrange at Range 6.2, Camp Ethan Allen, VT.

During these tests, daytime temperatures ranged from –16°C to –7°C. Winds were variable at 0–4 m/s with partially overcast skies. Firing was conducted only when winds diminished below 1 m/s. The snow depth at the firing points ranged from 33 to 60 cm, with depths exceeding 120 cm downrange at Range 6.5. No precipitation accumulated during testing although some light drifting occurred, especially during the firing and sampling of the first 12.7-mm firing point.

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

| Weapon | Munition (Mil / DODIC) | Propellant | Constituent | Constituent load (mg/ % of total load) |
|---|---|---|---|---|
| M16 Automatic Rifle (5.56-mm) | M855 / A059 (Ball) | WC844 | NG | 164 (9.2%)† |
| M249 Machine Gun (5.56-mm) | M27 / A059 (Linked) | | | |
| | M855 / A059 (Ball) | WC844 | NG | 189 (12.9%) |
| | M856 / A063 (Tracer) | WC844 | NG | 161.5 (12.6%) |
| M60 Machine Gun (7.62-mm) | M13 / A143 (Linked) | | | |
| | M80 / A143 (Ball) | WC846 | NG | 267 (10.2%)† |
| | | | DNT | 3.7 (0.14%)† |
| M9 Pistol (9-mm) | M882 / AA49 (Ball) | WPR289 | NG* | 39.5 (12.2%) |
| M2HB Machine Gun (12.7-mm / .50 Cal.) | M9 / A557(Linked) | | | |
| | M33 / A552 (Ball) | WC860 | NG | 1478 (9.7%)† |
| | M17 / A571 (Tracer) | WC857 | NG | 1570 (11 %) |

* Up to 1% DNT specified. None detected when raw propellant analyzed.

† Data from laboratory analyses. All others are range medians.

Refs: See Appendix A

## Munitions

Five types of munitions were fired during our tests (Table 1). The 5.56-mm test munitions both utilized the M855 ball cartridge, and the tests run with the M249 Squad Automatic Weapon (SAW, a machine gun) utilized the M856 tracer as every fifth round. Both types of cartridges contained WC844 propellant (U.S. Army 1994). The constituent of interest was nitroglycerin (NG). One hundred rounds were fired with the M16 automatic rifle, and 200 rounds were fired with the SAW. The 7.62-mm machine gun fired 100 M80 ball rounds containing WC846 propellant. This propellant contains NG and up to 1% DNT as an artifact of the reworked propellant. For the 9-mm pistol tests, 100 M882 ball cartridges with WPR289 propellant were fired. The propellant contains NG and up to 1% DNT, although no DNT was detected in an analysis of the raw propellant. For the 12.7-mm machine gun, we fired 95 and 100 rounds of M9 linked ammunition containing four M33 ball rounds for every one M17 tracer round. The respective cartridge propellants were WC860 and WC857. The propellant constituent of interest for both rounds was NG. Grains of raw propellant for both charges were analyzed for NG and DNT as a check on the specifications given for each round, as we could find only constituent ranges for some of the munitions. Although nitrocellulose (NC) is the major constituent for all these propellants (67–78% of the total load), we did not analyze for it as it is not soluble and is not a constituent of concern.

In addition, there is no reliable method for analyzing for NC in environmental samples. Appendix A contains complete munitions data for these tests.

## Tests

Our tests were conducted over the course of two separate deployments, the first on 9 February and the second on 23 February 2007. We were assisted during both series of tests by the Vermont National Guard, who scheduled ranges, provided the weapon systems and ammunition, and manned the guns for the firings.

Prior to the tests, background snow samples were collected at each range. Paths to firing points were packed out and meteorological conditions checked with a Nielsen-Kellerman Kestrel 3000. A single round was obtained prior to firing for the later analysis of the raw propellant to verify the propellant constituent loads.

The weapons were set up with a minimum of disturbance to the surrounding snow. Traffic around the firing points was kept to a minimum and restricted to established paths. The guns were elevated off the snow surface just high enough to minimize the surface effects of the muzzle blast (Fig. 2). This minimized wind velocity at the muzzle and reduced the dispersion of the non-ballistic material that comprised the plume. The minimum distance between firing positions was 10 m. The 9-mm pistol, 5.56-mm automatic rifle, and 7.62-mm machine gun were fired during the

Figure 2. Firing the M16 5.56-mm automatic rifle at Range 6.2, Camp Ethan Allen, VT.

first deployment in that order. Tests were conducted progressively upwind to avoid cross-contamination of the sampled areas. Two 12.7-mm and a 5.56-mm machine gun tests were conducted during the second deployment. Tests were conducted on different ranges.

For each test 100 rounds were fired, the exceptions being 200 rounds for the 5.56-mm machine gun and 95 for one of the 12.7-mm tests. The weapon system and any dunnage were returned to the staging area, and any cartridge cases that were lying on the surface were collected. One individual, common to all tests, then walked the outline of the visible plume. Downrange 2- × 6-m transect locations at 10, 20, 30, and 40 m from the firing point, depending on the test, were then measured out and the transects outlined. The areas sampled for each test are given in Table 2, listed in chronological order.

Table 2. Areas sampled for small-arms tests.

| Test | Firing Position L × W (m) | Outside-the-Plume (OTP) | Transects |
|---|---|---|---|
| 9-mm pistol | 4.5 × 3.5 | 0.8-m Width | 10, 20, & 30 m |
| 5.56-mm automatic rifle | 7.6 × 7 | 1.0-m Width | 10, 20, & 30 m |
| 5.56-mm machine gun | 12.3 × 9.1 | 1.0-m Width | 10, 20, & 30 m |
| 7.62-mm machine gun | 9.2 × 10 | 1.0-m Width | 20, 30, & 40 m |
| 12.7-mm machine gun | 19.7 × 19.4 | 1.5-m Width | — |
| 12.7-mm machine gun | 20.1 × 15.7 | 1.5-m Width | 20, 30, & 40 m |

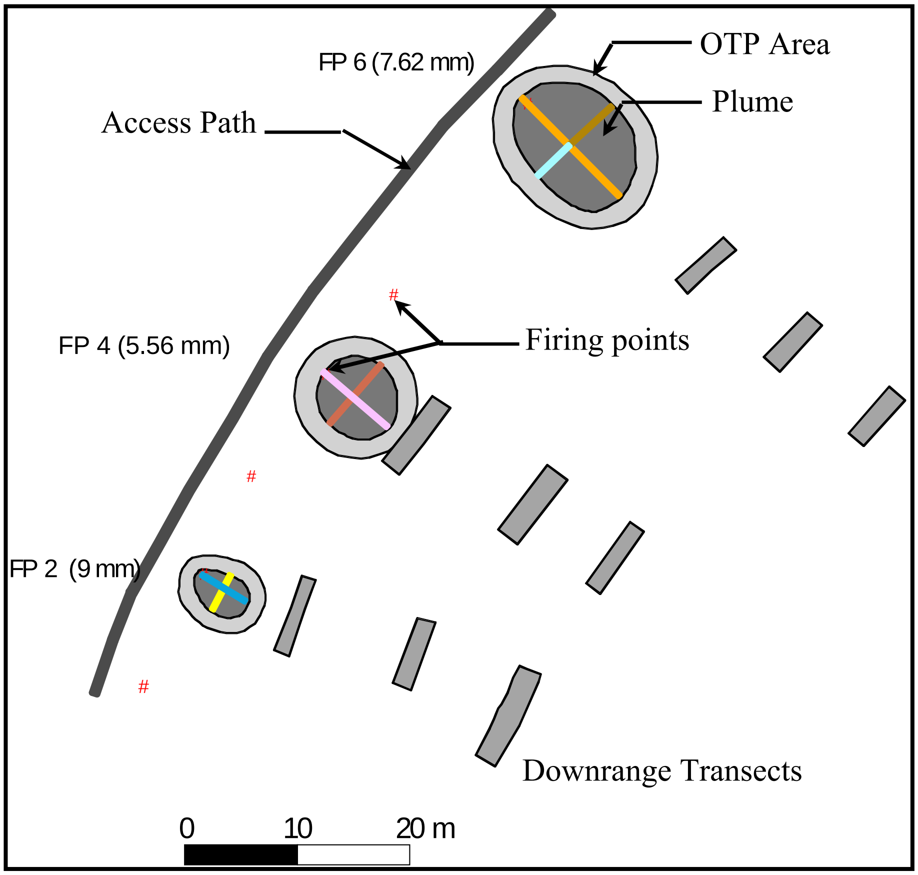
## Sampling Method

Sampling was done on a fresh snow surface following the protocol established by Walsh et al. (2005a). Briefly, 25–90 increments (10 × 10 × 2 cm deep) of surface snow are collected to make up a single sample within an area (inside the demarcated plume, outside the plume, within transects, etc.) until the area is representatively sampled (Fig. 3). The increments for a given sample are collected in a single, clean polyethylene bag to make up a multi-increment (MI) sample. Triplicate MI sampling allowed us to test and compensate for uncertainty derived from the small total area collected from within each decision unit, typically less than 1 $m^2$.

To estimate the mass of energetic residues, we need to know the area over which the energetic material is deposited and the average concentration for that area. A critical assumption is that the plume represents the major area of deposition. The plume is composed of deflagration products, and its depositional pattern will be affected by wind. However, because there is no other way to estimate the area of deposition, we assume that most residues are deposited within the plume. This assumption was tested by taking multi-increment samples in concentric annuli around the outside of the plume (OTP). The objectives of OTP sampling are to ensure that the plume was adequately outlined and to determine how much, if any, of the unconsumed energetics are measurable outside of the plume. Samples were obtained for annuli at varying distances (0–0.8 to 0–1.5 m) surrounding the plume edge.

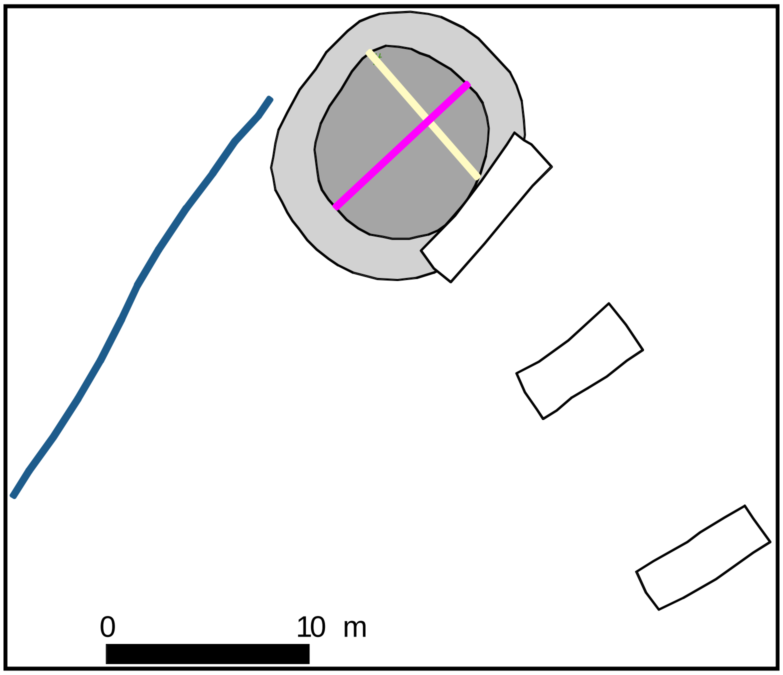
Figure 3. Sampling the M2HB 12.7-mm machine gun firing point decision units at Range 6.5, Camp Ethan Allen, VT.

The layouts of the various areas sampled during these tests are depicted in Figure 4. The maps are derived from data obtained with a Trimble GPS Pathfinder Pro XR system (±1 m) supplemented with hand measurements taken with a tape. On 9 February, two firing positions were set up for each munition tested (#), the upwind position being used for this study. One of these firing points was used for a parallel study not reported here. On 23 February, only one firing point was set up for each test related to this study. Two tests were conducted for the 12.7-mm machine gun, only one of which measured residues downrange along fixed transects. Increments were collected with Teflon-lined aluminum scoops to obtain 10- × 10- × 2-cm-deep volumes of snow. The number of increments was loosely based on the area sampled, with larger areas having a proportionately greater number of increments. Data for the sampling are given in Appendix B.

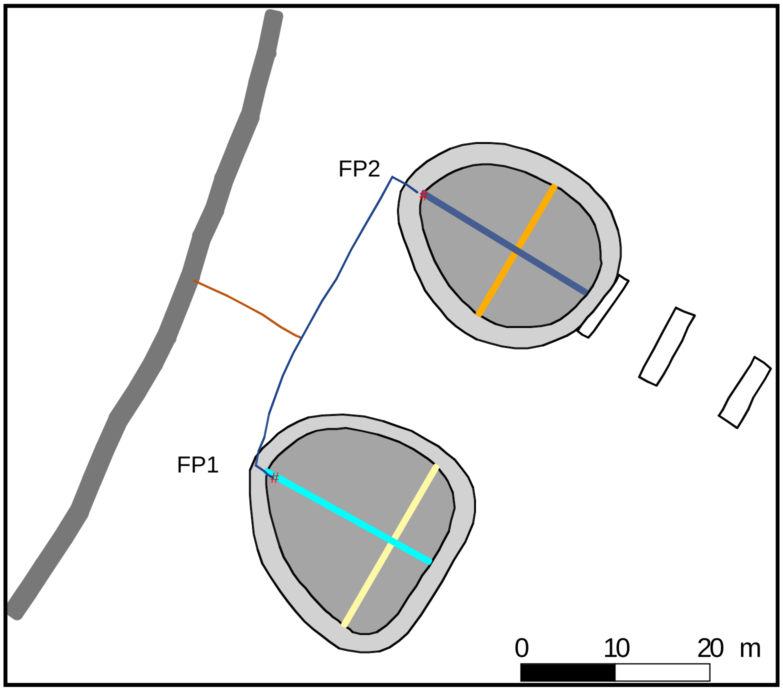


a. Test sampling layout, Camp Ethan Allen, Range 6.2, 9 February 2007.

Figure 4. Areas sampled for small arms propellant residues tests.



b. Test sampling layout, 5.56-mm machine gun, Camp Ethan Allen, Range 6.2, 23 February 2007.



c. Test sampling layout, 12.7-mm machine gun, Camp Ethan Allen, Range 6.5, 23 February 2007.

Figure 4 (cont.). Areas sampled for small arms propellant residues tests.

Figure 5. Concentric circle sampling of firing position plume and OTP areas.

Sampling for the tests on 9 February was done on foot. After the firing position plume and the downrange transects were demarcated, multi-increment samples were taken from within each area. Increments for the firing position were taken by walking in concentric circles and sampling every set number of paces, based on the size of the area being sampled (Fig. 5). The goal was to obtain between 50 and 100 increments per area. OTP areas were demarcated and similarly sampled. The transects were sampled from the edges towards the center, with an additional sampling lane down the center. The goal for the transects was 40 increments.

Because of the deeper snow, sampling for the tests on 23 February was from snowshoes. The demarcation of the firing position plumes, OTP areas, and downrange transects was conducted in the same way as for the tests on the 9th, but the sampling design differed. Lanes were marked and packed for the firing position plume area, and samples were taken from these lanes, using the same spacing but different starting points for each replicate (Fig. 6). OTPs were sampled from the firing position perimeter as well as from a path 1 m out. Downrange transect sampling remained the same.

Figure 6. Sampling from fixed lanes in firing position plume area.

The firing positions were also sampled for each test. These samples were taken from the gunner's position and encompassed a 2-m-diameter area. These areas were highly disturbed from the activities associated with setting up the weapon, firing the weapon, dismantling the position, and cleaning up the spent links and brass prior to sampling. It was difficult to obtain a sample from these areas. Replicate sampling was conducted in all sampled areas except one transect and the firing points.

## Sample Processing and Analysis

The multi-increment snow samples were trucked to Hanover for processing and analysis. Upon arrival, the samples were transferred from the field bags to clean bags, double-bagged, and placed in clean polyethylene tubs for thawing. Placing the samples in clean bags reduces the chances of cross-contamination from contact with adjoining bags and residues on the exterior of the sample bags. Double-bagging and the tubs were necessary because of the inclusion of debris such as plant stems collected with the snow samples. Plant stems can pierce the sample bags, allowing the thawed sample to leak.

Samples were shifted from warmer to cooler areas to prevent overwarming (>10°C) of the samples after melting. The order of processing was based on the weapon system (all samples from a weapon system were run before starting on the samples for a different weapon system), the area from which the samples were taken, and the completion of melting the samples in that group. The melted samples were filtered using a vacuum system to separate the soot fraction from the aqueous fraction. Filter papers (Whatman glass microfiber 90-mm ∅ grade GF/A) containing the soot are placed in clean amber jars, dried, and stored in a refrigerator at <5°C. For extraction, each sample was shaken with acetonitrile for 18 hours.

A 500-mL aliquot of the filtrate was pre-concentrated by passing it through a Waters Porpak RDX (Sep-Pak, 6-cm$^3$, 500-mg) solid-phase extraction cartridge and eluted with 5 mL of acetonitrile, resulting in a 100:1 concentration of the analytes (Walsh and Ranney 1998). The concentrate was split into two aliquots, 3.5 mL for analysis and 1.5 mL for archiving.

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

Prior to HPLC analysis, 1.00 mL of each acetonitrile extract was mixed with 3.00 mL of reagent-grade water. Determinations were made on a modular system from Thermo Electron Corporation composed of a Finnigan SpectraSYSTEM Model P4000 pump, a Finnigan SpectraSYSTEM UV2000 dual wavelength UV/VS absorbance detector set at 210 and 254 nm (cell path 1 cm), and a Finnigan SpectraSYSTEM

AS300 autosampler. Samples were introduced with a 100-µL sample loop. Separations were achieved on a 15-cm × 3.9-mm (4-µm) NovaPak C8 column (Waters Chromatography Division, Milford, MA) at 28°C and eluted with 1.4 mL/min of 15:85 isopropanol/water (v/v). HPLC analyses that needed confirmation were run on the GC.

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

Calibration standards were prepared from analytical reference materials obtained from Restek Corporation (Bellefonte, PA). The analytical reference materials were 8095 Calibration Mix A (1 mg/mL) and a single-component solution of NG (1 mg/mL). A spike solution at 1000 µg/L was prepared from 8330 Calibration Mix 1 and the single-component solution of NG (1 mg/mL). Spiked water samples at 2 µg/L were prepared by mixing 1.00 mL of the spike solution with 499 mL of water. Following SPE, the extract target concentration was 200 µg/L for each analyte.

To calculate the mass of unreacted energetics deposited on the snow, we combined the estimated masses derived for the soot and aqueous fractions. For the aqueous fraction, we divided the average concentration of the extract (in µg/L) by 100. We then multiplied this value by the total volume of filtrate for the sample (in L), giving us the mass dissolved in the meltwater from the snow (in µg). For the soot fraction, we multiplied the filter extract (in µg/L) by the volume of AcN used in the extraction process (in L), giving us the mass of residues on the filter (in µg). We then combined these mass values and divided by the area sampled, giving us a mass-per-unit-area estimate (in µg/m$^2$). Multiplying this value by the measured area of the decision unit (in m$^2$) gives us the final estimate for the residue mass for that sample (in µg) (Jenkins et al. 2002, Hewitt et al. 2003).

## Quality Control Procedures

Quality control (QC) procedures were conducted both in the field and in the lab. Field QC, noted previously, included replicate sampling within the residue plumes and sampling outside the demarcated plumes. In the processing laboratory, blank samples consisting of filtered water (Millipore Milli-Q reagent water filtration system) were periodically run through a filter assembly and SPE setup for later analysis at the lab. This procedure was designed to determine whether cross-contamination from the sample filtering apparatus was occurring. Water fractions for several samples were divided into three aliquots and run through the SPE to determine whether recovery rates from the SPE procedure were consistent. SPE spikes and blanks were run to determine cartridge filter retention and recovery during the elution process. These processes are described in greater detail in Walsh et al. (2005c).

# 4 Results

## Background Samples

The background samples collected from the FP areas prior to firing contained no detectable constituents of concern (NG and DNT), indicating clean test areas.

## Firing Points

A total of 82 multi-increment samples, composed of 4,091 increments, were taken. The demarcated plume sizes ranged from under 16 $m^2$ for the 9-mm pistol to over 300 $m^2$ for the 12.7-mm machine gun (Table 3). The location of downrange transects was determined based on wind direction and the size of the plume. Larger plume size indicated greater downrange dispersal of residues, and if the wind was from uprange, transects were extended out to 40 m. Maps of the test areas derived from the GPS data are shown in Figure 4.

Table 3. Sampled areas ($m^2$).

| Decision unit | 9-mm Pistol | 5.56-mm Rifle | 5.56-mm MG | 7.62-mm MG | 12.7-mm MG | 12.7-mm MG |
|---|---|---|---|---|---|---|
| Inner Plume | 16 | 42 | 79 | 94 | 310 | 250 |
| Outer Plume (OTP)* | 14 | 27 | 35 | 38 | 100 | 92 |
| Inner Plume + OTP* | 30 | 69 | 110 | 130 | 410 | 340 |
| Transect 10 m | 9.4 | 15 | 21 | — | — | — |
| Transect 20 m | 11 | 15 | 20 | 10 | - | 10 |
| Transect 30 m | 20 | 10 | 19 | 10 | — | 18 |
| Transect 40 m | — | — | — | 10 | — | 16 |
| Width of OTP (m)* | 0.8 | 1.0 | 1.0 | 1.0 | 1.5 | 1.5 |

*OTP widths varied based on snow depth and ability to reach for samples.

Analytical data averaged for the replicates are given in Table 4. The OTP quantities are included in the calculations but do not contribute a significant amount to the totals. Two significant digits are used for the data in this table and throughout this report (where applicable). The samples were analyzed for a series of energetic compounds: TNT, TNB, 1,3-DNB, 2,4-DNT, 2,6-DNT, RDX, HMX, and NG. NG and 2,4-DNT were the only target analytes detected in the firing point samples. Only the 7.62-mm machine-gun test had detectable quantities of DNT in the residues. The mass quantity was very small, less than 2 µg / round, and is not reported in the body of the table of analytical results.

Table 4. Analytical results and per-round calculations for small arms tests. (Results for NG only.)

| Sample area | Data from samples | | | Per-round calculations | | |
|---|---|---|---|---|---|---|
| | Aqueous mass (µg) | Soot mass (mg) | Total mass (mg) | Mass/round (mg) | Averages (mg) | SA/(SA+Plume) (%) |
| 9-mm Pistol: 100 Rounds of M882 (DODIC AA49) Ammunition Consumed | | | | | | |
| Plume | ND | 5.4 | 5.4 | 1.7 | | |
| | ND | 7.4 | 7.4 | 2.1 | | — |
| | 0.12 | 8.3 | 8.3 | 2.6 | 2.1 | |
| OTP: 0-3 m | 0.0030 | 0.052 | 0.052 | 0.013 | | |
| | 0.0021 | 0.030 | 0.030 | 0.009 | 0.011 | 0.52% |
| 10-m Transect | ND | 0.0022 | 0.0022 | 0.00040 | | |
| | ND | 0.0037 | 0.0037 | 0.00070 | | |
| | ND | 0.001 | 0.0010 | 0.00019 | 0.00043 | 0.020% |
| 20-m Transect | ND | ND | ND | — | | |
| | ND | ND | ND | — | | |
| | ND | ND | ND | — | | — |
| 30-m Transect | ND | ND | ND | — | | — |
| Firing Point 2 | 0.012 | 0.26 | 0.26 | 0.068 | | |
| Firing Point 1 | 0.0047 | 0.092 | 0.092 | 0.024 | 0.046 | 2.2% |
| *Lab / QA Samples* | | | | | | |
| Blank (DI Water) | | | ND | | | |
| Lab Spike | 0.95000 | | 0.00095 | | | |
| 5.56-mm Rifle: 100 Rounds of M855 (DODIC A059) Ammunition Consumed | | | | | | |
| Plume | 0.01 | 3.0 | 3.0 | 1.8 | | |
| | 0.01 | 2.8 | 2.8 | 1.7 | | |
| | 0.01 | 2.9 | 2.9 | 1.8 | 1.7 | — |
| OTP: 0-3 m | 0.0010 | 0.183 | 0.184 | 0.07 | | |
| | 0.0011 | 0.154 | 0.155 | 0.06 | 0.06 | 3.6% |
| 10-m Transect | ND | 0.020 | 0.020 | 0.0057 | | |
| | ND | 0.018 | 0.018 | 0.0052 | | |
| | ND | 0.018 | 0.018 | 0.0052 | 0.01 | 0.30% |
| 20-m Transect | ND | ND | ND | — | | |
| | ND | ND | ND | — | | |
| | ND | ND | ND | — | | — |
| 30-m Transect | ND | ND | ND | — | | |
| | ND | ND | ND | — | | — |
| Firing Point 2 | ND | 0.0063 | 0.0063 | 0.001 | | |
| Firing Point 1 | 0.0024 | 0.67 | 0.67 | 0.1 | 0.1 | 5.9% |
| *Lab / QA Samples* | | | | | | |
| Blank (DI Water) | | | ND | | | |
| Lab Spike | 0.95 | | 0.00095 | | | |

| Sample area | Data from samples | | | Per-round calculations | | |
|---|---|---|---|---|---|---|
| | Aqueous mass (µg) | Soot mass (mg) | Total mass (mg) | Mass/round (mg) | Averages (mg) | SA/(SA+Plume) (%) |
| 5.56-mm MG: 200 Rounds of M27 Linked (DODIC A064) M855 / M856 Ammunition Consumed | | | | | | |
| Plume | 7.3 | 0.92 | 0.93 | 0.53 | | |
| | 9.0 | 3.0 | 3.0 | 1.73 | | |
| | 10 | 2.8 | 2.8 | 1.62 | 1.3 | |
| OTP: 0-3 m | 0.7 | 0.080 | 0.080 | 0.029 | | |
| | ND | 0.077 | 0.077 | 0.026 | 0.03 | 2.1% |
| 10-m Transect | ND | 0.0068 | 0.0068 | 0.0019 | | |
| | ND | 0.0055 | 0.0055 | 0.0019 | | |
| | ND | 0.016 | 0.016 | 0.0058 | 0.0032 | 0.2% |
| 20-m Transect | ND | 0.001 | 0.0010 | 0.00030 | | |
| | ND | ND | ND | — | | |
| | ND | ND | ND | — | | |
| 30-m Transect | ND | ND | ND | — | | |
| | ND | ND | ND | — | | |
| | ND | 0.001 | 0.0012 | 0.0060 | | |
| Firing Point | ND | 0.011 | 0.011 | 0.056 | 0.031 | |
| *Lab / QA Samples* | | | | | | |
| Background 1 & 2 | ND | ND | ND | | | |
| Blank (DI Water) | | | ND | | | |
| Lab Spike | 0.95 | | 0.00095 | | | |
| 7.62-mm MG: 100 Rounds of M13 Linked (DODIC A143) M80 Ammunition Consumed | | | | | | |
| Plume | 0.00 | 1.0 | 1.0 | 1.1 | | |
| | 0.00 | 1.5 | 1.5 | 1.8 | | |
| | 0.00 | 1.2 | 1.2 | 1.6 | 1.5 | |
| OTP: 0-3 m | | 0.015 | 0.015 | 0.010 | | |
| | | 0.016 | 0.016 | 0.010 | 0.010 | 0.6% |
| 20-m Transect | ND | ND | ND | — | | |
| | ND | ND | ND | — | | |
| | ND | ND | ND | — | | |
| 30-m Transect | ND | ND | ND | — | | |
| | ND | ND | ND | — | | |
| | ND | ND | ND | — | | |
| 40-m Transect | ND | ND | ND | — | | |
| | ND | ND | ND | — | | |
| Firing Point 2 | 0.00058 | 0.060 | 0.061 | 0.0076 | | |
| Firing Point 1 | | 0.013 | 0.013 | 0.0025 | 0.0051 | |
| *Lab / QA Samples* | | | | | | |
| Background 1 & 2 | ND | ND | ND | | | |
| Blank (DI Water) | | | ND | | | |
| Lab Spike | 0.95 | | 0.00095 | | | |

| | Data from samples | | | Per-round calculations | | |
|---|---|---|---|---|---|---|
| Sample area | Aqueous mass (µg) | Soot mass (mg) | Total mass (mg) | Mass/round (mg) | Averages (mg) | SA/(SA+Plume) (%) |
| 12.7-mm MG-1: 95 Rounds of M9 Linked (DODIC A557) M33/M17 Ammunition Consumed | | | | | | |
| Plume | 11 | 1.4 | 1.4 | 5.5 | | |
| | 15 | 2.0 | 2.0 | 7.8 | | |
| | 13 | 2.7 | 2.7 | 10 | 7.8 | |
| OTP: 0-3 m | ND | 0.081 | 0.081 | 0.10 | | |
| | ND | 0.041 | 0.041 | 0.056 | 0.08 | 1.0% |
| Firing Point | | 0.0024 | 0.0024 | 0.00042 | 0.00042 | |
| *Lab / QA Samples* | | | | | | |
| Background 1 | ND | ND | ND | | | |
| Background 2 | ND | ND | ND | | | |
| Blank (DI Water) | | | ND | | | |
| Lab Spike | 0.95 | | 0.00095 | | | |
| 12.7-mm MG-2: 100 Rounds of M9 Linked (DODIC A557) M33/M17 Ammunition Consumed | | | | | | |
| Plume | 11 | 3.4 | 3.4 | 11 | | |
| | 14 | 3.2 | 3.2 | 10 | | |
| | 17 | 6.4 | 6.4 | 20 | 14 | |
| OTP: 0-3 m | ND | 0.021 | 0.021 | 0.025 | | |
| | ND | 0.044 | 0.044 | 0.051 | 0.04 | 0.3% |
| 20-m Transect | ND | 0.017 | 0.017 | 0.0050 | | |
| | ND | 0.012 | 0.012 | 0.0037 | | |
| | ND | 0.012 | 0.012 | 0.0039 | 0.0042 | 0.03% |
| 30-m Transect | ND | 0.006 | 0.0056 | 0.0032 | | |
| | ND | 0.003 | 0.0033 | 0.0019 | | |
| | ND | 0.004 | 0.0040 | 0.0023 | 0.0024 | 0.02% |
| 40-m Transect | ND | 0.001 | 0.0008 | 0.00035 | | |
| | ND | 0.002 | 0.0015 | 0.00059 | | |
| | ND | 0.001 | 0.0010 | 0.00032 | 0.00042 | 0.003% |
| Firing Point | ND | ND | ND | — | | |
| *Lab / QA Samples* | | | | | | |
| Blank (DI Water) | | | 0.000 | | | |
| Lab Spike | 0.95 | | 0.00095 | | | |

Notes

ND denotes non-detect on all analyses. Presence is below detection limits.

Data from samples is for sampled area only and is not extrapolated over the complete area sampled.

Per round calculations take the full area sampled into consideration.

DNT found only in 7.62-mm plume residues. Values were 1.5, 1.9, and 2.0 µg/round for the plume replicates.

The OTP sample results indicate that the demarcated plumes were adequately sized to encompass the major area of propellant residues deposition. The NG residues recovered from the OTPs averaged 1.35% (0.3–3.6%) of the combined residues of the plume plus the OTP. To test this conclusion, we lumped the OTPs with the plumes. The adjusted total residue (to two significant digits) is affected slightly by two OTP samples, the 5.56-mm rifle (1.7 vs. 1.8 mg/round) and one of the 12.7-mm machine guns (7.9 vs. 8.0 mg/round). These are the values reported in the summary. The downrange transects contained only small quantities of NG, less than 0.5% of that found in the plumes. Most of these residues were found in the transect closest to the plume. Of these, the average quantity compared to the plume was 0.14%. Downrange deposition extent will be discussed further in the next section.

The relative standard deviations (RSD) for the triplicate plume samples averaged 33% (3–49%), the RSD for the triplicate transect samples averaged 34% (6–59%), and the relative percent differences (RPD) for the duplicate OTP samples averaged 37% (4–68%).

In summary (Table 5), NG residues per round varied from an average of 1.3 mg per round (5.56-mm MG) to 11 mg per round (12.7-mm MG). On a percentage basis, the 9-mm pistol produced the highest percent residues (5.44% of the original NG load) and the 7.62-mm MG the lowest (0.56%). Consequently, consumption efficiencies for NG range from 94.56% to 99.44%, averaging 98.3%.

Table 5. Summary of small arms firing point propellant residues test results.

| Weapon system | Munition designation (Mil / DODIC) | Reported constituent | Post-firing residue per round (mg) | Post-firing residue per round (%) | Constituent consumption efficiency (%) |
|---|---|---|---|---|---|
| M9 / 9-mm Pistol - 125-mm barrel length | M882 / AA49 | NG | 2.1 | 5.44 | 94.56 |
| M16 / 5.56-mm Automatic Rifle - 508-mm barrel length | M855 / A059 | NG | 1.8 | 1.10 | 98.90 |
| M249 / 5.56-mm Squad Automatic Weapon (Machine Gun) - 465-mm barrel length | M855 / A059 | NG | 1.3 | 0.79 | 99.31 |
| | M856 / A063 | NG | 1.3 | 0.79 | 99.31 |
| M60 / 7.62-mm Machine Gun - 560-mm barrel | M80 / A143 | NG | 1.5 | 0.56 | 99.44 |
| | | 2,4-DNT | 0.0018 | 0.048 | 99.95 |
| M2 HB / 0.50 cal. Heavy Machine Gun - 1140-mm barrel length (Average of both tests) | M33 / A552 | NG | 11 | 0.73 | 99.27 |
| | M17 / A571 | NG | 11 | 0.73 | 99.27 |

In our ongoing effort to examine the possible sources of error in our field sampling method, we conducted some tests to determine how consistent each sampler was in obtaining their sample. At the end of sampling, we computed the statistics for the amount of liquid water from the snow each sampler obtained per sample increment. The results are presented in Table 6. The results for 1a, 2a, and 3 are for 9 February, while those for 1b, 2b, and 4 are for 23 February. The liquid water content differed substantially between the two tests due to the snow morphology. The snow on the 6.5 range is denser because of exposure to the wind and sun. The means and medians are quite close, with RSDs averaging around 12%.

Table 6. Sampler variation test results.

| Sampler | Number of samples | (mL water / sample increment) | | | Relative std. deviation (%) |
|---|---|---|---|---|---|
| | | Mean | Median | Range | |
| 1a | 11 | 15 | 15 | 5.0 | 11 |
| 2a | 20 | 21 | 22 | 5.3 | 9 |
| 3 | 14 | 14 | 13 | 5.1 | 11 |
| 1b | 11 | 33 | 35 | 13 | 14 |
| 2b | 15 | 40 | 40 | 16 | 9 |
| 4 | 14 | 38 | 36 | 19 | 17 |

What is indicated in our limited study is that different samplers may obtain different quantities of the sampled material (in our case, snow) from a plume, but the difference may not be significant. We are not sure if the differences between samples (range) are a function of depth of sampling (surface area sampled remains constant) or area (dragging the scoop through the snow, thus sampling more of the surface). Samplers 1, 2, and 3 are experienced samplers (in that order), while sampler 4 was a novice. Experience pays off with consistency, but even the novice did well.

# 5 Discussion

Testing out of doors always presents challenges. In our case, wind was the confounding factor. At the time of the tests, mild winds (<4 m/s) were blowing either across the line of fire or quartering from behind. We attempted to check fire when the wind kicked up but were not always successful. For this reason, we designated larger residue plumes than we normally would have. Transect and OTP results indicate that the plume designations are reasonable, with small amounts of residues found in both areas. Still, we feel that replication would have been better had there been no wind moving the surface snow around. Although we consider an RSD of less than 50% acceptable (ours averaged below 40%), we would have preferred that all the replicate groups had had an RSD below 50%. That said, we feel that our results are a good estimate of propellant residues deposition rates for small-arms munitions.

The area of deposition associated for each weapon system can be estimated from the data obtained for these tests. In Table 3, the total area for each sampled area is given, and in Figure 4, scaled maps of the firing point sampling configurations are illustrated. Data from Table 5 can be used to determine the extent of the residues deposition, from the plume, through the OTP area, and out across the transects. The data for our tests are summarized in Table 7. When sampling to obtain a residue accumulation estimation, these are likely minimum distances from the firing positions that need to be sampled, and they will need to be adjusted according to the prevailing wind direction. The sampling width will be half the distance to the adjoining lane on either side, as most small-arms firing ranges are set up with closely spaced lanes.

Table 7. Downrange estimates of small-arms propellant residues deposition.

| Weapon system | Propellant constituent | Major (>99%) deposition: downrange (m) | Detectable deposition: downrange (m) |
|---|---|---|---|
| 5.56-mm Rifle | NG | 8.6 | 10 |
| 5.56-mm MG | NG | 13 | 20 |
| 7.62-mm MG | NG | 9.2 | 10 |
|  | DNT | 9.2 | 9.2 |
| 9-mm Pistol | NG | 4.5 | 4.5 |
| 12.7-mm MG | NG | 20 | 40 |

So how do propellant residues from firing small arms stack up to the big guns? Table 8 summarizes the work cited previously that we have done with mortars and howitzers and compares it to the more recent small-arms results. The results are generalized to the propellant constituents of concern, mainly NG and DNT. Although the mass of residues per round is generally higher for the larger caliber munitions, their consumption efficiencies are much higher. Interestingly, the firing efficiencies of the mortar rounds we tested are generally less than those for the small arms. In this case, size is not the dominant factor. Deflagration pressure and time-in-barrel, related to barrel length, may be more important factors for burn efficiency.

Table 8. Comparison of various firing point residues loads.

| Weapon system | Propellant | Constituents | Load/ rnd (g) | Residues/ round (mg) | Residues/ load (%) |
|---|---|---|---|---|---|
| Howitzers | | | | | |
| 105-mm | M1-I & II | DNT | 42 | 34 | $8 \times 10^{-2}$ |
| 155-mm | M1 | DNT | 275 | 1.2 | $5 \times 10^{-4}$ |
| Mortars | | | | | |
| 81-mm | M9 | NG | 30 | 1,000 | 3.5 |
| 120-mm | M45 | NG | 26 | 350 | 1.4 |
| Small Arms | | | | | |
| 5.56-mm Rifle | WC844 | NG | 0.164 | 1.8 | 1.10 |
| 5.56-mm MG* | WC844 | NG | 0.163 | 1.3 | 0.79 |
| 7.62-mm MG | WC846 | NG, DNT | 0.271 | 1.5 | 0.56 |
| 9-mm Pistol | WPR289 | NG | 0.040 | 2.1 | 5.44 |
| 12.7-mm MG* | WC860 & WC857 | NG | 1.496 | 11. | 0.73 |

* Averages loads and residues from ball and tracer rounds in linked ammunition.

What do these results mean for the range manager? Small-arms ammunition, with the exception of that for the 9-mm pistol, tends to be efficient in its consumption of the propellant constituents of concern. However, two factors will offset this advantage: Small arms ranges tend to be very structured, and a large number of rounds are fired from these fixed locations. This means that there is a legitimate concern over the accumulation of constituents such as nitroglycerin at firing points.

The variability of propellant loads for a given munition family can be quite large. Army Technical Manual TM 43-0001-27 (1994) lists 17 types of 12.7-

mm cartridges, not counting blanks and plastic rounds. There is no "standard" propellant or load across all cartridges. Many cartridges have alternative propellant types and loads, making it very difficult to actually know what you have in your hand. It was only through a laborious learning process and verification through laboratory analyses that we were able to determine exactly what was fired. Even the lot specification sheets do not match the analysis data. It is imperative, therefore, to obtain as much information on the munitions being tested as possible, including DODIC, NSN, and lot numbers, and verify the information obtained using these numbers and the available databases with analysis of the raw propellant from each type of round tested, including both ball and tracer rounds where applicable.

# 6 Conclusions

A series of firing point tests were conducted on energetics associated with firing of military small arms. Firing points at two snow-covered ranges at Camp Ethan Allen were utilized on two dates in February 2007. Samples were taken from several areas associated with each test and analyzed for unburned explosives residues. Results indicate that the residue masses are small but significant, ranging from 1.3 mg/round (NG) to 11 mg/round (NG). Propellant consumption efficiency, illustrated by the percent of unburned energetics compared to the original constituent load, ranges from 0.56% to 5.4%. Smaller-caliber weapon systems tend to be less efficient than larger systems, and machine guns are slightly more efficient than non-fully-automatic weapons. Although residues per round are low, concentrated firing of a great quantity of rounds, typical on small-arms training ranges, will result in the deposition of a significant mass of propellant residues in a small (16–300 $m^2$) area. This study reinforces once again the importance of maintaining firing points to avoid their becoming a source of energetic residues on ranges.

These results are estimates of unreacted residues from activities associated with the live-fire of small-arms munitions. They are indicators of possible residue masses that will result from such activities. Some values, especially for the transects, are at or near detection limits for the analytical instrumentation and are difficult to interpret. It is important to keep in mind that there is much variability between range activities and some variability between rounds and that these results should be considered a general estimate.

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# Appendix A: Munitions Data

Table A1 contains information relevant to the munitions used during the tests covered in this report. Table A2 contains data on the energetic load of the test components. Propellant loads for the analytes of concern are given in Table 1.

Table A1. Munitions data.

| NSN | DODIC | Nomenclature | Lot No. | Drawn for tests |
|---|---|---|---|---|
| 1305-01-470-2090 | AA49 | Cartridge, 9-mm, Ball, NATO, M882 | WCC06A037-093 | 100 |
| 1305-01-155-5462 | A059 | Cartridge, 5.56-mm, Ball, M855 | — | 100 |
| 1305-01-156-7584* | A064 | CTG, 5.56-mm, 4 Ball M855 / 1 TR M856, LNKD M27 | LC-05E693L254 | 200 |
| 1305-00-892-2330 | A143 | Cartridge, 7.62-mm NATO Ball, M80 Linked | SPD05L001-002 | 100 |
| 1305-01-370-2594* | A557 | CTG, Cal .50, 4 Ball M33 / 1 TR M17, LNKD M9 | LC-05G614-137 | 200 |

Notes: Drawn from inventory, Camp Ethan Allen, and from USFPO-VT ASP, Camp Johnson, Colchester, VT

*Data from DA Form 581: Request for Issue and Turn-in of Ammunition (Doc. # W81EWF 70510500)

Table A2. Primary propellant constituents for fired rounds.

| Munition | Propellant | Mass / Round (g) | | | | | |
|---|---|---|---|---|---|---|---|
| | | NC | NG | DNT | DB | DP | Total** |
| Cartridge, 9-mm Ball, M882 | WPR289 | 0.253 | 0.040* | 0.00* | — | 0.003 | 0.32 |
| Cartridge, 5.56-mm Ball, M855 | WC844 | 1.13 | 0.189* | — | 0.101 | 0.025 | 1.69 |
| Cartridge, 5.56-mm Tracer, M856 | WC844 | 1.11 | 0.162 | — | 0.076 | 0.021 | 1.60 |
| Cartridge, 7.62-mm Ball, M80 | WC846 | 2.14 | 0.267* | 0.004* | 0.137 | 0.030 | 2.66 |
| Cartridge, CAL .50 Ball, M33 | WC860 | 12.0 | 1.48* | — | 1.22 | 0.172 | 15.2 |
| Cartridge, CAL .50 Tracer, M17 | WC857 | 11.7 | 1.57 | — | 0.856 | 0.178 | 14.6 |

Sources: MIDAS Database, JEDMICS Database, WARP Database (Restricted access Web sites); US Army (1998).

*Values for ammunition test-fired confirmed by GCMS at CRREL

** Total propellant mass per round includes constituents not shown in table.

# Appendix B: Sampling Data

Table B1 contains sampling data for the tests conducted at Camp Ethan Allen on 9 February. Table B2 contains sampling data for the 23 February Camp Ethan Allen tests.

Table B1. 9 February sampling data.

| Decision unit | Rep # | # Increments | Sampler | Volume (Melt-mL) | mL / Incr | Area sampled (m$^2$) |
|---|---|---|---|---|---|---|
| 9-mm Pistol | | | | | | |
| Plume | 1 | 50 | MRW | 940 | 18.8 | 0.50 |
| | 2 | 56 | MRW | 1060 | 18.9 | 0.56 |
| | 3 | 52 | MRW | 1060 | 20.4 | 0.52 |
| OTP: 0-0.8 m | 1 | 59 | MEW | 710 | 12.0 | 0.59 |
| | 2 | 53 | MEW | 740 | 14.0 | 0.53 |
| 10-m Transect | 1 | 52 | ST | 720 | 13.8 | 0.52 |
| | 2 | 50 | ST | 660 | 13.2 | 0.50 |
| | 3 | 50 | ST | 660 | 13.2 | 0.50 |
| 20-m Transect | 1 | 37 | MRW | 880 | 23.8 | 0.37 |
| | 2 | 40 | MRW | 760 | 19.0 | 0.40 |
| | 3 | 40 | MRW | 800 | 20.0 | 0.40 |
| 30-m Transect | 1 | 44 | MEW | 700 | 15.9 | 0.44 |
| FP-Mass | 1 | 20 | MRW | 460 | 23.0 | 0.20 |
| FP-Trays | 1 | 20 | MRW | 440 | 22.0 | 0.20 |
| | | | | Mean: | 17.7 | |
| | | | | Median: | 18.9 | |
| | | | | Range: | 11.7 | |
| 5.56-mm Automatic Rifle | | | | | | |
| Plume | 1 | 72 | MRW | 1480 | 20.6 | 0.72 |
| | 2 | 70 | MRW | 1400 | 20.0 | 0.70 |
| | 3 | 70 | MRW | 1330 | 19.0 | 0.70 |
| OTP: 0-1 m | 1 | 72 | MEW | 1010 | 14.0 | 0.72 |
| | 2 | 71 | DJL | 1380 | 19.4 | 0.71 |
| 10-m Transect | 1 | 50 | ST | 660 | 13.2 | 0.50 |
| | 2 | 50 | ST | 700 | 14.0 | 0.50 |
| | 3 | 50 | ST | 800 | 16.0 | 0.50 |
| 20-m Transect | 1 | 42 | MEW | 640 | 15.2 | 0.42 |
| | 2 | 40 | MEW | 600 | 15.0 | 0.40 |
| | 3 | 40 | MEW | 580 | 14.5 | 0.40 |

| Decision unit | Rep # | # Increments | Sampler | Volume (Melt-mL) | mL / Incr | Area sampled ($m^2$) |
|---|---|---|---|---|---|---|
| 30-m Transect | 1 | 46 | ST | 770 | 16.7 | 0.46 |
|  | 2 | 50 | ST | 810 | 16.2 | 0.50 |
| FP-Mass | 1 | 27 | MRW | 600 | 22.2 | 0.27 |
| FP-Trays | 1 | 30 | MRW | 560 | 18.7 | 0.30 |
|  |  |  |  | Mean: | 16.7 |  |
|  |  |  |  | Median: | 16.1 |  |
|  |  |  |  | Range: | 9.0 | 0.00 |
| 7.62-mm Machine Gun |  |  |  |  |  |  |
| Plume | 1 | 84 | MRW | 1980 | 23.6 | 0.84 |
|  | 2 | 80 | MRW | 1820 | 22.8 | 0.80 |
|  | 3 | 72 | MRW | 1580 | 21.9 | 0.72 |
| OTP: 0-1 m | 1 | 60 | MEW | 980 | 16.3 | 0.60 |
|  | 2 | 66 | MEW | 1120 | 17.0 | 0.66 |
| 20-m Transect | 1 | 25 | MRW | 600 | 24.0 | 0.25 |
|  | 2 | 28 | MRW | 620 | 22.1 | 0.28 |
|  | 3 | 30 | MEW | 500 | 16.7 | 0.30 |
| 30-m Transect | 1 | 50 | ST | 660 | 13.2 | 0.50 |
|  | 2 | 50 | ST | 600 | 12.0 | 0.50 |
|  | 3 | 50 | ST | 580 | 11.6 | 0.50 |
| 40-m Transect | 1 | 50 | ST | 660 | 13.2 | 0.50 |
|  | 2 | 50 | ST | 620 | 12.4 | 0.50 |
| FP-Mass* | 1 | 40 | MRW | 900 | 22.5 | 0.40 |
| FP-Trays | 1 | 25 | MRW | 560 | 22.4 | 0.25 |
| Background-1 | 1 | 50 | MEW | 600 | 12.0 | 0.50 |
| Background-2 | 1 | 50 | ST | 720 | 14.4 | 0.50 |
|  |  |  |  | Mean: | 18.1 |  |
|  |  |  |  | Median: | 17.0 |  |
|  |  |  |  | Range: | 12.4 |  |

Table B2. 23 February sampling data.

| Decision unit | Rep # | # Increments | Sampler | Volume (Melt-mL) | mL / Incr | Area sampled ($m^2$) |
|---|---|---|---|---|---|---|
| 12.7-mm (.50 cal) Machine gun 1 |  |  |  |  |  |  |
| Plume | 1 | 84 | MRW | 4120 | 49.0 | 0.84 |
|  | 2 | 84 | MRW | 3520 | 41.9 | 0.84 |
|  | 3 | 84 | MRW | 3060 | 36.4 | 0.84 |
| OTP: 0- 1.5 m | 1 | 84 | TH | 2440 | 29.0 | 0.84 |
|  | 2 | 79 | MEW | 2140 | 27.1 | 0.79 |

| Decision unit | Rep # | # Increments | Sampler | Volume (Melt-mL) | mL / Incr | Area sampled (m$^2$) |
|---|---|---|---|---|---|---|
| Susan .50cal | 1 | 37 | MRW | 1400 | 37.8 | 0.37 |
| FP Mass | 1 | 30 | TH | 920 | 30.7 | 0.30 |
| | | | | Mean: | 36.0 | |
| | | | | Median: | 36.4 | |
| | | | | Range: | 22.0 | |
| 5.56-mm Machine gun | | | | | | |
| Plume | 1 | 68 | MRW | 2920 | 42.9 | 0.68 |
| | 2 | 68 | MRW | 2720 | 40.0 | 0.68 |
| | 3 | 68 | MRW | 2680 | 39.4 | 0.68 |
| OTP: 0-1 m | 1 | 49 | MEW | 1320 | 26.9 | 0.49 |
| | 2 | 52 | TH | 1720 | 33.1 | 0.52 |
| 10-m Transect | 1 | 38 | TH | 1340 | 35.3 | 0.38 |
| | 2 | 30 | MEW | 1020 | 34.0 | 0.30 |
| | 3 | 28 | MRW | 920 | 32.9 | 0.28 |
| 20-m Transect | 1 | 32 | MEW | 1140 | 35.6 | 0.32 |
| | 2 | 38 | MEW | 1400 | 36.8 | 0.38 |
| | 3 | 37 | MEW | 1360 | 36.8 | 0.37 |
| 30-m Transect | 1 | 37 | TH | 1240 | 33.5 | 0.37 |
| | 2 | 36 | TH | 1540 | 42.8 | 0.36 |
| | 3 | 35 | TH | 1540 | 44.0 | 0.35 |
| FP Mass | 1 | 25 | MRW | 1040 | 41.6 | 0.25 |
| Susan 5.56mm | 1 | 50 | MRW | 1440 | 28.8 | 0.50 |
| | | | | Mean: | 36.5 | |
| | | | | Median: | 36.2 | |
| | | | | Range: | 17.1 | |
| Background 1 | 1(.50 cal) | 27 | MEW | 660 | 24.4 | 0.27 |
| Background 2 | 1(.50 cal) | 41 | TH | 1160 | 28.3 | 0.41 |
| 12.7-mm (.50 cal) Machine gun 2 | | | | | | |
| Plume | 1 | 79 | MRW | 3580 | 45.3 | 0.79 |
| | 2 | 78 | MRW | 3080 | 39.5 | 0.78 |
| | 3 | 78 | MRW | 3280 | 42.1 | 0.78 |
| OTP: 0-1.5 m | 1 | 77 | MEW | 2520 | 32.7 | 0.77 |
| | 2 | 80 | TH | 2760 | 34.5 | 0.80 |
| FP Mass | 1 | 32 | MRW | 1240 | 38.8 | 0.32 |
| 20-m Transect | 1 | 30 | TH | 1330 | 44.3 | 0.30 |
| | 2 | 28 | TH | 1320 | 47.1 | 0.28 |
| | 3 | 27 | TH | 1200 | 44.4 | 0.27 |
| 30-m Transect | 1 | 32 | MRW | 1340 | 41.9 | 0.32 |
| | 2 | 32 | MRW | 1220 | 38.1 | 0.32 |

| Decision unit | Rep # | # Increments | Sampler | Volume (Melt-mL) | mL / Incr | Area sampled (m$^2$) |
|---|---|---|---|---|---|---|
|  | 3 | 32 | MRW | 1220 | 38.1 | 0.32 |
| 40-m Transect | 1 | 37 | MEW | 1280 | 34.6 | 0.37 |
|  | 2 | 41 | MEW | 1520 | 37.1 | 0.41 |
|  | 3 | 51 | TH | 2220 | 43.5 | 0.51 |
|  |  |  |  | Mean: | 40.1 |  |
|  |  |  |  | Median: | 39.5 |  |
|  |  |  |  | Range: | 14.4 |  |
| Background 1 | 1(5.56mm) | 20 | TH | 740 | 37.0 | 0.20 |
| Background 2 | 1(5.56mm) | 20 | MEW | 700 | 35.0 | 0.20 |

# Appendix C: Firing Point Test Analytical Results

Tables C1 through C3 contain the analytical results for the firing point tests. The results in Tables C1 and C3 are for NG, the major constituent of concern recovered from the samples. DNT in small quantities was recovered from only one test and is reported in Table C2.

Table C1. Analytical results (NG) for small-arms tests conducted on 9 February 2007.

| Sample # | Decision unit | Volume (mL) | Snow |  | Soot |  |
|---|---|---|---|---|---|---|
|  |  |  | Melt conc. (mg/L) | Mass (ug) | Extract conc. (mg/L) | Mass (mg) |
| 9-mm Pistol |  |  |  |  |  |  |
| CEA07-1 | Plume | 940 | 0.19 | 182 | 540 | 5.4 |
| CEA07-2 |  | 1060 | 0.14 | 153 | 740 | 7.4 |
| CEA07-3 |  | 1060 | 0.11 | 120 | 830 | 8.3 |
| CEA07-4 | OTP | 710 | 0.0042 | 3.0 | 520 | 0.052 |
| CEA07-5 |  | 740 | 0.0029 | 2.1 | 300 | 0.030 |
| CEA07-6 | 10-m Transect | 720 | <0.0005 | — | 22 | 0.0022 |
| CEA07-7 |  | 660 | <0.0005 | — | 37 | 0.0037 |
| CEA07-8 |  | 660 | <0.0005 | — | 10 | 0.0010 |
| CEA07-9 | 20-m Transect | 880 | <0.0005 | — | <0.05 | — |
| CEA07-10 |  | 760 | <0.0005 | — | <0.05 | — |
| CEA07-11 |  | 800 | <0.0005 | — | <0.05 | — |
| CEA07-12 |  | 700 | <0.0005 | — | <0.05 | — |
| CEA07-17 | FP-Mass | 460 | 0.026 | 12 | 260 | 0.26 |
| CEA07-18 | FP-Trays | 440 | 0.011 | 4.7 | 920 | 0.092 |
| CEA07-18-1 | Blank-1 | 1000 | <0.0005 |  | <0.05 |  |
| CEA07-18-2 | LCS-1 | 500 | 0.0019 | 1.0 |  |  |
| 5.56-mm Automatic rifle |  |  |  |  |  |  |
| CEA07-19 | Plume | 1480 | 0.0046 | 6.8 | 300 | 3.0 |
| CEA07-20 |  | 1400 | 0.0050 | 7.0 | 280 | 2.8 |
| CEA07-21 |  | 1330 | 0.0056 | 7.4 | 290 | 2.9 |
| CEA07-22 | OTP | 1010 | 0.0010 | 1.0 | 180 | 0.18 |
| CEA07-23 |  | 1380 | 0.0008 | 1.1 | 150 | 0.15 |
| CEA07-24 | 10-m Transect | 660 | <0.0005 | — | 200 | 0.020 |
| CEA07-25 |  | 700 | <0.0005 | — | 180 | 0.018 |

| | | | Snow | | Soot | |
|---|---|---|---|---|---|---|
| Sample # | Decision unit | Volume (mL) | Melt conc. (mg/L) | Mass (ug) | Extract conc. (mg/L) | Mass (mg) |
| CEA07-26 | | 800 | <0.0005 | — | 180 | 0.018 |
| CEA07-27 | 20-m Transect | 640 | <0.0005 | — | <0.05 | — |
| CEA07-28 | | 600 | <0.0005 | — | <0.05 | — |
| CEA07-29 | | 580 | <0.0005 | — | <0.05 | — |
| CEA07-30 | 30-m Transect | 770 | <0.0005 | — | <0.05 | — |
| CEA07-31 | | 810 | <0.0005 | — | <0.05 | — |
| **CEA07-35** | FP-Mass | 600 | <0.0005 | — | 63 | 0.0063 |
| CEA07-36 | FP-Trays | 560 | 0.0043 | 2.4 | 670 | 0.67 |
| CEA07-36-1 | Blank-2 | 1000 | <0.0005 | | <0.05 | |
| CEA07-36-2 | LCS-2 | 500 | 0.0019 | 1.0 | | |
| 7.62-mm Machine gun | | | | | | |
| CEA07-37 | Plume | 1980 | 0.0014 | 2.8 | 1000 | 1.0 |
| CEA07-38 | | 1820 | 0.0017 | 3.1 | 1500 | 1.5 |
| CEA07-39 | | 1580 | 0.0019 | 3.0 | 1200 | 1.2 |
| CEA07-40 | OTP: 0-3 m | 980 | <0.0005 | | 150 | 0.015 |
| CEA07-41 | | 1120 | <0.0005 | | 164 | 0.016 |
| **CEA07-45** | 20-m Transect | 600 | <0.0005 | | <0.05 | |
| CEA07-46 | | 620 | <0.0005 | | <0.05 | |
| CEA07-47 | | 500 | <0.0005 | | <0.05 | |
| CEA07-48 | 30-m Transect | 660 | <0.0005 | | <0.05 | |
| CEA07-49 | | 600 | <0.0005 | | <0.05 | |
| CEA07-50 | | 580 | <0.0005 | | <0.05 | |
| CEA07-51 | 40-m Transect | 660 | <0.0005 | | <0.05 | |
| CEA07-52 | | 620 | <0.0005 | | <0.05 | |
| CEA07-53 | FP-Mass | 900 | 0.0006 | 0.6 | 600 | 0.060 |
| CEA07-54 | FP-Trays | 560 | <0.0005 | | 126 | 0.013 |
| CEA07-55 | Background-1 | 600 | <0.0005 | | <0.05 | |
| CEA07-56 | Background-2 | 720 | <0.0005 | | <0.05 | |
| CEA07-56-1 | Blank-3 | 1000 | <0.0005 | | <0.05 | |
| CEA07-56-2 | LCS-3 | 500 | 0.0019 | 1.0 | | |

Table C2. Analytical results (DNT) for small-arms test conducted on 9 February 2007.

| Sample # | Decision unit | Volume (mL) | Snow | | Soot | |
|---|---|---|---|---|---|---|
| | | | Melt conc. (mg/L) | Mass (ug) | Extract conc. (mg/L) | Mass (mg) |
| 7.62-mm Machine gun | | | | | | |
| CEA07-37 | Plume | 1980 | <0.0005 | — | 13 | 0.0013 |
| CEA07-38 | | 1820 | <0.0005 | — | 16 | 0.0016 |
| CEA07-39 | | 1580 | <0.0005 | — | 15 | 0.0015 |
| CEA07-40 | OTP: 0-3 m | 980 | <0.0005 | — | <0.02 | — |
| CEA07-41 | | 1120 | <0.0005 | — | <0.02 | — |
| CEA07-45 | 20-m Transect | 600 | <0.0005 | — | <0.02 | — |
| CEA07-46 | | 620 | <0.0005 | — | <0.02 | — |
| CEA07-47 | | 500 | <0.0005 | — | <0.02 | — |

Table C3. Analytical results (NG) for small-arms tests conducted on 23 February 2007.

| Sample # | Decision unit | Volume (mL) | Snow | | Soot | |
|---|---|---|---|---|---|---|
| | | | Melt conc. (mg/L) | Mass (ug) | Extract conc. (mg/L) | Mass (mg) |
| 12.7-mm Machine gun - 1 | | | | | | |
| CEA07-101 | Plume | 4120 | 0.27 | 11 | 14.2 | 1.4 |
| CEA07-102 | | 3520 | 0.44 | 15 | 20.1 | 2.0 |
| CEA07-103 | | 3060 | 0.41 | 13 | 27.1 | 2.7 |
| CEA07-104 | OTP | 2440 | <0.05 | — | 8.09 | 0.081 |
| CEA07-105 | | 2140 | <0.05 | — | 4.1 | 0.041 |
| CEA07-118 | FP Mass | 920 | <0.05 | | 0.24 | 0.0024 |
| CEA07-118-1 | Blank 1 | 1000 | <0.05 | | <0.05 | |
| CEA07-118-2 | LCS 1 | 500 | 0.19 | 0.95 | | |
| 5.56-mm Machine gun | | | | | | |
| CEA07-119 | Plume | 2920 | 0.25 | 7.3 | 9.19 | 0.92 |
| CEA07-120 | | 2720 | 0.33 | 9.0 | 29.9 | 3.0 |
| CEA07-121 | | 2680 | 0.36 | 10 | 28.0 | 2.8 |
| CEA07-122 | OTP | 1320 | 0.05 | 0.7 | 7.98 | 0.080 |
| CEA07-123 | | 1720 | <0.05 | — | 7.68 | 0.077 |
| CEA07-124 | 10-m Transect | 1340 | <0.05 | — | 0.68 | 0.0068 |
| CEA07-125 | | 1020 | <0.05 | — | 0.55 | 0.0055 |
| CEA07-126 | | 920 | <0.05 | — | 1.56 | 0.016 |
| CEA07-127 | 20-m Transect | 1140 | <0.05 | — | 0.10 | 0.001 |
| CEA07-128 | | 1400 | <0.05 | — | <0.05 | — |

| | | | Snow | | Soot | |
|---|---|---|---|---|---|---|
| Sample # | Decision unit | Volume (mL) | Melt conc. (mg/L) | Mass (ug) | Extract conc. (mg/L) | Mass (mg) |
| CEA07-129 | | 1360 | <0.05 | — | <0.05 | — |
| CEA07-130 | 30-m Transect | 1240 | <0.05 | — | <0.05 | — |
| CEA07-131 | | 1540 | <0.05 | — | <0.05 | — |
| CEA07-132 | | 1540 | <0.05 | — | 0.12 | 0.001 |
| CEA07-135 | FP Mass | 1040 | <0.05 | — | 1.11 | 0.011 |
| CEA07-136-1 | Blank 2 | 1000 | <0.05 | | <0.05 | |
| CEA07-136-2 | LCS 2 | | 0.20 | | | |
| CEA07-137 | Background 1 | 660 | <0.05 | — | <0.05 | — |
| CEA07-138 | Background 2 | 1160 | <0.05 | — | <0.05 | — |
| 12.7-mm Machine gun - 2 | | | | | | |
| CEA07-139 | Plume | 3580 | 0.32 | 11 | 34.1 | 3.4 |
| CEA07-140 | | 3080 | 0.44 | 14 | 32.1 | 3.2 |
| CEA07-141 | | 3280 | 0.53 | 17 | 31.8 | 6.4 |
| CEA07-142 | OTP | 2520 | <0.05 | — | 2.11 | 0.021 |
| CEA07-143 | | 2760 | <0.05 | — | 4.41 | 0.044 |
| CEA07-144 | FP Mass | 1240 | <0.05 | — | <0.05 | — |
| CEA07-145 | 20-m Transect | 1330 | <0.05 | — | 1.66 | 0.017 |
| CEA07-146 | | 1320 | <0.05 | — | 1.15 | 0.012 |
| CEA07-147 | | 1200 | <0.05 | — | 1.15 | 0.012 |
| CEA07-148 | 30-m Transect | 1340 | <0.05 | — | 0.56 | 0.006 |
| CEA07-149 | | 1220 | <0.05 | — | 0.33 | 0.003 |
| CEA07-150 | | 1220 | <0.05 | — | 0.40 | 0.004 |
| CEA07-151 | 40-m Transect | 1280 | <0.05 | — | 0.08 | 0.001 |
| CEA07-152 | | 1520 | <0.05 | — | 0.15 | 0.002 |
| CEA07-153 | | 2220 | <0.05 | — | 0.10 | 0.001 |
| CEA07-154 | Background 1 | 740 | <0.05 | — | <0.05 | — |
| CEA07-155 | Background 2 | 700 | <0.05 | — | <0.05 | — |
| CEA07-155-1 | Blank 3 | 1000 | <0.05 | | <0.05 | |
| CEA07-155-2 | LCS 3 | | 0.18 | | | |

All samples taken with 10- x 10- x 2-cm scoops

Soot: Filters extracted with 10 mL of AcN with the exception of CEA07-141, which had 20 mL

* 20 mL of acetonitrile used

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-0188*

**1. REPORT DATE** *(DD-MM-YYYY)*
September 2007

**2. REPORT TYPE**
Technical Report

**3. DATES COVERED** *(From - To)*

**4. TITLE AND SUBTITLE**

Propellant Residues Deposition from Small Arms Munitions

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**6. AUTHOR(S)**

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Nancy M. Perron, Dennis J. Lambert, and Alan D. Hewitt

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

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

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

**8. PERFORMING ORGANIZATION REPORT NUMBER**

ERDC/CRREL TR-07-17

**9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)**
Strategic Environmental Research and Development Program (SERDP)
Arlington, Virginia 22203

**10. SPONSOR/MONITOR'S ACRONYM(S)**

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

**12. DISTRIBUTION / AVAILABILITY STATEMENT**
Approved for public release; distribution is unlimited.

Available from NTIS, Springfield, Virginia 22161.

**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

Military live-fire training missions utilize a variety of energetic materials that are never completely consumed during firing. In February 2007, the U.S. Army Cold Regions Research and Engineering Laboratory teamed with the Vermont National Guard at Camp Ethan Allen to conduct tests to determine the propellant residues deposition related to the firing of small arms. Samples were collected from the snow surface at the firing points for 5.56-, 7.62-, 9-, and 12.7-mm (0.50-cal.) weapons, as well as from areas up to 40 m downrange. Six tests were conducted utilizing five weapon systems. Samples were analyzed to derive an estimate of the mass of unreacted energetics deposited from each activity. The areas sampled at the 5.56-mm firing points contained 1.8 and 1.3 mg NG (1.1% and 0.80% original mass) per round, the 7.62-mm firing point contained 1.5 mg NG and 0.0018-mg DNT (0.56% and 0.048% original mass) per round, the 9-mm firing point contained 2.1-mg NG (5.4% original mass) per round, and the 12.7-mm firing points averaged 11 mg NG (0.73% original mass) per round. These results indicate that although consumption rates for this class of ammunition are high, accumulation of energetic residues should be considered for range sustainment programs.

**15. SUBJECT TERMS**

| | | | |
|---|---|---|---|
| Deposition | Firing points | Nitroglycerin | Small arms |
| Energetics | Munitions | Propellants | Snow |
| | NG | Residues | |

| **16. SECURITY CLASSIFICATION OF:** | | | **17. LIMITATION OF ABSTRACT** | **18. NUMBER OF PAGES** | **19a. NAME OF RESPONSIBLE PERSON** |
|---|---|---|---|---|---|
| **a. REPORT** | **b. ABSTRACT** | **c. THIS PAGE** | | | **19b. TELEPHONE NUMBER** *(include area code)* |
| U | U | U | U | 45 | |