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Estimates for Explosives Residue from the Detonation of Army Munitions

Alan D. Hewitt, Thomas F. Jenkins, Thomas A. Ranney, Jeffrey A. Stark, Marianne E. Walsh, Susan Taylor, Michael R. Walsh, Dennis J. Lambert, Nancy M. Perron, Nicholas H. Collins, and Richard Karn

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ABSTRACT

Snow was used as a collection medium to examine explosives residues following the high-order detonation of various military munitions. After detonation, a set of large (1-m^2) samples of residue-covered snow were collected, processed, and analyzed for explosives without cross contamination from previous detonations and other potential matrix interferences. Trials were performed to quantify explosives residues following the detonation of 60-, 81-, and 120-mm mortar rounds, 105- and 155-mm howitzer rounds, M67 hand grenades, 40-mm rifle grenades, blocks of C4, several different types of land mines, bangalore torpedoes, and a shaped demolition charge. Munitions were detonated following both common military live-fire and blow-in-place techniques. When possible, the same munition was detonated several times using the same conditions to provide a more reliable estimation of the percentage of high explosives that were deposited on the snow surface. In addition to using the snow surface as a collection medium, aluminum trays and steel plates were used in some of the detonation trials.

The blowing in place of TNT-filled munitions often resulted in the deposition of near-percent levels of TNT from the main charge that was estimated to lead to mg/kg concentrations in surface soils. When we observed high concentrations of TNT in residue samples, often 2,4-DNT, 2,6-DNT, TNB, 2-ADNT, and 4-ADNT were also present at much lower concentrations. In contrast, the percentage of high explosives deposited from live-fire detonations of Comp-B-filled howitzer rounds, mortar rounds, and hand grenades was always less than 0.002%, leading to low μg/kg or ng/kg surface soil concentrations. Overall residue deposition from live-fire–high-order detonations was much lower than for munitions destroyed using blow-in-place techniques. Detonation residues for other munitions that were evaluated fell between these two ranges. Residues from blown-in-place detonations collected on pre-positioned aluminum trays and steel plates showed concentrations similar to the adjacent snow surfaces, and for one detonation allowed for an energetic particle size distribution analysis.

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PREFACE

This report was prepared by Alan D. Hewitt, Research Physical Scientist, and Dr. Thomas F. Jenkins, Research Chemist, Environmental Sciences Branch (ESB), U.S. Army Engineer Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire; by Thomas A. Ranney, Staff Scientist, Science and Technology Corporation, Lebanon, New Hampshire; Jeffrey A. Stark, Research Civil Engineer, Civil and Infrastructure Engineering Branch, ERDC-CRREL; Marianne E. Walsh, Chemical Engineer, ESB, ERDC-CRREL; Dr. Susan Taylor, Research Physical Scientist, ESB, ERDC-CRREL; Michael R. Walsh, Mechanical Engineer, Engineering Resources Branch (ERB), ERDC-CRREL; Dennis J. Lambert, Research Physical Scientist, ERB, ERDC-CRREL; Nancy M. Perron, Physical Science Technician, Snow and Ice Branch, ERDC-CRREL; Nicholas H. Collins, Physical Scientist, Military Programs Office, Applied and Military Research Branch, ERDC-CRREL; and Richard Karn, Research Chemist, Environmental Chemistry Branch, Environmental Laboratory, ERDC, Vicksburg, Mississippi.

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NOMENCLATURE

1,3-DNB	1,3-dinitrobenzene
TNB	1,3,5-trinitrobenzene
TNT	2,4,6-trinitrotoluene
2,4-DNT	2,4-dinitrotoluene
2,6-DNT	2,6-dinitrotoluene
2-ADNT	2-amino-4,6-dinitrotoluene
4-ADNT	4-amino-2,6-dinitrotoluene
ACN	Acetonitrile
BIP	Blow in place
CRREL	Cold Regions Research and Engineering Laboratory
EOD	Explosive Ordnance Disposal
EPA	Environmental Protection Agency
ERDC	Engineer Research and Development Center
GC-ECD	Gas chromatography-electron capture detection
HE	High explosive
HMX	1,3,5,7-hexahydro-1,3,5,7-trinitro-1,3,5,7-tetrazocine
MDL	Method detection limit
NG	Nitroglycerin
RDX	1,3,5-hexahydro-1,3,5-trinitro-1,3,5-triazine
RP-HPLC-UV	Reversed-phase high-performance liquid chromatography ultraviolet detection
SERDP	Strategic Environmental Research and Development Program
UXO	Unexploded ordnance

Estimates for Explosives Residue Deposition from the Detonation of Army Munitions

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1 INTRODUCTION

Background

Recently, there has been an increased awareness that routine military training and testing exercises involving munitions can potentially cause a buildup of explosives residues in soil that can result in contamination of underlying groundwater (U.S. EPA 2000, Jenkins et al. 2001). For example, munitions training and testing was curtailed at Massachusetts Military Reservation (MMR) following the discovery of low concentrations of RDX in the groundwater aquifer below the impact range (U.S. EPA 2000). At MMR and other military testing and training ranges, candidate energetic sources for this contamination include releases from breached casings of unexploded (UXO) or partially exploded ordnance, poor disposal practices, open burn and open detonation operations, and the accumulation of high-order detonation residues in impact areas. The explosives residue contributions from these various activities on training ranges are often confounded by their co-location. Determining the relative importance of these candidate sources of explosives residues on ranges is important if management practices are to be developed to minimize the possibility of their off-site migration.

To help develop sound management practices for military testing and training ranges, the Strategic Environmental Research and Development Program (SERDP) initiated studies focusing on the distribution and fate of explosives residues. The goal of this effort is to identify source strengths and pathways so that corrective measures can be implemented to reduce or eliminate the presence of explosives residues. One of the knowledge gaps identified by this program

was the quantification of explosives residues resulting from the high-order detonation of different munitions commonly used during military training exercises. More specifically, what amount and what specific explosives compounds compose the explosives residues that are dispersed into the environment as a result of the detonation of munitions.

The major products of the detonation of energetic materials are typically CO_2, CO, H_2O, N_2, and carbon (i.e., "soot" [U.S. Army Materiel Command 1972]), while forensic analysis of post-blast residues has established the presence of trace quantities of explosives (Yinon and Zitrin 1993). Recent site characterization studies of impact ranges have confirmed the presence of explosives residues both at elevated levels (Jenkins et al. 1997, 1999, 2001; Thiboutot et al. 1998; Pennington et al. 2001, 2002, in prep) and trace levels (Ogden Environmental and Energy Services 2000, USACHPPM 2000, U.S. EPA 2000, Jenkins et al. 2001, Walsh et al. 2001). To quantify explosives residues following the high-order detonation of a munition, Jenkins et al. (2000a,b, 2002), developed a systematic approach that utilizes a fresh snow surface as a collection medium. This approach was influenced by an earlier observation that a darkened soot plume existed on the surface around impact craters when munitions were fired into a snowpack (Collins and Calkins 1995). Advantages of using a snow surface as a collection medium are that the areas of deposition are clearly delineated, residues exist in a matrix that is free of interferences, residues from previous range activities are avoided (if little or no surface soil is disturbed), and a large surface area can be sampled to help address the spatial heterogeneity that is common to the deposition of particulates.

Objective

The objective of this study was to use the systematic approach developed by Jenkins et al. (2000a,b, 2002) to quantify the explosives residues produced by the high-order detonation of a variety of munitions using accepted military protocols. When possible, five or more replicate detonations were performed to provide statistically based estimates. Munitions were detonated using two different operational procedures, i.e., live-fire and blowing in place. A live-fire trial encompasses artillery and mortar-fired projectiles, tossed hand grenades, fired rifle grenades and other detonations where munition was initiated with pre-set fusing (e.g., impact, timed, or proximity). Munitions were also blown in place using C4 or blasting caps. More attention will be given to those munitions that are fired into the impact ranges, e.g., artillery rounds and grenades, than those munitions used by battlefield engineers, i.e., demolition munitions and land mines. Because very low concentrations of explosives residues were anticipated, we collected large surface samples and, when necessary, used a new gas chromatographic

electron capture (GC-ECD) method developed recently by Walsh and Ranney (1999, U.S. EPA 1999), which has lower levels of detection than reversed-phase high-performance liquid chromatography (RP-HPLC).

2 EXPERIMENTAL METHODS

General sampling scheme

All detonation trials were performed over snow-covered ranges. Flat locations were chosen for blow-in-place operations, and, when possible, as target locations for live-fire trials. When snowpack depths exceeded 30 cm or when sampling inside an impact range, we used snowshoes to assist with mobility and to reduce the possibility of disturbing unexploded ordnance (UXO). Following the high-order detonation of a munition, the area where energetic residues were deposited on the snow surface was identified by the presence of a black soot plume. The formation of soot is characteristic of the detonation of materials with an oxygen-to-carbon ratio of less than one (U.S. Army Material Command 1972). TNT ($C_7H_5N_3O_6$), motor oil, waxes, and some of the plastizers (e.g., phthalates) and stabilizers are examples of materials in the main charge of various munitions that would contribute to the formation of soot particles during detonation. Tape measurements and recordings taken by a global positioning system (GPS) were used to map the soot plumes, craters, and sampling locations. A set of large (approximately 1 m^2) snow samples was randomly collected within each plume.

An unpainted aluminum snow shovel, covered with a sheet of Teflon film, was used to remove the top 0.5 to 2 cm of the surface, depending on the conditions. Typically, the wetter the snow (tending to clump), the greater was the sampling depth. Upon completion of the collection process there was no or very little visible soot remaining within the sampling plot. In a couple instances when soot penetrated deeper into the snow column, the shovel or a small scoop was used to collect these deeper portions. Within the crater it was impractical to use a large shovel since the walls were conical, very irregular, and in some cases partially covered with soil and ice as a result of the intense release of energy and heat associated with the detonation point. For crater sampling, the surface snow and ice samples were collected with a small stainless steel scoop and we estimated the percentage of the total crater surface that was sampled. The snow shovel and scoop were cleaned between trials by washing with soap and water, rinsing with water, and rinsing several times with acetone. In the field these sampling tools were cleaned between sampling locations by inserting them into a clean snowpack and wiping with a clean towel. All surface snow samples were transferred to particulate-free polyethylene bags that were closed with a cable tie. The sampling date, munition type, sample number, surface area sampled, and distance to the crater was recorded for each sample. In cases where live-fire detonation plumes overlapped, the distance to the crater was omitted. The size of the soot plumes

varied both with the type of munition and with the ambient conditions (e.g., wind speed) at the time of detonation. Whenever possible, detonations were performed under low wind conditions. When several munitions of one type were detonated, one of the replicates was intensively sampled. Background snow samples also were collected prior to a detonation trial.

During several of the blow-in-place trials, steel plates (46 × 46 × 0.64 cm) were used to minimize the disruption of soil below the detonation point. Munitions were placed directly on top of the steel plates in some cases and in others the munition was placed on top of snow and the steel plate was buried at the base of the snowpack. In both orientations the steel plate helped to minimize the amount of topsoil that was distributed by the detonation. When the munition was placed directly on the steel plate, the surface of the plate was sampled. In addition, for a couple of trials, aluminum cooking trays (46 × 66 cm, 0.3 m^2) were pre-positioned to collect detonation residues for both chemical residue analysis and particle characterization. Following a detonation, the trays were placed in large plastic bags. Lastly, for two of the blow-in-place trials, pre-positioned video cameras photographed the detonation event.

Detonation trials

Camp Ethan Allen, Vermont: 19 January 2001

At two locations in an open area, EOD personnel from the Vermont Air National Guard blew in place a fuzed 81-mm mortar round (0.95 kg of Composition B, "Comp B" 60% RDX, 39% TNT, 1% wax) and a demolition block of C4 (0.57 kg, 91% RDX). The 81-mm mortar round was laid sideways on top of the 45-cm-deep snowpack and a fused (M6 blasting cap) demolition block of C4 was laid across the top of the round. At a second location, a 0.57-kg block of C4 was laid on top of the 45-cm deep snowpack and detonated with an M6 blasting cap. Both detonations were initiated with a radio-transmitted signal. Several surface snow samples and a single crater sample were obtained from each of the detonation plumes. The amount of soot-covered snow that was sampled in each case was less than 2% of the total plume. Figures 1 and 2 show the sampling locations and plume boundaries for these two detonations.

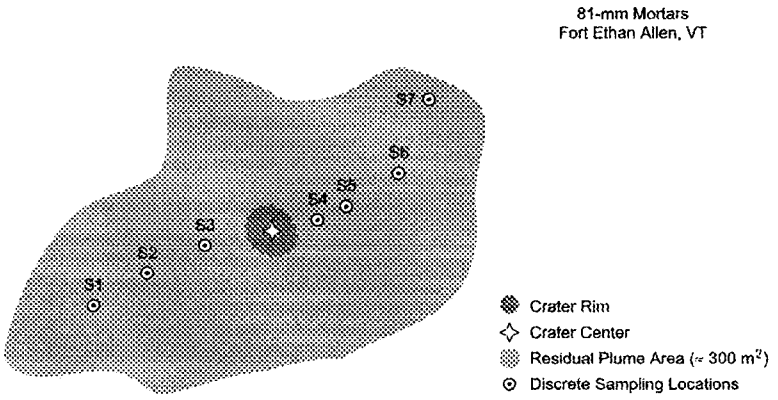

Figure 1. Residue plume from the blowing in place of 81-mm mortar round with a block of C4, with sampling and crater locations marked.

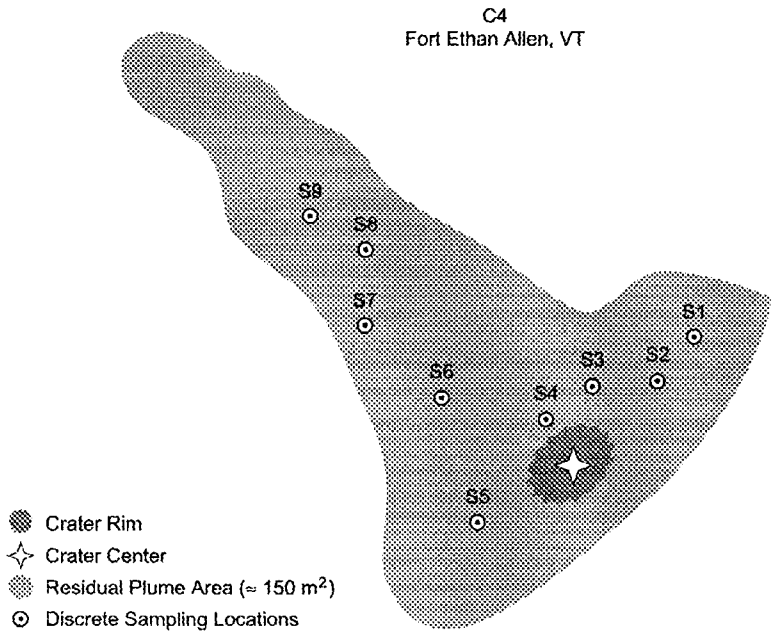

Figure 2. Residue plume from the blowing in place of a block of C4, with sampling and crater locations marked.

Fort Drum, New York: 7 February 2001

U.S. Army personnel detonated a bangalore torpedo, two unfuzed anti-tank mines, and a Claymore mine at four locations within a training range. The bangalore torpedo (4.86 kg, Comp B4: 59.75% RDX and 39.75% TNT) was used in

a training exercise to breach a barbed-wire barrier and was detonated with a timed fuse. Two anti-tank mines, an M19 (9.53 kg of Comp B) and an M15 (10.3 kg of Comp B), were blown in place after being turned upside down with half of a demolition block (0.28 kg) of C4 placed on top of the mine. A blasting cap with a 5-minute time fuse was used to initiate the block of C4. At a fourth location, a Claymore mine (0.68 kg of C4) was detonated using a 5-minute time fuse. Following the detonation of the bangalore torpedo, ten snow samples were collected within the soot plume and three snow samples were collected from the walls of the crater. Ten, nine, and six snow samples were collected, respectively, from within the soot plumes created by the detonation of the M19, M15, and Claymore mines, respectively. Also, at least one crater sample was collected for each of these mines. For these four munitions, less than 2% of the snow surface covered with soot was sampled, similar to what is shown in Figures 1 and 2.

Camp Ethan Allen, Vermont: 16 February 2001

Six 60-mm mortars (0.36 kg, Comp B) with the fuse set to detonate 1 to 2 m above surface (proximity setting) and seven 40-mm (32 g, Comp B) rifle grenades set to detonate upon impact were fired by a unit from the Vermont National Guard into an impact range. Five of the 60-mm mortars' detonation plumes were sampled by collecting large (10 to 80%) portions of the soot-covered snow. Because these projectiles detonated in the air, there was no distinct crater. The sixth mortar had an air burst some 3 to 4 m above the surface (apparently set off by a treetop), leaving little visible residue on the surface, therefore, it was not sampled. Three of the 40-mm grenades that were fired did not detonate because they failed to hit a target. Because of the safety concerns with one of these UXOs in the snowpack, we were able to sample only three of the detonation plumes. The three 40-mm grenades that we sampled were located behind a rectangular steel structure, behind a target vehicle, and around the left front corner of the same target. As with the 60-mm mortars, these rounds detonated above the surface and didn't have distinct craters. For the 40-mm rifle grenades, 50% or greater of the soot-covered snow surface was collected.

Fort Drum, New York: 8 March 2001

Seven hand grenades (186 g, Comp B) were thrown by U.S. Army personnel into the Fort Drum hand-grenade training range. Each grenade was intentionally thrown to a separate location in the range so that the detonation plumes would not overlap. This impact range was covered with between 30 and 60 cm of snow that in places had a hard crust less than a centimeter below the snow surface. Surface snow samples and at least one crater wall sample were collected for all seven

detonation areas. In each case more than 20% of the soot-covered snow was collected. Figures 3 though 9 depict the sample sizes relative to the plume dimensions and give the respective surface concentrations (ng/m^2) of RDX for each sample.

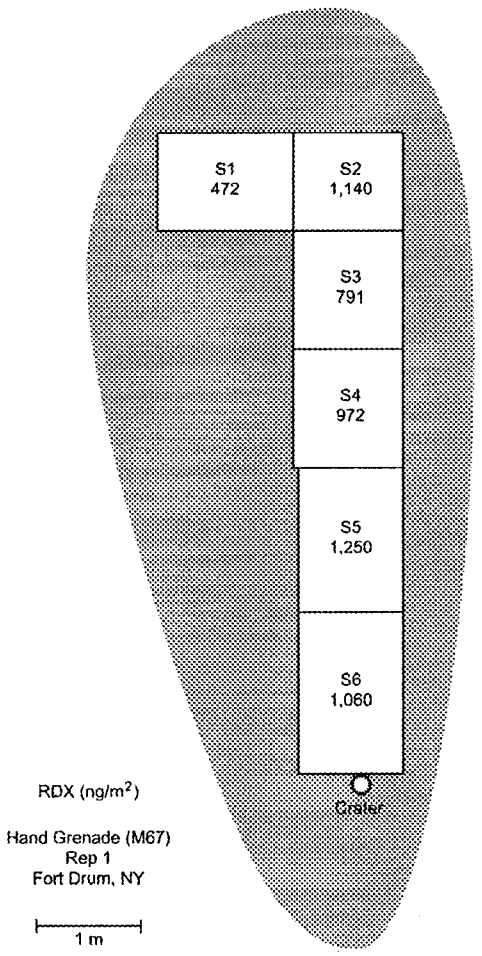

Figure 3. Residue plume #1 from the live-fire detonation of M67 hand grenade with the surface area sampled and concentrations of RDX determined.

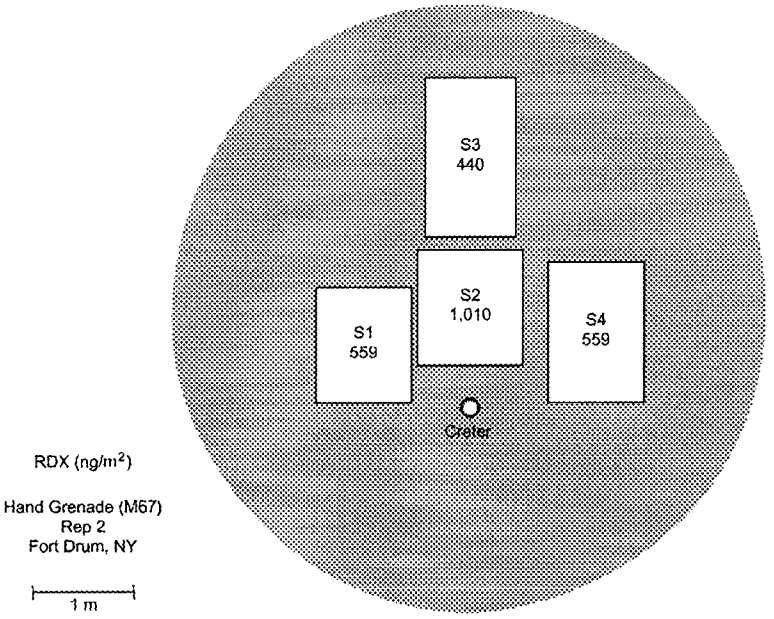

Figure 4. Residue plume #2 from the live-fire detonation of M67 hand grenade with the surface area sampled and concentrations of RDX determined.

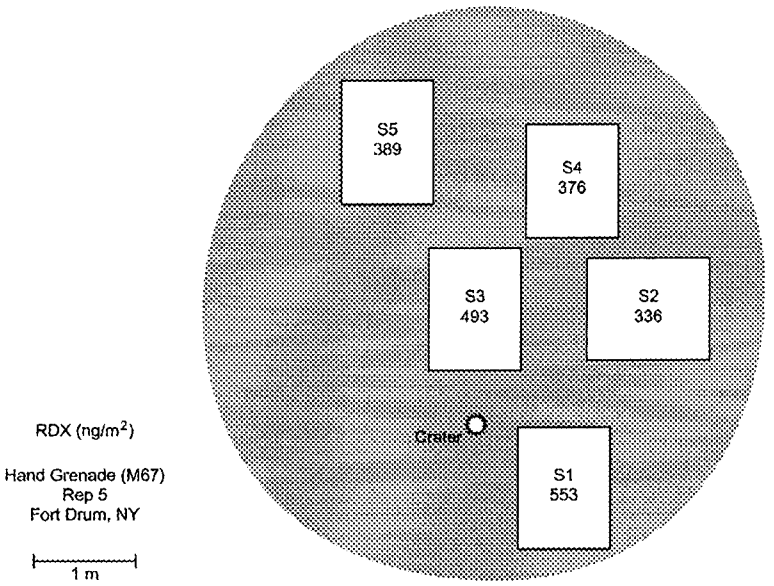

Figure 5. Residue plume #3 from the live-fire detonation of M67 hand grenade with the surface area sampled and concentrations of RDX determined.

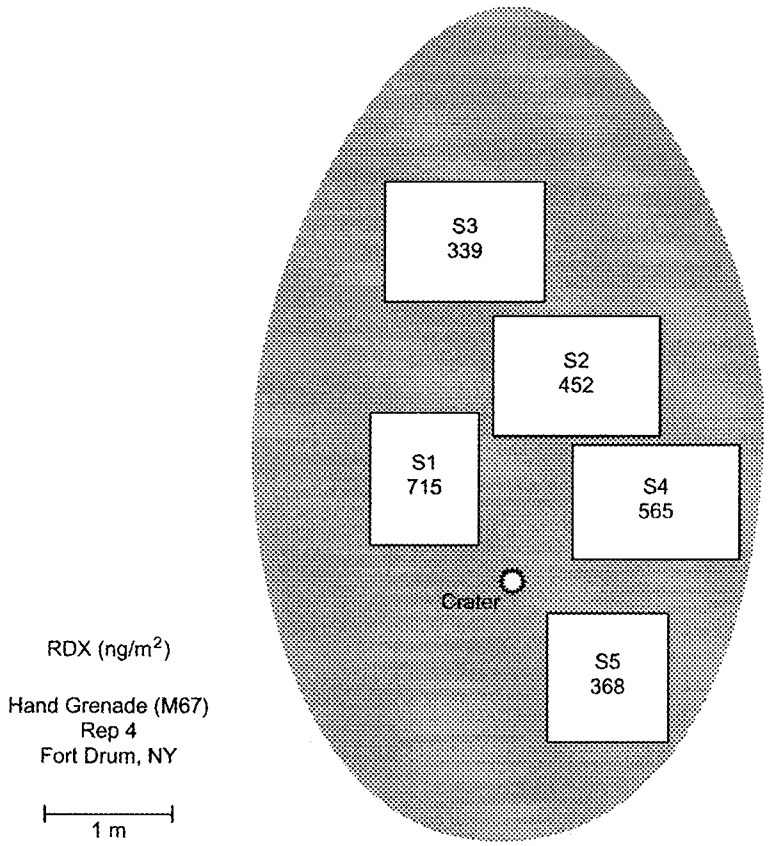

Figure 6. Residue plume #4 from the live-fire detonation of M67 hand grenade with the surface area sampled and concentrations of RDX determined.

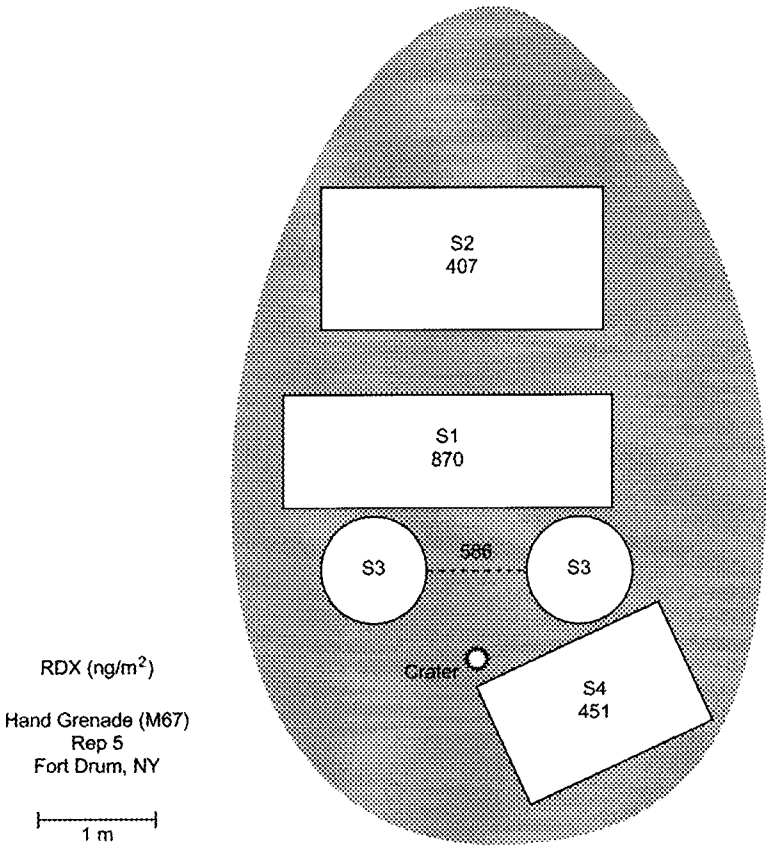

Figure 7. Residue plume #5 from the live-fire detonation of M67 hand grenade with the surface area sampled and concentrations of RDX determined.

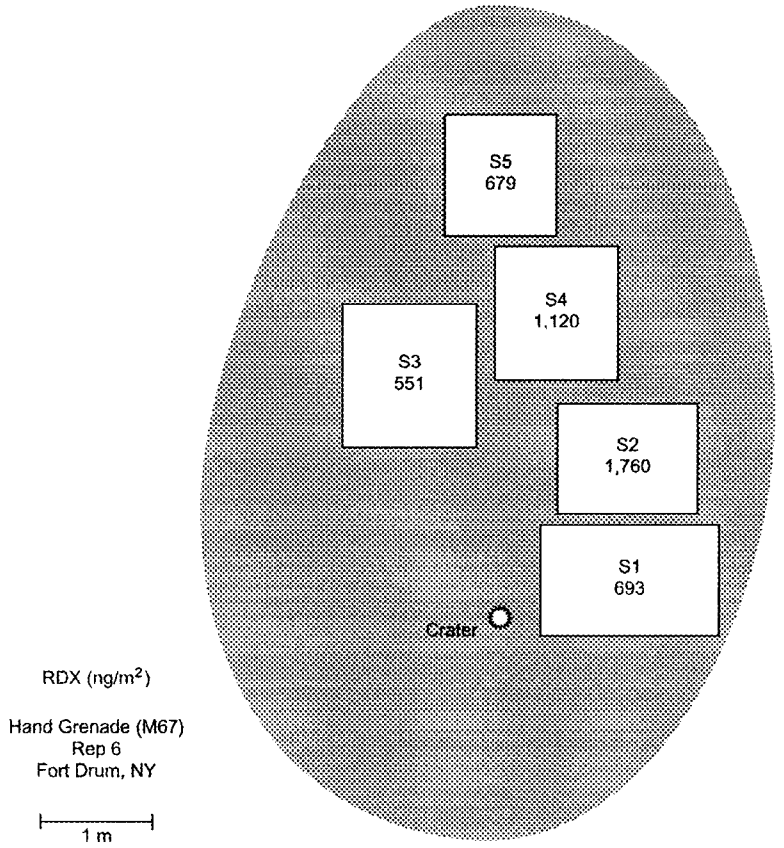

Figure 8. Residue plume #6 from the live-fire detonation of M67 hand grenade with the surface area sampled and concentrations of RDX determined.

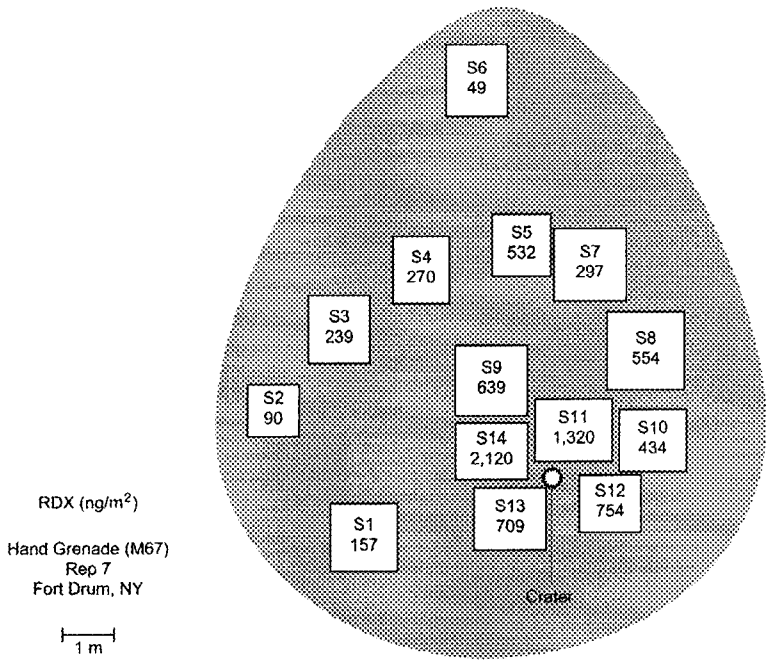

Figure 9. Residue plume #7 from the live-fire detonation of M67 hand grenade with the surface area sampled (intensively sampled) and concentrations of RDX determined.

Camp Ethan Allen, Vermont: 19 March 2001

Seven 120-mm mortar rounds (2.99 kg, Comp B), set for detonation upon impact, were fired by a unit from the Vermont National Guard into an impact range. The depth of the snowpack in the impact area ranged between 40 and 60 cm. The detonations created a 2-m or wider diameter crater and removed about 15 cm of topsoil at the point of impact. As a result the plume around each impact crater was a combination of soot and soil; because it was a warm sunny day, this dark layer warmed quickly, producing a brownish melt solution that sank into the

snowpack. The surface snow collected for these detonations represents only 2% or less of the soot plume and included some discolored snow from within the snowpack that contained the brownish surface melt solution (e.g., see Fig. 1 and 2). In addition to snow samples, two of the 120-mm mortar tail fins were recovered.

Camp Ethan Allen, Vermont: 16 January 2002

Two pairs of 0.57-kg demolition blocks of C4 (91% RDX) were blown in place by EOD personnel from the Vermont Air National Guard in a field covered with a 20-cm-deep snowpack. The blocks of C4 were detonated with a radio-initiated blasting cap in a training area that had recently been cleared of vegetation and graded specifically for these trials. To limit the disruption of the soil beneath the snow, each block of C4 was placed on top of a 46- × 46- × 0.64-cm steel plate that had been pushed down into the snowpack. For each pair of detonations, 12 aluminum cooking trays (46 × 66 cm) were positioned near one of the blocks of the C4, three at each of the four compass points. Two trays were placed next to each other to collect detonation residues for chemical analysis (A and B, left to right, from the block of C4), and a third tray, used to collect particles, was positioned 1 m to the right of the B tray. Each tray was pushed down into the snow leaving the top edge flush with the snow surface. For the first pair of detonations, the trays were positioned at a distance of 7.5 m from the block of C4, and for the second pair, the trays were set at 3.5 m from the C4. Two video cameras were positioned to record the detonation of the blocks of C4 surrounded by the aluminum trays. The cameras were positioned to the north and east, about 90° from each other and some 50 m or more from the detonation point.

Following each pair of detonations, the trays that were within the soot plume were covered with aluminum foil and placed inside a large plastic bag. Adjacent to each tray, a surface snow sample was collected. Trays within the soot plume had a small amount of snow thrown onto them, and some of the trays that were placed at the 3.5-m distance were moved slightly by the detonation. Two of the steel plates that blocks of C4 had been placed on were split open and two were folded over at a 90° angle. The surface snow samples collected represented approximately 5% of the area covered by soot for each plume (e.g., Fig. 10).

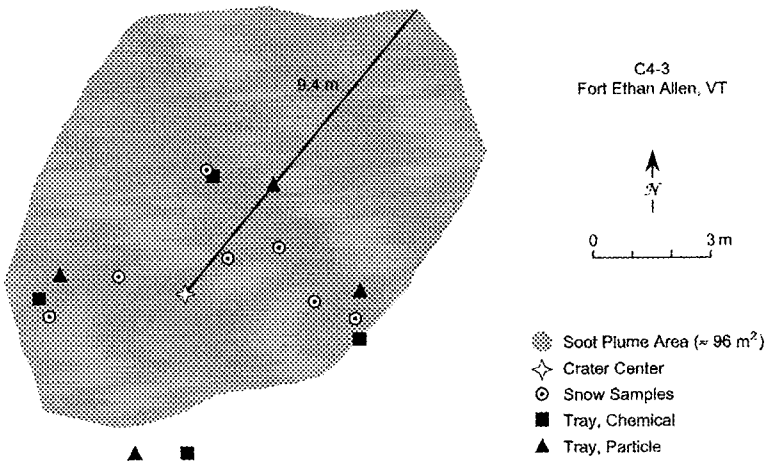

Figure 10. Residue plume from the blowing in place of a demolition block of C4. Also shown are the locations for the collection of snow surface samples, crater, and the aluminum trays to collect residue for chemical and physical analysis.

Camp Ethan Allen, Vermont: 2 February 2002

Seven Claymore mines (directional fragmentation mine, 0.68 kg of C4 and 700 steel balls) were detonated by a unit from the Vermont National Guard in the training area created for these trials. The snow depth was 28 cm, with a 0.3-cm ice crust on the surface. The temperature was −11°C, the wind speed and direction were variable. Four Claymore mines were detonated at 1300 hours and three were detonated at 1500 hours. In front of the first four mines, silhouette targets were positioned at a distance ranging from 20 to 30 m for training. We set out aluminum trays to collect detonation residues for chemical analysis and to collect particulates, in front and behind two of the Claymore mines that were detonated in the first set. Trays were positioned at 5, 7.5, 10, and 15 m in front of and at 3.5 m behind the Claymore mines. The subsequent soot plumes from these detonations extended some 15 m behind each mine but only about 7 m in front, and were only 3 to 4 m wide. Wind gusts caused the plumes to drift to the east in several cases. Following the detonation of each set of Claymore mines, trays (when used) and snow samples were collected. In all cases, more surface snow samples were collected behind the detonation point than in front. The surface snow collected for these detonations was about 5% of the soot-plume-covered area (e.g., Fig. 11).

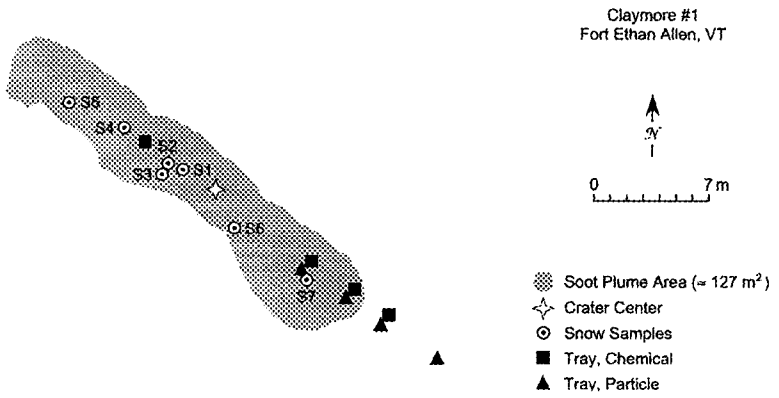

Figure 11. Residue plume from the live-fire detonation of a Claymore mine. Also shown are the locations for the collection of snow surface samples, crater, and the aluminum trays to collect residue for chemical and physical analysis.

Camp Ethan Allen, Vermont: 15 February 2002

Three 0.57-kg demolition blocks of C4 were individually blown in place by EOD personnel from the Vermont Air National Guard in the training area created for these trials. Each block was detonated over a 46- × 46- × 0.64-cm steel plate that had been buried under 20 to 30 cm of snow. The C4 blocks were set off using radio-initiated blasting caps. After detonation the metal plates were covered with an aqueous (melted snow) black residue solution, and were only slightly deformed. Snow and crater wall samples were collected for each plume. The surface snow samples collected represented approximately 5% of the area covered by soot for each plume (e.g., see Fig. 10).

Camp Ethan Allen, Vermont: 28 February 2002

Eight unfuzed 155-mm howitzer rounds (6.8 kg, TNT) were each blown in place by EOD personnel from the Vermont Air National Guard in a large open area. Each 155-mm howitzer round was hung about 1.3 m above the snow surface from a metal chain that attached to a four-legged wood A-frame (tall sawhorse). The metal chain hooked into a heavy metal nose ring that was screwed into the fuze hole. A 0.57-kg demolition block of C4 and blasting cap initiated by a radio signal was taped to the side of each round. Four of the howitzer rounds were detonated at 1000 hours and the remaining four at 1330 hours. For each set of detonations, two rounds were positioned in an area that was clear of vegetation above the snow cover and two were in locations where there were brush and small trees. All four of the howitzer rounds were more than 100 m apart from one

another. For the second set of detonations, the howitzer rounds were offset approximately 20 to 50 m from the first four positions.

The detonation of one of the 155-mm howitzer rounds was filmed from a distance of about 200 m by two cameras positioned 90 degrees from one another. One round for each of the two times was filmed. The round that was filmed also had aluminum trays positioned on the surface for the collection of particles. For the first detonation set, trays were positioned at the four compass points at a distance of 15 m from the howitzer round. Because of the prevailing winds, during the second set of detonations the trays were positioned only on the east, south, and west sides, at a distance of about 8 m from the round. Figures 12 and 13 show the sampling and tray locations for these two plumes. Throughout the day the sky was partly cloudy and very windy, with gusts up to 4 m/s, averaging from 1.6 to 3.0 m/s. Snow and crater samples were collected from seven of the plumes. The surface snow samples represented 1 to 2% of the plume area.

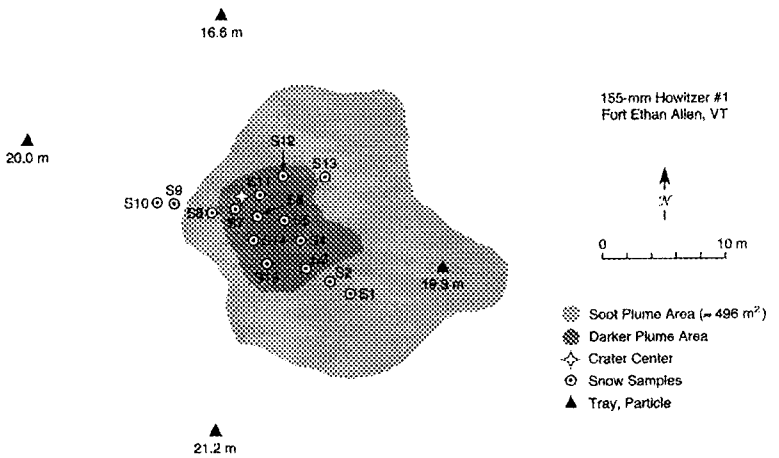

Figure 12. Residue plume from the blowing in place of a 155-mm howitzer round #1 with a demolition block of C4. Also shown are the locations for the collection of snow surface samples, crater, and the aluminum trays to collect residue for physical analysis.

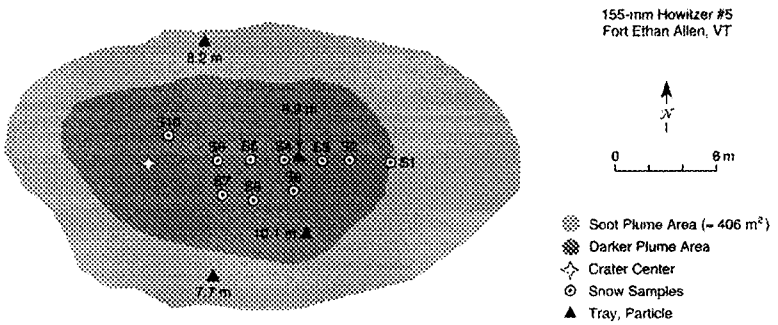

Figure 13. Residue plume from the blowing in place of a 155-mm howitzer round #5 with a demolition block of C4. Also shown are the locations for the collection of snow surface samples, crater, and the aluminum trays to collect residue for physical analysis.

Camp Ethan Allen, Vermont: 7 March 2002

Eight unfuzed anti-personnel mines, two each of four different types, were blown in place by EOD personnel from the Vermont Air National Guard, in the training area created for these trials. The four types of anti-personnel mines were PMA-1A, PPM-2, PMA-2, and VS-50. Each mine was detonated over a 46- × 46- × 0.64-cm steel plate that had been buried under 20 to 30 cm of snow. The PMA-1A and PMA-2 mines were detonated with blasting caps that had been placed inside a fuse well and the PPM-2 and VS-50 mines were detonated with a half (0.28 kg) demolition block of C4 initiated with a blasting cap. Trays were positioned around one of each of the four different types of mines. These trays for the collection of particles were positioned 5 m from the mine at each of the four compass points (Fig. 14). The surface snow samples collected represented about 5% of the plume area.

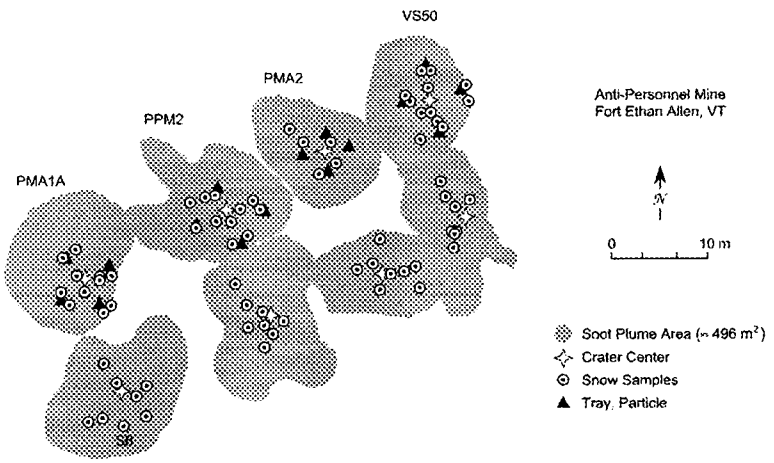

Figure 14. Residue plumes from the blowing in place of four different types of anti-personnel mines. Also shown are the locations for the collection of snow surface samples, crater, and the aluminum trays to collect residue for physical analysis.

Fort Richardson, Alaska: 13 March 2002

Fifteen 81-mm mortar rounds (Comp B, 0.93 kg) with an impact fuse setting were rapidly fired by Army personnel into the Eagle River Flats impact range. This impact range was covered with snow that was on top of a thick sheet of ice. In the impact area only two plumes were sampled because of time limitations. One plume was created from a single round and the other consisted of overlapping plumes from 13 rounds (Fig.15). Within the multi-round plume, a 34-m^2 area was covered with an ice surface that allowed the soot to be swept into piles with a broom and shoveled into the plastic bags (four different bags), with only a small amount of snow being collected. In total, 63 snow and ice surface samples and 14 crater samples were collected. The impact detonation of these rounds did not penetrate the ice sheet; therefore, no soil was present in any of the samples. For each of these two plumes about 5% of the soot-covered surface was sampled.

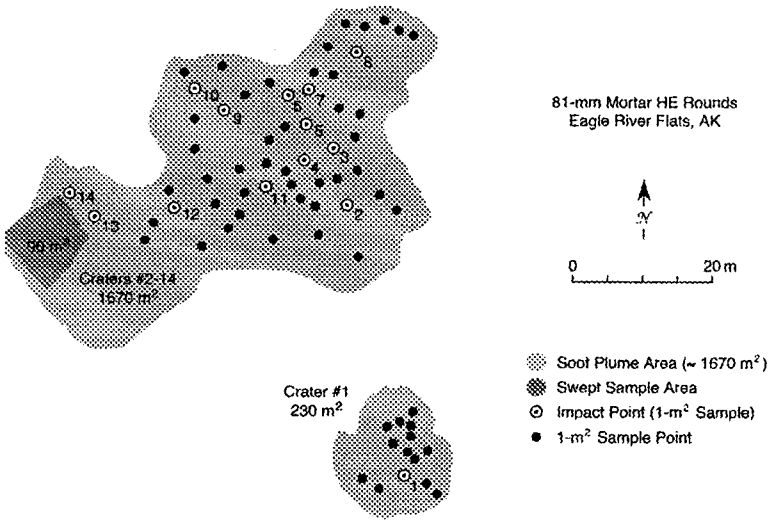

Figure 15. Single plume and a cluster of overlapping residue plumes from the live-fire detonations of 81-mm mortars. Also shown are the locations for the collection of snow surface samples and the crater.

Fort Richardson, Alaska: 14 March 2002

Fifteen 105-mm howitzer rounds (2.09 kg, Comp B) with an impact fuse setting were fired by Army personnel into the Eagle River Flats impact range. In the impact range, nine plumes were sampled. Seven of the plumes were formed by a single round each, one from the overlapping plumes from two rounds and the remaining one consisting of four overlapping plumes (e.g., Fig. 15). In total, 113 snow surface and 13 crater samples were collected. The impact detonation of these rounds again did not penetrate the ice sheet. The soot-covered snow samples collected represented from 1 to 8% of the plumes.

Fort Richardson, Alaska: 20 March 2002

Several 18-kg shaped demolition charges (M3A1, 13.4 kg, Comp B) and bangalore torpedos (4.86 kg, Comp B4) were set off by Army personnel in the impact range. Surface snow samples and crater samples were obtained for one of each of these two types of demolition munitions. In all, 12 surface snow and crater samples were obtained within the shaped charge soot plume and eight within the bangalore torpedo plume. The detonation of the bangalore torpedo did not penetrate the ice sheet. The detonation of the shaped demolition charge pene-

trated the ice sheet; however, no soil was dispersed onto the surface. For both of these plumes about 1% of the soot-covered snow was sampled (e.g., Fig. 1).

Snow-sample processing and analysis

A complete description of snow sample processing and analysis methods has been reported elsewhere (Jenkins et al. 2000a, b). Briefly, the soot-covered snow samples were melted in the plastic sample bags at either room temperature or at 4°C. When only a small amount of ice remained, the bag was vigorously shaken, suspending the soot in solution, then the entire sample in 1-L aliquots was quickly poured into a funnel and filtered by passing through a large glass-fiber filter (Whatman glass microfiber, 90-mm, grade GF/A). Depending on the amount of soot (and in some cases the amount of debris, e.g., soil, vegetation), one to more than ten individual filters were used. Both the filtrate (in some cases only a portion of the total snowmelt volume) and filters were immediately transferred to clean glass bottles and stored at 4°C.

A 500-mL portion of the filtrate was poured into a volumetric flask and then pulled by vacuum passed through a solid-phase extraction (SPE) cartridge (Jenkins et al. 1995). This technique retains the explosives on a pre-packed cartridge of Porapak RDX (Sep-Pak, 6-cm^3, 500-mg, Waters Corporation) and they were subsequently eluted with 5.00 mL of acetonitrile (100-fold pre-concentration). Based on the concentrations of RDX and TNT in the snowmelt fraction of the sample, the soot-covered filters were extracted with acetonitrile either on a shaker table or in a Soxhlet (SOX) apparatus. When the aqueous solution concentrations of RDX or TNT were above 1.0 mg/L, the filtered portion was extracted on a shaker table for 18 hours. All other filtered portions were shipped to the Environmental Measurements Laboratory in Vicksburg, Mississippi, for SOX extraction. Use of a shaker table for the extraction of explosives from detonation residues is unique to this study. This extraction method was used as a safety precaution because a detailed microscopic analysis of the soot fraction of a residue sample established the presence of hundreds of individual particles of energetic materials (Taylor etal., in prep). This soot sample corresponded to a snow sample with a high (> 1 mg/L) snowmelt concentration. Our concern was that the Soxhlet extraction of a sample containing milligram quantities of explosives could result in a small explosion, if accidentally allowed to go to dryness. A 20-mL portion of the final SOX extract volume (initial volume was 200 mL) was returned to the Cold Regions Research and Engineering Laboratory (CRREL) for analysis.

Some of the steel plates on which munitions were detonated for blow-in-place operations and all of the aluminum trays that were covered with detonation

residues were sampled. For the chemical analysis of residue concentrations, the plates and trays were allowed to dry (snow was blown onto them by the detonation), then they were wiped with acetone-moistened cotton balls held with metal tweezers. The entire surface of the aluminum trays was wiped and one to four 10- × 10-cm or larger soot-covered areas were wiped on the steel plates. One to five acetone-moistened cotton balls were used to wipe an area, depending on the amount of soot. The cotton balls were then dried before extracting with acetonitrile in a water-cooled sonic bath for 18 hours. Similarly, acetone-moistened cotton balls were used to wipe mortar fins collected in the field following the live-fire detonation of 120-mm mortars.

For physical characterization, the residues on the tray were swept to a corner with a small paintbrush. The residues were then transferred onto weighing paper, weighed, and transferred to a 40-mL amber vial. Each tray was then wiped down with acetone-moistened cotton balls. The cotton balls, up to three for each tray, were placed in a separate amber vial. When the presence of explosives was detected from analysis of these cotton balls, we analyzed the solid residue collected from the trays. To help us characterize the tray residues, they were dry-sieved into <53, 53- to 106-, 106- to 125-, 125- to 180-, 180- to 250-, 250- to 500-, and >500-μm-size fractions. Subsamples of each size fraction were examined under a light microscope and, when found, the explosive grains were removed from the 250- to 500- and >500-μm-size fractions. For the five smallest-size fractions, <53, 53–106, 106–125, 125–180, and 180–250 μm, we dissolved the residue in acetonitrile for mass determination.

Samples (SPE, shaker table, sonic bath, and SOX) were analyzed by either gas chromatography with electron capture detection (GC-EDC) or reversed-phase high-performance liquid chromatography (RH-HPLC), or both. The GC was a HP6890 equipped with a micro cell Ni^{63} ECD and the analysis protocol followed the EPA SW-846 Method 8095 guidelines (Walsh and Ranney 1998, U.S. EPA 1999). Primary and secondary GC-ECD analyses were performed using a 7-m × 0.53-mm-ID fused silica column, with a 0.5-μm coating of 5%-(phenyl)-methylsiloxane (RTx-5MS from Restek, Bellefonte, Pennsylvania) and a 6-m × 0.53-mm-ID fused silica column with a 1.0-μm coating of a proprietary phase (Rtx-TNT-2 also from Restek), respectively. RP-HPLC analyses were performed on a modular system (Thermo Separation Products, Inc., San Jose, California) consisting of a P1000 isocratic pump, UV2000 dual wavelength absorbance detector set at 210 and 254 nm, and AS3000 auto sampler. Analyte separations were performed using the 15-cm × 3.9-mm (4-mm) NovaPac C-8 column (Waters Chromatography Division, Milford, Massachusetts) eluted with 15:85 isopropanol/water (v/v), at 1.4 mL/min. Both standards and solvent extracts were diluted 1:3, acetonitrile to water. Samples with explosives analyte concentrations of

greater than 200 μg/L were typically analyzed by RP-HPLC. Subsets of samples from each detonation trial were either analyzed by both RP-HPLC and GC-ECD, or by primary and secondary column GC-ECD analysis to confirm the presence of explosive analytes. Estimates of the practical reporting limits for these samples by both methods are listed in Table 1. These reporting limit estimates were based on method detection limits and certified reporting limits for soil and water (Jenkins et al. 1992; Walsh and Ranney 1998, 1999). In general, the filtered portion (soot) of the sample contained the most interferences as a result of the inclusion of vegetation and small pieces of plastic for those munitions with plastic casings.

Table 1. Estimates of practical reporting limits for the filtered extracts and filtrate (snowmelt) portions of residue-covered snow samples, based on method detection limits or certified reporting limits established for soil and water samples.

	Filter extracts (μg/L)		Snowmelt (μg/L)	
Analyte	RP-HPLC	GC-ECD	RP-HPLC	GC-ECD
HMX	26	26	0.21	0.004
RDX	34	3	0.27	0.004
TNB	16	3	0.042	0.007
TNT	16	1	0.068	0.01
2,6DNT	19	0.8	NA	0.003
2,4DNT	28	0.8	0.085	0.009
2AmDNT	38	2.5	0.046	0.003
4AmDNT	32	1.6	NA	0.003
NG	20	22	NA	0.2

Appendix A contains the data tables for all of the individual detonation trials. These tables contain the explosives residue concentrations ($\mu g/m^2$) that were established for each snow and crater sample. Each value is composed of the snowmelt (filtrate) and soot (filtered) explosives residue concentrations, i.e., the total mass of each of the various nitroaromatics and nitramines per surface area sampled obtained by adding the values established for both of these fractions. With the exception of the anti-personnel mines, these tables show the values for all of the explosives analytes that were frequently detected. For the anti-personnel mines, only the explosives analytes present in the main charge are reported in Appendix A. In cases where the residue plumes from multiple detonations overlapped, all of the values were placed in a single table and an average value per round was determined. To estimate the total quantity (mass) of a high explosive

deposited, the mean surface concentration was multiplied by the area of the residue plume, without inclusion of the crater. The mass of the analytes deposited in the crater was similarly determined and then added to the mass determined for snow samples. The explosives residue concentration established for the crater samples were not averaged with the other samples because they had been collected using a different sampling protocol. More important, in cases where the crater was found to contain elevated concentrations of explosives residues, it could have a disproportional influence (craters were often less than 1% of the total plume area) on the estimation of the total mass for the plume.

3 RESULTS AND DISCUSSION

Deposition of RDX and TNT

Table 2 lists composition of the explosives in the main charge of the different munitions that were detonated. Table 3 lists the detonation trials in chronological order and gives the total amount of the RDX and TNT that was ignited. The total amount of RDX for a munition that was blown in place with a demolition block of C4 includes the amount of RDX that is in the demolition charge. Also, for two of the munitions, the amount of RDX present in the booster was added to the main charge value. In most cases, the energetic materials in the boosters and fuses were not included in Table 3, because the Department of Defense Identification Code (DODIC) and NSN numbers were not available. This calculation and all others used in the presentation of information are listed in Appendix B.

Table 2. Composition of main charge in detonated munitions.

Munition type	Main charge formulation	Main charge composition
1. Artillery rounds		
60-, 81-, 120-mm mortars and 105-mm howitzer	Comp B	60% RDX, 39% TNT, 1% wax
155-mm howitzer	TNT	100% TNT
2. Grenades		
M67 hand grenade and 40-mm rifle grenade	Comp B	60% RDX, 39% TNT, 1% wax
3. Mines		
M15 and M19 anti-tank	Comp B	60% RDX, 39% TNT, 1% wax
Claymore mine	C4	91% RDX, 9% oil and wax
PPM-2, PMA-2, and PMA-1A	TNT	100% TNT
VS50	RDX	100%RDX
4. Demolition		
C4	C4	91% RDX, 9% oil and wax
Bangalore torpedo	Comp B4	59.75% RDX, 39.75% TNT
Shaped demo charge	Comp B	60% RDX. 39% TNT, 1% wax

Table 3. Description of munitions detonated over snow-covered ranges.

Munition detonated	Date	Blow-in-place charge or fuse setting	Total amount (kg)	
			RDX	TNT
81-mm mortar*	1/19/2001	Blasting cap and 0.54 kg C4	1.1	0.37
C4 block	1/19/2001	Blasting cap	0.52	—
M15 Anti-tank mine	2/7/2001	Blasting cap and 0.28 kg C4	6.4	4.0
M19 Anti-tank mine	2/7/2001	Blasting cap and 0.28 kg C4	6.0	3.7
Claymore mine	2/7/2001	Blasting cap	0.62	—
Bangalore torpedo	2/7/2001	Blasting cap	2.9	1.9
60-mm mortar	2/16/2001	Proximity fuse	0.22	0.14
40-mm rifle grenade	2/16/2001	Impact fuse	0.019	0.012
Hand grenade	3/8/2001	Timed fuse	0.11	0.073
120-mm mortar	3/19/2001	Impact fuse	1.8	1.2
C4 block	1/16/2002	Blasting cap	0.52	—
Claymore mines	2/2/2002	Blasting cap	0.62	—
C4 block	2/15/2002	Blasting cap	0.52	—
155-mm howitzer	2/28/2002	Blasting cap and 0.54 kg C4	0.52	6.8
Antipersonnel mines				
VS50	3/7/2002	Blasting cap and 0.28 kg C4	0.30	—
PPM-2	3/7/2002	Blasting cap and 0.28 kg C4	0.26	0.13
PMA-2	3/7/2002	Blasting cap/ booster	0.013	0.100
PMA-1A	3/7/2002	Blasting cap	—	0.200
81-mm mortar*	3/13/2002	Impact fuse	0.56	0.36
105-mm howitzer	3/14/2002	Impact fuse	1.3	0.82
Bangalore torpedo	3/20/2002	Blasting cap	2.9	1.9
Shaped demo charge	3/20/2002	Blasting cap/ booster	8.1	5.3

* 81-mm mortars were from different manufacturers.

After establishing the total deposited mass of RDX and TNT in the detonation residue samples (Appendix A), the amount of these two high explosives that was present prior to detonation was used to determine the percentage of these

two explosives that was deposited on the surface within the visible detonation plume. In the case of overlapping residue plumes, the percent deposited was calculated on a per-round basis. Four recognized sources of uncertainty in these percent deposited determinations are 1) the entire surface area where residues were visibly deposited was not sampled; 2) the area delineated by the soot plume may not be totally inclusive of all of the deposited residues; 3) the dispersion of residues (particles of unconsumed high-explosive material) is heterogeneous, therefore, sample concentrations would not necessarily be characterized by a normal distribution (i.e., not Gaussian); and 4) military-grade RDX may contain anywhere from <1 to 15% HMX, as an impurity from the manufacturing process. Even with these potential sources of error, the mean concentration for the area visibly impacted by detonation residues can be used to establish order-of-magnitude estimates until better data become available (Jenkins et al. 2000b).

For each detonation, Tables 4 and 5 list the mass of RDX and TNT deposited, the percent of the RDX and TNT in the munition that was deposited, the mean snow surface concentrations of residues of these two high explosives, and an estimated soil concentration if these residues were deposited within the first 0.5 cm of the topsoil (density 1.7 g/cm^3). The snow and soil concentrations do not include the crater residue concentrations. This table also includes the plume area and an overall mean when five or more replicate detonations were performed. Lastly, these two tables separate those values established for live-fire exercises (Table 4) from those established for blow-in-place (Table 5) operations.

Table 4. Estimates of RDX and TNT deposited from the live-fire detonation of various munitions.

Munition detonated	Mass deposited (μg)		Mean surface % deposited[a]		Mean surface Concentration (μg/m^2)[b]		Plume Area (m^2)	Estimated mean Soil concentration (μg/kg)[c]	
	RDX	TNT	RDX	TNT	RDX	TNT		RDX	TNT
60-mm mortar	5.2	ND	2×10^{-6}	ND	0.73	ND	7.1	0.086	ND
60-mm mortar	6.6	2.2	3×10^{-6}	2×10^{-6}	1.1	0.35	6.2	0.13	0.041
60-mm mortar	28	11	1×10^{-5}	8×10^{-6}	3.9	1.6	7.1	0.46	0.19
60-mm mortar	150	40	7×10^{-5}	3×10^{-5}	1.9	0.51	78	0.22	0.06
60-mm mortar	180	17	8×10^{-5}	1×10^{-5}	25	2.4	7.1	2.9	0.28
Mean	**74**		**3×10^{-5}**		**6.5**			**0.75**	
40-mm rifle grenade	1400	7.7	7×10^{-3}	6×10^{-5}	350	1.9	4.0	41	0.22

Munition detonated	Mass deposited (μg)		Mean surface % deposited[a]		Mean surface Concentration ($\mu g/m^2$)[b]		Plume Area (m^2)	Estimated mean Soil concentration ($\mu g/kg$)[c]	
	RDX	TNT	RDX	TNT	RDX	TNT		RDX	TNT
40-mm rifle grenade	3400	6.8	2×10^{-2}	6×10^{-5}	480	0.95	7.1	56	0.11
40-mm rifle grenade	25	1.1	1×10^{-4}	9×10^{-6}	8.0	0.35	3.1	0.94	0.041
M67 hand grenade	23	ND	2×10^{-5}	ND	0.94	ND	23	0.11	ND
M67 hand grenade	19	ND	2×10^{-5}	ND	0.64	ND	27	0.075	ND
M67 hand grenade	14	ND	1×10^{-5}	ND	0.43	ND	24	0.051	ND
M67 hand grenade	12	ND	1×10^{-5}	ND	0.49	ND	19	0.058	ND
M67 hand grenade	15	ND	1×10^{-5}	ND	0.58	ND	23	0.12	ND
M67 hand grenade	32	ND	3×10^{-5}	ND	0.96	ND	29	0.11	ND
M67 hand grenade	59	ND	5×10^{-5}	ND	0.58	ND	99	0.068	ND
Mean	**25**		**2×10^{-5}**		**0.66**			**0.085**	
81-mm mortar	5400	2200	1×10^{-3}	6×10^{-4}	23	9.9	224	2.7	1.2
81-mm mortar[d]	8700	1000	2×10^{-3}	3×10^{-4}	72	8.5	121	8.5	1.0
Mean	**8500**	**1100**	**2×10^{-3}**	**3×10^{-4}**	**68**	**8.6**		**8.5**	**1.0**
120-mm mortar	1100	170	6×10^{-5}	1×10^{-5}	1.0	0.16	1090	0.12	0.019
120-mm mortar	460	16	3×10^{-5}	1×10^{-6}	0.81	0.028	570	0.095	0.0033
120-mm mortar	2700	370	2×10^{-4}	3×10^{-5}	3.2	0.48	770	0.38	0.056
120-mm mortar	1800	48	1×10^{-4}	4×10^{-6}	4.6	0.25	170	0.54	0.029
120-mm mortar	1100	56	6×10^{-5}	5×10^{-6}	1.4	0.15	310	0.16	0.018
120-mm mortar	17,000	1400	9×10^{-4}	1×10^{-4}	13	1.1	1270	1.5	0.13
120-mm mortar	5500	150	3×10^{-4}	1×10^{-5}	6.2	0.17	860	0.73	0.020
Mean	**4200**	**320**	**2×10^{-4}**	**2×10^{-5}**	**4.3**	**0.33**		**0.50**	**0.039**
105-mm howitzer	84	130	6×10^{-6}	2×10^{-5}	0.14	0.22	582	0.016	0.026
105-mm howitzer[e]	87	140	7×10^{-6}	2×10^{-5}	0.23	0.38	380	0.027	0.045

Munition detonated	Mass deposited (μg)		Mean surface % deposited[a]		Mean surface Concentration (μg/m²)[b]		Plume Area (m²)	Estimated mean Soil concentration (μg/kg)[c]	
	RDX	TNT	RDX	TNT	RDX	TNT		RDX	TNT
105-mm howitzer	170	210	1×10^{-5}	3×10^{-5}	0.23	0.27	770	0.027	0.032
105-mm howitzer	83	260	6×10^{-6}	3×10^{-5}	0.18	0.57	460	0.021	0.067
105-mm howitzer	25	43	2×10^{-6}	5×10^{-6}	0.09	0.15	280	0.011	0.018
105-mm howitzer	56	130	4×10^{-6}	2×10^{-5}	0.11	0.26	490	0.013	0.031
105-mm howitzer	260	31	2×10^{-5}	4×10^{-6}	0.58	0.07	450	0.068	0.008
105-mm howitzer	100	160	8×10^{-6}	2×10^{-6}	0.20	0.31	530	0.024	0.036
105-mm howitzer	38	210	3×10^{-6}	3×10^{-5}	0.07	0.40	540	0.008	0.047
Mean	**95**	**170**	**7×10^{-6}**	**2×10^{-5}**	**0.20**	**0.36**		**0.023**	**0.043**
Bangalore torpedo	1.1×10^{5}	150	4×10^{-3}	8×10^{-6}	190	0.25	580	22	0.029
Bangalore torpedo	9.0×10^{4}	ND	3×10^{-3}	ND	85	ND	1060	10	ND
Shaped demo. charge	4.2×10^{6}	ND	5×10^{-2}	ND	2700	ND	1540	320	ND
Claymore mine	50,000	—	8×10^{-3}	—	120	—	415	14	—
Claymore mine	13,000	—	2×10^{-3}	—	100	—	126	12	—
Claymore mine	7400	—	1×10^{-3}	—	45	—	134	5.3	—
Claymore mine	2000	—	3×10^{-4}	—	15	—	128	1.8	—
Claymore mine	8000	—	1×10^{-3}	—	49	—	115	5.8	—
Claymore mine	2800	—	5×10^{-4}	—	11	—	106	1.3	—
Claymore mine	27,000	—	4×10^{-3}	—	220	—	117	26	—
Claymore mine	17,000	—	3×10^{-3}	—	140	—	124	16	—
Mean	**16,000**		**2×10^{-3}**		**88**			**10**	

[a] Relative to total mass of analyte in the munition.
[b] Deposited in area of visual soot plume.
[c] Soil density of 1.7 g/cm³ and a 0.5-cm depth to compute the estimate.
[d] Thirteen overlapping plumes, values based on a per-round basis.
[e] Two overlapping plumes, values based on a per-round basis.
[f] Four overlapping plumes, values based on a per-round basis.

Table 5. Estimates of RDX and TNT deposited from the blow-in-place detonation of various munitions.

Munition detonated	Mass deposited (mg)		% deposited[a]		Concentration ($\mu g/m^2$)[b]		Area (m^2)	Soil concentration ($\mu g/kg$)[c]	
	RDX	TNT	RDX	TNT	RDX	TNT		RDX	TNT
C4 (0.57 kg)	61	—	1×10^{-2}	—	260	—	148	30	—
C4 (0.57 kg)	14	—	3×10^{-3}	—	57	—	214	6.7	—
C4 (0.57 kg)	18	—	3×10^{-3}	—	200	—	88	24	—
C4 (0.57 kg)	3.6	—	7×10^{-4}	—	38	—	94	4.5	—
C4 (0.57 kg)	12	—	2×10^{-3}	—	59	—	206	6.9	—
C4 (0.57 kg)	4.4	—	8×10^{-4}	—	22	—	177	2.6	—
C4 (0.57 kg)	3.5	—	7×10^{-4}	—	26	—	122	3.1	—
C4 (0.57 kg)	4.6	—	9×10^{-4}	—	28	—	156	3.3	—
Mean	**15**		**3×10^{-3}**		**86**			**10**	
81-mm mortar/ C4	14	0.081	1×10^{-3}	2×10^{-5}	40	0.13	295	4.7	0.015
M15 anti-tank/C4	40	0.076	6×10^{-4}	2×10^{-6}	18	0.04	2180	2.1	0.005
M19 anti-tank/C4	2.7	ND	4×10^{-5}	ND	3.1	ND	895	0.36	ND
155-mm howitzer/ C4	—	1.0×10^{5}	—	1	—	2.1×10^{5}	495	—	25,000
155-mm howitzer/ C4	—	38,000	—	0.6	—	1.2×10^{5}	309	—	14,000
155-mm howitzer/ C4	—	45	—	7×10^{-4}	—	130	343	—	15
155-mm howitzer/ C4	—	0.50	—	7×10^{-6}	—	1.5	343	—	0.18
155-mm howitzer/ C4	—	6,900	—	0.1	—	17,000	405	—	2,000
155-mm howitzer/ C4	—	200	—	3×10^{-3}	—	680	300	—	35

Munition detonated	Mass deposited (mg)		% deposited[a]		Concentration ($\mu g/m^2$)[b]		Area (m^2)	Soil concentration ($\mu g/kg$)[c]	
	RDX	TNT	RDX	TNT	RDX	TNT		RDX	TNT
155-mm howitzer/ C4	—	80	—	1×10^{-3}	—	170	473	—	20
Mean		**2×10^4**		**0.2**		**5×10^4**			**5900**
PMA-1A mine	—	280	—	0.1	—	2000	139	—	240
PMA-1A mine		1100	—	0.5	—	7300	147	—	860
PMA2 mine	0.77	2.3	6×10^{-3}	2×10^{-3}	5.8	21	110	0.68	2.5
PMA2 mine	1.6	550	1×10^{-2}	0.6	16	5700	96	1.9	670
PPM2 mine w/C4	49	1100	2×10^{-2}	0.8	320	6600	148	38	780
PPM2 mine w/C4	44	7900	2×10^{-2}	6	270	42,000	156	55	4,900
VS50 mine w/C4	170	—	6×10^{-2}	—	1300	—	107	150	—
VS50 mine w/C4	100	—	3×10^{-2}	—	740	—	120	87	—

[a] Relative to total mass of analyte in the munition.
[b] Deposited in area of visual soot plume.
[c] Soil density of 1.7 g/cm^3 and a 0.5-cm depth to compute the estimate.

The term "live-fire detonation" involves a chain of reactions where the main charge is initiated by a shock wave generated from a fuse or fuse-booster combination that was specially designed for that munition. Moreover, this initial shock wave ignites the main charge within a sealed casing. Fuses were initiated by a variety of techniques, i.e., electrical, timed (mechanical/electrical/ignited), proximity, or impact. The types of munitions that were detonated using a live-fire sequence were 105-mm artillery rounds, 60-, 81-, and 120-mm mortars, hand and 40-mm rifle grenades, bangalore torpedos, Claymore mines, and a shaped demolition charge. The term "blow in place" is used to describe a detonation where the main charge is initiated by a separate charge that is not specially designed for use with that munition: for instance, the detonation of a demolition block of C4 placed against the outer casing of the munition, or the detonation of a generic blasting cap that is inserted into the fuse well of an anti-personnel mine. Both the live-fire and blow-in-place operations performed in this study resulted in high-order detonations (high-order detonation being defined as an explosion that

leaves no large intact casing fragments or chunks of high explosives that are readily visible to the naked eye).

Live-fire detonations

Typically, thousands of artillery and mortar rounds are fired annually into impact ranges at active training facilities. Moreover, these impact ranges cover areas that often exceed 100 km^2. One artillery round and three types of mortar rounds were detonated using live-fire conditions in this study. All of these rounds contained Comp B as the main charge. The five 60-mm mortars that were detonated, having a proximity fuse setting of between 1 and 2 m above the surface, showed a mean percent deposition of 3×10^{-5}% for RDX and a percent deposition ranging from undetectable to 3×10^{-5}% for TNT. Jenkins et al. (2002) assessed the residues remaining following the live-fire detonation of two 60-mm mortars (0.36 kg, Comp B) with an impact fuse setting. Their work showed deposition ranging from 4×10^{-5} to 9×10^{-5}% for RDX and undetectable levels of TNT. Our mean deposition estimate for RDX appears to be a little lower than this earlier study, perhaps because of the different fuse setting. The presence or absence of TNT in the residue may be a function of the variability in the manufacturing process of Comp B. Jenkins et al. (2002) established the presence of HMX and NG, in addition to RDX. We also detected HMX and NG, as well as 2,4-DNT and 2,6-DNT.

In comparison to the 60-mm mortars, the residues from the live-fire detonation of 81-mm and 120-mm mortars generally showed higher percent deposition of RDX and TNT, and frequently showed the presence of 2Am-DNT and 4Am-DNT. We also observed that, among the analytes detected in the residues from the detonation of mortar rounds in this study and elsewhere (Jenkins et al. 2002), no HMX was detected in the residues of the 81-mm mortar rounds fired at Fort Richardson, Alaska. The reason for this discrepancy is not known; however, a possible explanation is that the RDX in the Comp-B-filled 81-mm rounds fired at Fort Richardson, Alaska, was more pure than the usual grade. HMX, 2,4-DNT, 2,6-DNT, 2Am-DNT, and 4Am-DNT are present in the residue samples either because of impurities in the manufacturing process or other components of the round, or both. NG most likely comes from the propellant ignition cartridge (Jenkins et al. 2000b). This theory was supported by presence of NG on the surface of the two 120-mm mortar fins recovered during this study and elsewhere (Hewitt 2002). The residue plumes for the thirteen 105-mm howitzer rounds showed only trace quantities (at or below GC-ECD detection capabilities listed in Table 1) of RDX and TNT. The resulting mean percent deposition estimates were 7.0×10^{-6}% for RDX and 2.0×10^{-5}% for TNT. With the exception of the 105-mm

howitzer rounds, there tended to be greater percent deposition of RDX relative to TNT.

The highest overall mean ($n \geq 5$) percent deposition for the live-fire detonations of howitzer and mortar rounds (metal-encased munitions) was 0.002% for RDX and 3×10^{-4}% for TNT. These mean deposition values were estimated for 81-mm mortar rounds and indicate that up to 99.998% of the high explosives were consumed during the detonation. If the deposited residues were homogeneously distributed over the ground surface under the detonation plume, and were contained within the first 0.5 cm of top soil (density 1.7 g/cm^3), the average surface soil concentrations would be 8.1 μg/kg for RDX and 1.0 μg/kg for TNT (Table 4). Contributions (average surface soil concentrations) of RDX and TNT to surface soils would be 1 to 3 orders of magnitude less for the howitzer and other mortar rounds detonated using live-fire conditions. Very low levels of explosives residue concentrations in surface soils are consistent with results from efforts to characterize the energetics on active artillery impact ranges, the results of which have shown that explosives residues are often below detection when using a random or systematic sampling plan (USACHPPM 2000, U.S. EPA 2000, Ogden Environmental and Energy Services 2000, Jenkins et al. 2001, Walsh et al. 2001) and are only in the low microgram-per-kilogram range when judgmentally sampled around heavily impacted targets that are absent of partially detonated (low-ordered) munitions (Pennington et al. 2001, 2002; Jenkins et al. 2001; Walsh et al. 2001).

Two types of grenades were detonated in live-fire trials. Facilities for training with hand grenades are typically smaller than 1000 m^2, and those for rifle grenades are around 1 km^2 in size. These ranges typically are heavily used, similar to an artillery range (thousands of detonations annually). Both of these munitions contain Comp B. Both RDX and TNT were found in the residues from the detonation of the rifle grenades but only RDX was detected in the hand grenade residues. In addition to these two analytes, HMX, 2,6-DNT, 2,4-DNT, 4Am-DNT, and 2Am-DNT were present in the detonation residues of the 40-mm rifle grenade, and 2,6-DNT was detected for the M67 hand grenade. For both types of grenades, RDX was present in the highest concentrations of all the explosives analytes detected.

The three rifle grenades had depositions that ranged from 0.007 to 0.02% relative to the amount of RDX in the grenade and from 9.0×10^{-6} to 6.0×10^{-5}% for TNT. The estimated range of surface soil concentrations below these residue plumes are 0.94 to 56 μg/kg for RDX and 0.041 to 0.22 μg/kg for TNT (Table 4). Walsh et al. (2001) sampled a target berm (approximately 100 m^2) that had been used for a training exercise for the firing of 1800 rifle grenades (40-mm) at Fort

Greely, Alaska. The rifle grenades used at Fort Greely, Alaska, were filled with Comp A5 (55 g, 98.5% RDX) and the sampling was done 20 months after the firing exercise. Five composite samples were collected horizontally along the face of the berm at 1-m intervals. Their investigation showed that the RDX concentrations ranged from 4 to 1700 μg/kg and that there was a distinct trend showing increasing concentrations going from the top to the bottom of the berm. The estimated level of RDX in the soil based on the detonation residue concentrations and measured levels for this target are in reasonable agreement given the time between the firing exercise and sampling event.

The live-fire detonations of M67 hand grenade had an overall mean percent deposition of 2.0×10^{-5}% for RDX (indicating a 99.99995% consumption of the main charge) and an estimated soil concentration of 0.085 μg/kg (Table 4). Based on these findings, the presence of RDX, TNT, and HMX should be difficult to detect in surface soils in hand-grenade ranges. However, surface and shallow profile surface soil samples from active hand-grenade training ranges have often shown moderately high concentrations for all three of these analytes. For example, Jenkins et al. (2001) reported median concentrations of 1560, 543, and 728 μg/kg for RDX, TNT, and HMX, respectively, in surface soils from a hand grenade range. However, they also reported that there was evidence of partial detonations, based on the discovery of large fragments of M67 hand-grenade casings with Comp B remaining on the casing surface (Jenkins et al. 2001). Therefore, to account for the apparently anomalous high soil concentrations of RDX, TNT, and HMX on this hand-grenade range and on other ranges, the presence of hand grenades that have undergone a partial detonation has been suggested (Walsh et al. 2002).*

Live-fire detonation residues from three other munitions were evaluated in this study, e.g., Claymore mines, bangalore torpedoes, and a shaped demolition charge. These munitions are typically used by battlefield engineers for specific tasks and see limited use during military training and testing exercises. Of these three munitions, the detonation of a shaped demolition charge produced the highest deposition of energetics from the main charge (Table 4). However, since only a single muniton of this type has been evaluated, this value is tentative. The overall mean percent deposition of RDX for Claymore mines was 0.002%, and the estimated soil concentration is 10 μg/kg (Table 4). Of this group of munitions, only the detonation of a Claymore mine (0.62 kg C4) has been evaluated on a training range (Pennington et al. 2002). Composite surface soil samples collected in front of the detonation point of a single Claymore mine failed to show the

* Personal communication, Thomas F. Jenkins, Research Chemist, CRREL, 2001.

presence of RDX, which is not that surprising based on the mean estimated surface soil concentration of 10 μg/kg.

Blow-in-place detonations

The results in Table 5 show that, for the munitions that were blown in place, the greatest percent deposited for individual detonations was 2 and 6% for TNT from a 155-mm howitzer round and a PPM-2 anti-personnel mine, respectively. The blowing in place of two PPM-2, a PMA-2, and two PMA-1A anti-personnel mines, along with three 155-mm howitzer rounds, showed a high (greater than 0.1%) percentage of deposited TNT. The main charge in all four of these munitions is TNT (RDX in the booster was added to the main charge of the PMA-2). These findings indicate that the blowing in place of TNT-filled munitions typically is not as efficient at consuming the main charge as the live-fire detonation of Comp-B-filled munitions.

Lewis et al. (in prep.) reported that frequently there are high recoveries (greater than 0.1%) of RDX and TNT from the blowing in place of munitions with a demolition block of C4. The munitions blown in place in their study were 60- and 81-mm mortar rounds, M67 hand grenades, a 105-mm howitzer round, and blocks of TNT formed in the shape of a PMA-2 anti-personnel mine. Overall these findings were very complementary of our findings with respect to residues concentration resulting from blow-in-place operations. They also blew in place four M67 hand grenades with blasting caps that were placed into the fuse well. Their experiments also used a fresh snow surface as a collection medium; however, they were different from ours in some other respects owing to safety concerns and study objectives. All of the munitions blown-in-place had their fuses removed, therefore the casing was breached, and, when used, the amount of demolition C4 varied between 5 to 150 g (40 to 150 g for the artillery and mortar rounds). These two factors may have contributed to the high levels of deposited explosives residues.

The blowing in place of 155-mm howitzer rounds filled with TNT had percent deposition values that ranged over five orders of magnitude (7×10^{-6} to 2%), the largest distribution of values seen for all the munitions studied. The detonation residues also showed the presence of several other analytes (e.g., TNB, 2,4-DNT, 2AmDNT, and 4AmDNT) at lower concentrations. The estimated soil concentrations below the detonation plumes showing the lowest and highest percent deposition of TNT are 0.18 and 26,000 μg/kg (Table 5). Following the melting of the snowpack, approximately 2 months after the 155-mm howitzer rounds had been blown in place, composite surface soil samples (top 1–2 cm) were collected in concentric rings around both of these detonation points. A single composite

sample was collected 3 m from the detonation point for the round that showed the lowest TNT deposition. Three separate composite samples were collected at distances of 3, 5, and 10 m (nine total) around the detonation point of the round with the highest TNT deposition (Hewitt and Walsh 2003). TNT was not detected in the composite soil sample collected for the round showing the lowest deposition of this analyte. In contrast, TNT was present in all of the composite surface soil samples collected around the round that had the highest deposition, and the overall average was 49,000 μg/kg. This overall average presumably would have been even higher if the sampling depth had been limited to the top 0.5 cm. Even so, the TNT concentrations obtained for the surface soil samples collected around both of these detonation points are in very good agreement with the levels anticipated.

Pennington et al. (2002) presented information about the blowing in place of three UXOs and a 500-lb bomb containing TNT that had low-ordered, i.e., about half of the main charge remained unconsumed in the bomb's breached casing. All of these munitions were found on an active training range. The UXO items consisted of two separate 155-mm howitzer rounds and the combination of 155-mm howitzer round and an 81-mm mortar round found side by side. Composite soil samples were collected around each of these blow-in-place operations before and after detonation, using the same sampling design. The 155-mm howitzer rounds and the combination of the 155-mm howitzer round and 81-mm mortar round were each blown in place with two demolition blocks (0.57 kg) of C4, and three demolition blocks of C4 were used for the bomb. Explosives residue concentrations in the surface soil samples increased following each of these operations. On average, the high explosive that showed the largest increase in concentration ranged from greater than 6000-fold (<10 to 65,600 μg/kg RDX) to less than 50 (129 to 6100 μg/kg TNT). Increases of TNT in the composite samples that were collected at 3, 5, and 10 m from the low-order bomb after detonation ranged from 3.1 to 39×. The main charge in the 155-mm howitzer rounds could not be established prior to detonation because no visible markings remained on their exposed surface. However, based on the concentrations of high explosives found in the soil samples following the detonation of the 155-mm howitzer round that showed greatest deposition of energetics, this round most likely contained Comp B. The U.S. Army Engineering and Support Center (USAESC) has also reported on the blowing in place of different Comp-B-filled artillery rounds (60-, 81-, 120-mm mortar rounds and 105- and 155-mm howitzer rounds) with C4 (USAESC, 2002). They used a sand pit and metal trays as collection surfaces to obtain four composite samples to assess residue concentrations. Overall, the highest post-detonation residue concentrations were obtained for RDX and the values for this high explosive often exceeded 1000 μg/kg. These findings indicate that effi-

ciency of consuming the high explosives for blowing in place of Comp-B-filled rounds is similar to what was obtained above for TNT-filled rounds and that the dispersion of unconsumed RDX can lead to milligram-per-kilogram levels in surface soils.

Detonation residues from the blowing in place of demolition blocks of C4 and six different types of land mines were also evaluated. Of these munitions, the blowing in-place of anti-personnel mines resulted in the highest deposition of energetics (TNT) from the main charge and also showed the highest estimated soil concentrations (Table 5). High residue concentrations from land mines are expected, since their design is not optimal for the buildup of detonation pressure as compared to artillery and mortar rounds.* Overall, the deposition of explosives from the main charge of these anti-personnel mines ranged from 6 to 0.002%. Residues from the blowing in place of the anti-personnel mines filled with TNT also showed the presence of manufacturing impurities (2,4DNT and 2,6DNT) and TNT transformation products (TNB, 2AmDNT, and 4AmDNT). Values for these other analytes were not reported in Appendix A, because they often were much lower than TNT in concentration and had not been confirmed by a second analysis.

The mean percent deposition of RDX for blowing in place of demolition blocks of C4 was 0.003%, and the mean estimated surface soil concentration is 10 μg/kg (Table 5). These values are consistent with the live-fire detonations of Claymore mines, a munition that contains a slightly greater (17%) quantity of C4 as the main charge (Table 3). Based on this finding, explosives residues from the detonation of a single block of C4 would be difficult to detect in surface soils. C4 was used to blow in place two anti-personnel mines (PPM-2 and VS-50), two anti-tank mines (M15 and M19), an 81-mm mortar round, and seven 155-mm howitzer rounds. The PPM-2 and 155-mm mortar rounds were filled with TNT, the VS-50 with RDX, and the anti-tank mines and 81-mm mortar round contained Comp B. Half a block of C4 (0.28 kg) was used to blow in place the anti-personnel and anti-tank mines, and a full block (0.57 kg) was used for all of the other munitions. For the TNT-filled munitions, the percent deposition of RDX ranged from below detection to 0.02%, for, respectively, the 155-m howitzer rounds and for two PPM-2 anti-personnel mines. For the RDX-filled munition, the percent deposition of RDX ranged from 0.03 to 0.06%, and for the Comp-B-filled munitions, the percent deposition of RDX ranged from 4×10^{-5} to 0.001%. Clearly, RDX in the block of C4 contributed to the detonation residues from the blowing in place of the PPM-2 anti-personnel mine; however, it most likely was

* Personal communication, P. Brousseau, Canadian National Defense Scientist, Defence Research Establishment-Valcartier (DREV), Val-Belair, Quebec, March 2003.

efficiently consumed in the blowing in place of the 155-mm howitzer rounds. A 155-mm howitzer round contains a much larger quantity of energetics than the anti-personnel mine. For the other munitions (81-mm mortar round, VS50 anti-personnel mine, and anti-tank mines) blown in place with C4, the contribution of RDX from this demolition muntion could not be distinguished from the main charge contribution of this high explosive.

Collection of residues on trays and plates

Along with the collection of snow samples, aluminum trays were set out to collect residues for chemical analysis during the blowing in place of two demolition blocks of C4 and two Claymore mines. For the first block of C4, the aluminum trays were placed 7.5 m from the detonation point. No residues (soot) were deposited on any of the trays for this trial. For the second block of C4, the trays were positioned 3.5 m from the detonation point. In this detonation trial, six (three sets) of the trays were within the detonation soot plume. A snow sample was collected adjacent to each set of the trays that was within the soot plume. For two of the Claymore mines, one set (one for chemical and one for particle analysis) of aluminum trays was positioned behind and four sets were positioned directly in front at 5, 7.5, 10, and 15 m. The detonation plume from one of the Claymore mines encompassed three sets of trays while the other only covered one set of trays.

A chemical analysis also was performed on four steel plates that had demolition blocks of C4 detonated on top of them. The surface residue concentrations of RDX established for the trays and plates and for the adjacent snow surface were similar (Table 6). Therefore, multiple trays and plates could have been used instead of the snow cover to collect detonation residues from blow-in-place operations. However, precautions would have to be taken to prevent contaminated soil from previous detonations from interfering with subsequent detonations. Other obvious disadvantages would be the inability to predict where the detonation plume will deposit residues and the inability to place plate or trays close to the detonation point without disruption. One way some of these concerns have been addressed was to use a pit filled with clean sand for the detonation point (USAESC 2002). Another way some of these concerns have been addressed is to use a raised thick steel plate as a detonation platform.*

Some of the aluminum trays were set out with the express purpose of finding explosive particles, so as to describe their appearance and size distribution. The

* Personal communication, Sonia Thiboutot, Canadian National Defence Scientist, Defence Research Establishment–Valcartier (DREV), Val–Belair, Quebec, September 2001.

analysis of the cotton balls used to wipe the trays after the removal of particles established that only the blowing in place of the TNT-filled anti-personnel mines and two 155-mm howitzer rounds warranted further investigation. To establish that certain classes of particles contained TNT, we used tetra-butyl-ammonium hydroxide, a reagent that reacts with TNT to form a red product. We found explosive grains on only one of the trays that was deployed during the blowing in place of a 155-mm howitzer round. Despite high concentrations of TNT in the residues recovered from some of the trays with the cotton balls for the other howitzer round and for two of the antipersonnel mines, we found no explosive grains in these samples. This suggests that the particles were very small and enmeshed in the ubiquitous soot generated by the detonation (Taylor et al., in prep.).

Table 6. RDX surface concentrations collected on trays and plates and adjacent snow surfaces. All samples within the detonation plumes of blocks of C4 and Claymore mines.

RDX ($\mu g/m^2$)	
Aluminum tray	**Snow**
16	31
0.57	0.06
ND	ND
23	120
9.0	17
18	30
Steel plate	**Snow***
300	1300
120	170
16	13
390	73

* Snow collected from within the crater.

For the 155-mm howitzer tray sample with grains of TNT, we measured the actual sizes of all TNT particles greater than 250 μm in the following manner: we first photographed all the TNT grains using a digital camera attached to the microscope. Then we used NIH image, a freeware image-processing program, to process each image and obtained the number of TNT particles, as well as the perimeter length, and the length of the major and minor axes for each particle. To estimate the number of TNT particles in the five smallest size fractions we ex-

tracted and analyzed the sample as described above and used the concentration of TNT in the sample to estimate the number of particles (assuming a given diameter) in each size fraction needed to give the measured concentration (Taylor et al., in prep.). The diameters chosen were 40, 75, 110, 150, and 200 μm, respectively, for the <53-, 53- to 106-, 106- to 125-, 125- to 180-, 180- to 250-μm-size fractions. Figure 16 shows the size distribution of particles that were collected on a tray. Clearly, there are several orders of magnitude more particles that are less than 0.1 mm in diameter than particles that are greater than 1 mm. However, the majority of the unconsumed TNT mass is in the particles larger than 0.1 mm in diameter. Likewise a soot (filtered) portion of a snow sample from this 155-mm howitzer detonation plume was also analyzed for TNT particles. Overall, the same general trend was established for the particle size distribution (Taylor et al., in prep.).

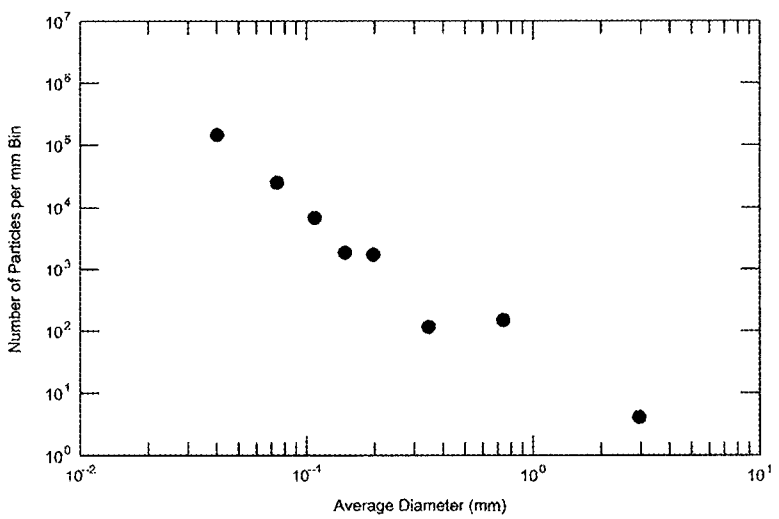

Figure 16. Size distribution of residue TNT particle measured for the blowing in place of a 155-mm howitzer round.

Video records of some of the detonations were made to provide the data needed to model the detonation and compare the predicted particle distribution with that measured. This work is being done in collaboration with Aerodyne and is not yet completed.*

* Personal communication, Susan Taylor, Research Physical Scientist, CRREL, February 2003.

4 SUMMARY

Our findings show that the high-explosives filler in the main charge of howitzer rounds, mortar rounds, and hand grenades is efficiently consumed during live-fire operations that result in high-order detonations. Analysis of detonation residues collected on snow following the live-fire detonations of three different mortar rounds, one type of howitzer round, and one type of hand grenade, all filled with Comp B, shows that on average 99.997% or more of the RDX and TNT was consumed. The high explosives that are not consumed during these detonations are presumably very fine particles (<50 μm) that are spread over an area that would, on average, contribute 10 μg/kg or less of these energetics to the ground surface concentrations. This amount of explosives residue is consistent with the very low concentrations of energetic residues that have been established for a majority of the landscape on active impact ranges, with the exception of soil samples collected near munitions that have been blown-in-place or have partially detonated (i.e., low-ordered; breached casing and presence of unconsumed main charge). Therefore, it does not appear that high-order detonation from live-fire training is distributing large amounts of explosives residues on Army training ranges.

Using C4 to blow in place UXOs contributes RDX to the detonation residues when this operation is performed with small munitions. More important, the practice of blowing in place a munition with a block of C4 frequently results in the random dispersion of percent, or near-percent, levels of the unconsumed high-explosives filler from the main charge. The majority of mass of unconsumed explosives appears to exist in the particle size range from >0.1 mm to a couple of millimeters. When only 90% to 99.9% of the main charge is consumed, the dispersion of energetic materials contribute milligram-per-kilogram quantities to the ground surface concentrations. In comparison to partial detonations, the release of energetics from a single blow-in-place operation is typically smaller. With the exception of the small training ranges (e.g., hand grenade, rifle grenade, ground-to-ground rocket, or missile ranges) both blowing in place and partial detonations are often spatially isolated. Large munitions that have partially detonated, small areas where partial detonations frequently occur, and locations (demolition ranges) where blow-in-place-type operations are repeatedly performed, are all likely candidate source zones of high explosives that may be of environmental concern.

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APPENDIX A: DATA

Table A1. Surface concentrations of explosives residues from the detonation of a 81-mm mortar with a 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, Vt., 1/19/01.

Area: Soot plume 300 m^2; Crater 5.5 m^2

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)			
			RDX	TNT	HMX	NG
S1	9.8	2.1	8.6	ND	2.5	18
S2	6.6	1.7	22	ND	4.1	1400
S3	3.3	1.1	65	ND	19	5200
S4	2.2	0.98	73	0.19	25	2300
S5	3.6	0.98	94	0.34	7.3	2700
S6	6.6	1.5	11	0.18	4.0	800
S7	10.4	1.3	3.0	0.18	ND	45
Crater	–	0.55*	330	7.8	150	7900
Total mass (μg) deposited:						
Without Crater (295 m^2)			12,000	38	2600	530,000
With Crater (300 m^2)			14,000	81	3400	570,000

* Estimated that10% of crater was sampled.

Table A2. Surface concentrations of explosives residues from the detonation of a 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, Vt., 1/19/01.

Area: Soot plume 150 m^2; Crater 2.5 m^2

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
S1	4.9	1.4	2.0	ND
S2	2.8	1.1	66	28
S3	2.3	0.95	660	260
S4	1.7	0.86	1100	470
S5	3.4	1.2	1.7	ND
S6	4.3	1.1	160	57
S7	7.2	0.99	100	45
S8	8.4	1.6	90	48
S9	10.1	0.99	122	62
Crater	–	0.25*	9200	3900
Total mass (μg) deposited				
Without Crater (148 m^2)			38,000	16,000
With Crater (150 m^2)			61,000	26,000

* Estimated that10% of the crater was sampled.

Table A3. Surface concentrations of explosives residues from the detonation of an M15 anti-tank mine with a 0.62-lb (0.28-kg) block of C4 at Ft. Drum, NY, 2/7/01.

Area: Soot plume 2200 m^2; Crater 20 m^2

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)		
			RDX	TNT	HMX
S1	23	1.3	0.12	ND	0.015
S2	9.8	0.85	1.0	ND	0.17
S3	7.1	0.90	2.5	ND	0.26
S4	3.6	0.76	5.3	0.13	0.74
S5	3.1	0.71	180	0.33	1.8
S6	12	1.2	0.50	ND	0.031
S7	6.2	0.86	5.9	ND	2.0
S8	9.3	0.60	16	ND	6.9
S9	10	0.70	22	ND	6.9
S10	15	1.0	0.65	ND	2.2
S11	24	0.77	0.40	ND	1.4
S12	28	0.68	1.4	ND	1.9
S13	34	0.81	0.086	ND	0.16
Crater #1	–	0.5*	0.25	ND	ND
Crater #2	–	0.5*	0.54	ND	0.67
Crater #3		0.5*	2.2	0.037	0.48
Total mass (μg) deposited					
Without Crater (2180 m^2)			40,000	76	4,100
With Crater (2200 m^2)			40,000	76	4,100

* Estimated that 2.5% of the crater was sampled.

Table A4. Surface concentrations of explosives residues from the detonation of an M19 anti-tank mine with a 0.62-lb (0.28-kg) block of C4 at Ft. Drum, NY, 2/7/01.

Area: Soot plume 870 m^2; Crater 5 m^2

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
S1	6.1	1.17	3.5	11
S2	11	1.1	4.6	14
S3	22	1.43	3.9	10
S4	27	0.77	4.4	7.0
S5	38	0.77	1.1	3.2
S6	17	0.72	7.8	14
S7	13	0.64	2.8	16
S8	8.7	1.3	1.1	16
S9	6.4	1.07	1.4	4.4
S10	6.6	0.72	0.60	0.54
S11**	11	0.95	0.25	0.10
Crater #1	–	0.25*	3.9	12
Crater #2	–	0.25*	1.1	7.4
Crater #3	–	0.25*	0.53	0.22
Total mass (μg) deposited				
Without Crater (865 m^2)			2700	8300
With Crater (870 m^2)			2700	8300

* Estimated that 5% of the rater was sampled.

** Sample collected just outside of visual soot plume, not include in estimate of residue concentration.

Table A5. Surface concentrations of explosives residues from the detonation of a Bangalore Torpedo at Ft. Drum, NY, 2/7/01.

Area: Soot plume 590 m^2; Crater 10 m^2

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)		
			RDX	TNT	HMX
S1	13	0.81	2.3	ND	0.45
S2	14	0.51	3.2	0.16	ND
S3	10	1.0	4.7	ND	2.2
S4	8.1	0.72	1.5	ND	0.49
S5	4.6	0.72	17	2.6	5.4
S6	8.5	0.81	360	ND	73
S7	8.1	0.66	360	ND	69
S8	12	0.56	420	ND	52
S9	7.7	0.70	690	ND	120
S10	20	0.68	170	ND	20
S11	27	0.88	31	ND	0.79
Crater #1	–	0.5*	98	0.15	12
Crater #2	–	0.5*	560	0.058	38
Crater #3	–	0.5*	320	0.38	38
Total mass (μg) deposited					
Without Crater (580 m^2)			110,000	150	18,000
With Crater (590 m^2)			110,000	150	18,000

* Estimated that 5% of the crater was sampled.

Table A6. Surface concentrations of explosives residues from the detonation of a Claymore mine at Ft. Drum, NY, 2/7/01.

Area: Soot plume 420 m^2; Crater 5 m^2

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
S1	4.7	0.9	54	100
S2	2.1	0.75	88	120
S3	2.2	1.10	58	40
S4	2.6	0.99	480	210
S5	5.5	1.31	22	15
S6	8.6	1.49	4.9	7.3
Crater #1	–	0.5*	43	80
Total mass (μg) deposited				
Without Crater (415 m^2)			50,000	34,000
With Crater (420 m^2)			50,000	34,000

* Estimated that10% of the crater was sampled.

Table A7. Surface concentration of explosives residues from the live fire detonation of a 60-mm mortar with a proximity fuse setting of approximately 2 m at Camp Ethan Allen, Vt., 2/16/01.

Sample	Soot plume area (m^2)	Area sampled (m^2)	($\mu g/m^2$)					
			RDX	TNT	HMX	2,6-DNT	2,4-DNT	NG
Mortar #1	7.1	2.8	0.73	ND	0.55	ND	0.77	1.3
Mortar #2	6.2	5.0	1.1	0.35	0.092	0.63	0.32	3.7
Mortar #3	7.1	4.3	3.9	1.6	0.63	4.1	1.1	2.0
Mortar#4	78	7.8	1.9	0.51	0.55	0.13	0.43	0.17
Mortar #5	7.1	3.6	25	2.4	5.9	2.2	1.2	5.9
			Total mass (μg)					
Mortar #1			5.2	ND	3.9	ND	5.5	9.1
Mortar #2			6.6	2.2	0.57	3.9	2.0	23
Mortar #3			28	11	4.5	29	8.1	14
Mortar #4			150	40	43	10	33	13
Mortar #5			180	17	42	15	8.8	15

Table A8. Surface concentration of explosives residues from the live fire detonation of 40-mm rifle grenades with impact fuse setting at Camp Ethan Allen, Vt., 2/16/01.

Sample	Soot plume area (m^2)	Area sampled (m^2)	($\mu g/m^2$)						
			RDX	TNT	HMX	2,6-DNT	2,4-DNT	4AmDNT	2AmDNT
Grenade #1	4.0	2.0	350	1.9	45	0.14	2.1	12	3.2
Grenade #2	7.1	3.6	480	0.95	61	ND	2.3	22	5.9
Grenade #3	3.1	2.5	8.0	0.34	4.9	1.2	0.64	0.21	ND
			Total mass (μg)						
Grenade #1			1400	7.7	180	0.58	8.4	47	13
Grenade #2			3400	6.8	440	ND	17	150	42
Grenade #3			25	1.1	15	3.8	2.0	0.66	ND

Table A9. Surface concentrations of explosives residues from the detonation of a hand grenade with a timed fuse at Ft. Drum, NY, 3/8/01.

Area: Soot plume 24 m^2; Crater 1 m^2 (1 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	2,6-DNT
S1-1	6.5	1.2	0.47	0.32
S1-2	6.3	1.0	1.1	0.84
S1-3	5.3	1.2	0.79	0.60
S1-4	4.2	1.2	0.97	0.41
S1-5	3.1	1.4	1.2	1.1
S1-6	1.9	1.6	1.1	0.27
Crater	–	0.5	1.4	0.64
Total mass (μg) deposited				
Without Crater (23 m^2)			22	13
With Crater (24 m^2)			23	14

* Estimated that 50% of the crater was sampled.

Table A10. Surface concentrations of explosives residues from the detonation of a hand grenade with a timed fuse at Ft. Drum, NY, 3/8/01.

Area: Soot plume 28 m^2; Crater 1 m^2 (2 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	2,6-DNT
S2-1	1.3	1.1	0.56	0.49
S2-2	1.0	1.2	1.0	0.50
S2-3	2.5	1.4	0.44	0.47
S2-4	1.5	1.3	0.56	0.50
Crater	–	0.5	2.2	0.46
Total mass (μg) deposited				
Without Crater (27 m^2)			17	13
With Crater (28 m^2)			19	13

* Estimated that 50% of the crater was sampled.

Table A11. Surface concentrations of explosives residues from the detonation of a hand grenades with a timed fuse at Ft. Drum, NY, 3/8/01.

Area: Soot plume 25 m^2; Crater 1 m^2 (3 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	2,6-DNT
S3-1	1.0	1.1	0.55	0.63
S3-2	2.3	1.2	0.33	0.078
S3-3	1.3	1.1	0.49	0.56
S3-4	2.6	0.99	0.38	0.36
S3-5	3.0	1.1	0.39	0.60
Crater	–	0.5*	4.4	0.15
Total mass (μg) deposited				
Without Crater (24 m^2)			10	11
With Crater (25 m^2)			14	11

* Estimated that 50% of the crater was sampled.

Table A12. Surface concentrations of explosives residues from the detonation of a hand grenade with a timed fuse at Ft. Drum, NY, 3/8/01.

Area: Soot plume 20 m^2; Crater 1 m^2 (4 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	2,6-DNT
S4-1	1.0	0.89	0.72	0.40
S4-2	1.8	1.2	0.45	0.29
S4-3	3.8	1.2	0.34	0.22
S4-4	1.3	1.2	0.57	0.44
S4-5	1.1	0.95	0.37	0.29
Crater	–	0.5*	3.0	0.14
Total mass (μg) deposited				
Without Crater (19 m^2)			9.3	6.3
With Crater (20 m^2)			12	6.4

* Estimated that 50% of the crater was sampled.

Table A13. Surface concentrations of explosives residues from the detonation of a hand grenade with a timed fuse at Ft. Drum, NY, 3/8/01.

Area: Soot plume 24 m^2; Crater 1 m^2 (5 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	2,6-DNT
S5-1	1.8	2.7	0.87	0.15
S5-2	3.5	2.9	0.41	0.16
S5-3	1.1	1.6	0.59	0.29
S5-4	1.2	1.9	0.45	0.31
Crater	–	0.5*	2.4	0.36
Total mass (μg) deposited				
Without Crater (23 m^2)			13	5.3
With Crater (24 m^2)			15	5.7

* Estimated that 50% of the crater was sampled.

Table A14. Surface concentrations of explosives residues from the detonation of a hand grenade with a timed fuse at Ft. Drum, NY, 3/8/01.

Area: Soot plume 30 m^2; Crater 1 m^2 (6 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	2,6-DNT
S6-1	1.2	1.6	0.69	0.12
S6-2	1.8	1.4	1.8	0.14
S6-3	2.3	1.6	0.55	0.26
S6-4	2.7	1.3	1.1	0.15
S6-5	4.0	1.1	0.68	0.24
Crater	–	0.33*	4.4	0.22
Total mass (μg) deposited				
Without Crater (29 m^2)			28	5.2
With Crater (30 m^2)			32	5.4

* Estimated that 33% of the crater was sampled.

Table A15. Surface concentrations of explosives residues from the detonation of a hand grenade with a timed fuse at Ft. Drum, NY, 3/8/01.

Area: Soot plume 100 m^2; Crater 1 m^2 (7 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	2,6-DNT
S7-1	3.9	1.7	0.16	0.18
S7-2	5.6	1.0	0.090	0.27
S7-3	5.1	1.6	0.24	0.20
S7-4	4.7	1.4	0.27	0.11
S7-5	4.5	1.4	0.53	0.078
S7-6	7.8	1.7	0.049	0.068
S7-7	4.2	2.0	0.30	0.075
S7-8	3.0	2.1	0.55	0.094
S7-9	2.1	1.9	0.64	0.11
S7-10	2.1	1.6	0.43	0.075
S7-11	1.0	1.8	1.3	0.16
S7-12	1.4	1.3	0.75	0.13
S7-13	1.0	1.7	0.71	0.18
S7-14	1.2	1.5	2.1	0.16
Crater #1	–	0.5*	1.4	0.018
Crater #2	–	0.5*	2.1	ND
Total mass (μg) deposited				
Without Crater (99 m^2)			57	14
With Crater (1 m^2)			59	14

* Estimated that 50% of the crater was sampled.

Table A16. Surface concentrations of explosives residues from a 120-mm mortar round with impact fuse setting at Camp Ethan Allen, Vt., 3/19/01.

Area: Soot plume 1100 m^2; Crater 10 m^2 (1 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)							
			RDX	TNT	HMX	2,6-DNT	2,4-DNT	4AmDNT	2AmDNT	NG
S1-0P**	30.2	1.89	ND	0.021	ND	ND	ND	ND	ND	0.053
S1-1	25.2	2.03	0.18	0.10	0.058	ND	0.18	0.17	ND	0.025
S1-2	21.4	2.03	0.37	0.17	0.078	0.072	ND	ND	ND	0.063
S1-3	17.8	1.56	0.50	0.37	0.10	ND	ND	0.10	ND	0.047
S1-4	14.8	1.69	3.9	0.21	0.13	0.10	0.099	0.80	0.17	ND
S1-5	11	1.82	0.60	0.15	0.095	ND	ND	ND	ND	ND
S1-6	8.2	1.68	0.63	ND	0.097	ND	ND	0.63	0.14	ND
S1-7	5.1	1.62	1.1	0.080	0.092	ND	ND	0.080	ND	0.070
S1-8	2.8	1.21	1.7	0.37	0.24	ND	ND	0.67	ND	0.90
S1-9	7.4	1.37	2.9	0.15	0.089	0.027	ND	ND	ND	0.21
S1-10	7.9	1.32	0.45	0.13	ND	ND	ND	0.22	ND	ND
S1-11	8.6	1.32	1.2	0.05	0.11	0.025	ND	0.11	ND	ND
S1-12	9.9	1.50	1.4	0.12	0.10	ND	ND	0.15	ND	ND
S1-13	11.1	1.50	1.3	0.15	0.064	ND	ND	ND	ND	0.040
S1-14	6.7	1.50	0.99	0.35	0.085	ND	0.053	ND	ND	ND
S1-15	8.6	1.44	0.64	0.11	0.047	0.057	ND	ND	ND	0.088
S1-16	12.9	1.30	0.52	0.14	0.031	ND	ND	0.10	ND	ND
S1-17	22.4	1.44	0.44	0.20	0.024	0.066	0.11	0.18	ND	0.057
S1-18	26.9	1.56	ND	0.084	ND	0.089	0.081	ND	ND	0.051
Crater	–	0.5*	12	ND	2.5	ND	ND	ND	ND	9.4
Total mass (μg) deposited										
Without Crater (1090 m^2)			1100	170	87					94
With Crater (1100 m^2)			1200	170	110					190

* Estimated that 5% of the crater was sampled.

** Sample collected outside of soot plume.

Table A17. Surface concentrations of explosives residues from a 120-mm mortar round with impact fuse setting at Camp Ethan Allen, Vt., 3/19/01.

Area: Soot plume 570 m^2; Crater sample lost (2 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)							
			RDX	TNT	HMX	2,6-DNT	2,4-DNT	4AmDNT	2AmDNT	NG
S2-1	7.6	4.00	0.55	0.039	0.038	0.027	ND	0.12	0.097	0.025
S2-2	8.0	6.30	0.33	0.022	0.044	0.006	ND	0.075	ND	0.92
S2-3	13.2	5.00	0.20	0.022	0.022	0.014	ND	ND	ND	0.017
S2-4	11.7	4.32	2.0	0.052	0.082	0.011	ND	ND	ND	ND
S2-5	20.0	5.40	0.98	0.004	0.020	ND	ND	ND	ND	0.31
Total mass (μg) deposited										
Plume (570 m^2)			460	16	23					140

Note: Crater sample was lost.

Table A18. Surface concentrations of explosives residues from a 120-mm mortar round with impact fuse setting at Camp Ethan Allen, Vt., 3/19/01.

Area: Soot plume 780 m^2; Crater 10 m^2 (3 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)							
			RDX	TNT	HMX	2,6-DNT	2,4-DNT	4AmDNT	2AmDNT	NG
S3-1	16.0	0.72	1.4	0.29	0.18	ND	ND	0.26	ND	0.48
S3-2	13.5	0.81	0.81	0.14	0.045	ND	ND	0.14	ND	0.14
S3-3	9.6	1.27	1.2	0.65	0.088	0.33	0.26	0.24	ND	0.39
S3-4	5.1	0.64	1.9	0.22	0.12	0.10	ND	ND	0.24	2.0
S3-5	2.3	0.33	9.3	0.88	0.63	0.73	ND	ND	ND	38
S3-6	2.3	0.63	4.2	0.58	0.22	0.070	ND	0.25	ND	7.8
S3-7	3.6	0.63	4.3	0.24	0.15	ND	ND	ND	ND	25
S3-8	12.3	0.56	2.2	0.84	0.054	0.17	ND	0.22	ND	1.0
Crater	–	0.5*	34	0.30	2.2	1.4	ND	3.7	ND	120
Total mass (μg) deposited										
Without Crater (770 m^2)			2400	370	150					7200
With Crater (780 m^2)			2700	370	170					8400

* Estimated that 5% of the crater was sampled.

Table A19. Surface concentrations of explosives residues from a 120-mm mortar round with impact fuse setting at Camp Ethan Allen, Vt., 3/19/01.

Area: Soot plume 180 m^2; Crater 10 m^2 (4 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)							
			RDX	TNT	HMX	2,6-DNT	2,4-DNT	4AmDNT	2AmDNT	NG
S4-1	7.7	1.1	1.9	0.12	0.14	0.15	ND	0.12	ND	0.069
S4-2	8.4	1.38	0.83	0.20	0.080	ND	ND	ND	ND	0.94
S4-3	7.2	1.21	1.3	0.17	ND	0.040	ND	ND	ND	0.52
S4-4	5.4	0.86	1.6	0.46	0.12	0.13	ND	0.14	ND	1.1
S4-5	3.0	0.75	9.5	0.68	0.75	0.18	ND	ND	ND	3.3
S4-6	4.5	0.79	14	0.15	0.80	ND	ND	ND	0.22	2.2
S4-7	5.2	1.11	3.2	ND	0.095	ND	ND	ND	ND	0.94
Crater	–	0.5*	100	0.56	18	2.8	1.5	5.6	ND	78
Total mass (μg) deposited										
Without Crater (170 m^2)			790	42	48					220
With Crater (180 m^2)			1800	48	230					1000

* Estimated that 5% of the crater was sampled.

Table A20. Surface concentrations of explosives residues from a 120-mm mortar round with impact fuse setting at Camp Ethan Allen, Vt., 3/19/01.

Area: Soot plume 320 m^2; Crater 10 m^2 (5 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)							
			RDX	TNT	HMX	2,6-DNT	2,4-DNT	4AmDNT	2AmDNT	NG
S5-1	6.1	0.90	3.2	0.20	0.72	ND	ND	ND	ND	0.35
S5-2	7.8	1.08	2.8	0.14	0.12	ND	ND	0.10	ND	0.56
S5-3	7.5	1.54	1.1	0.028	ND	0.089	ND	ND	ND	1.0
S5-4	8.3	1.38	0.22	0.16	0.044	ND	ND	ND	ND	1.4
S5-5	11.2	1.50	0.57	0.41	0.079	0.033	ND	ND	ND	0.63
S5-6	10.5	1.32	0.93	0.15	ND	ND	ND	ND	ND	0.065
S5-7	5.2	1.26	1.2	0.087	ND	ND	ND	ND	ND	2.6
S5-8	5.8	1.20	0.93	0.046	ND	0.088	ND	ND	ND	0.15
Crater	–	0.5*	70	0.85	6.0	ND	ND	ND	ND	190
Total mass (μg) deposited										
Without Crater (310 m^2)			430	47	37					260
With Crater (320 m^2)			1100	56	97					2200

* Estimated that 5% of the crater was sampled.

Table A21. Surface concentrations of explosives residues from a 120-mm mortar round with impact fuse setting at Camp Ethan Allen, Vt., 3/19/01.

Area: Soot plume 1280 m^2; Crater 10 m^2 (6 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)							
			RDX	TNT	HMX	2,6-DNT	2,4-DNT	4AmDNT	2AmDNT	NG
S6-1	22	0.90	3.0	0.62	0.22	0.21	ND	0.22	ND	0.50
S6-2	21.3	0.90	2.2	0.062	ND	0.060	0.12	0.083	ND	0.52
S6-3	17.7	0.72	26	6.6	0.26	0.31	0.17	0.31	ND	0.76
S6-4	14.1	0.90	9.6	0.38	0.44	ND	ND	ND	ND	1.3
S6-5	9.7	0.95	15	0.070	0.68	ND	0.12	ND	ND	0.48
S6-6	10.4	1.05	11	0.083	0.46	ND	0.083	ND	0.082	0.41
S6-7	7.4	0.68	21	0.19	0.20	0.18	0.38	ND	ND	ND
Crater	--	0.5*	32	1.2	4.8	0.69	1.7	ND	ND	23
Total mass (μg) deposited										
Without Crater (1270 m^2)			16,000	1500	410					720
With Crater (1280 m^2)			16,000	1500	460					950

* Estimated that 5% of the crater was sampled.

A22. Surface concentrations of explosives residues for a 120-mm mortar with impact fuse setting at Camp Ethan Allen, Vt., 3/19/01.

Area: Soot plume 870 m^2; Crater 10 m^2 (7 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)							
			RDX	TNT	HMX	2,6-DNT	2,4-DNT	4AmDNT	2AmDNT	NG
S7-1	7.4	1.05	5.0	0.071	ND	ND	0.10	ND	ND	0.058
S7-2	5.5	1.44	29	0.73	0.35	ND	0.54	ND	ND	ND
S7-3	11.5	1.98	4.5	ND	0.098	0.091	0.25	ND	ND	0.041
S7-4	11.4	2.06	1.9	ND	ND	0.057	ND	ND	ND	0.49
S7-5	11.7	1.40	0.71	ND	0.041	ND	ND	ND	ND	0.38
S7-6	9.3	1.38	1.5	ND	ND	0.033	0.13	0.10	ND	ND
S7-7	14.1	1.05	0.83	0.041	ND	0.086	0.039	0.11	ND	0.071
Crater	--	0.5*	20	ND	2.7	ND	9.7	ND	ND	3.6
Total mass (μg) deposited										
Without Crater (860 m^2)			5300	150	60					130
With Crater (870 m^2)			5500	150	87					170

* Estimated that 5% of the crater was sampled.

Table A23. Surface concentrations of explosives residues from the detonation of 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, Vt., 1/16/2002.

Area: Soot plume 216 m^2; Crater 1.5 m^2 (1 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
S1-1	5.8	1.00	12	4.6
S1-2	3.3	1.00	32	8.9
S1-3	2.0	1.00	250	100
S1-4	1.9	1.00	200	91
S1-5	3.0	1.00	10	5.9
S1-6	5.1	1.00	2.1	2.4
S1-7	7.0	1.00	0.80	0.89
S1-8	5.0	0.85	8.3	2.7
S1-9	2.6	0.86	31	11
S1-10	2.1	0.86	110	42
S1-11	7.7	1.00	1.5	0.76
S1-12	8.1	1.00	14	3.2
S1-13	6.4	1.00	37	17
S1-14	4.6	1.00	89	36
S1-15	2.3	1.00	110	45
S1-16	15	2.00	6.9	4.0
Crater	–	0.075*	1300	400
Total mass (μg) deposited				
Without Crater (214 m^2)			12,000	5100
With Crater (216 m^2)			14,000	5700

* Estimated that 5% of the crater was sampled

A24. Surface concentrations of explosives residues from the detonation of 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, Vt., 1/16/2002.

Area: Soot plume 90 m^2; Crater 1.5 m^2 (2 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
S2-1	1.6	0.67	460	160
S2-2	2.0	0.76	480	140
S2-3	3.1	0.76	350	130
S2-4	4.5	0.90	140	63
S2-5	7.6	0.65	1.8	0.74
S2-6	7.6	0.66	28	7.2
S2-7	3.8	0.90	130	57
S2-8	2.1	0.76	38	13
Crater	–	0.075*	170	240
Total mass (μg) deposited				
Without Crater (88 m^2)			18,000	6200
With Crater (90 m^2)			18,000	6600

* Estimated that 5% of the crater was sampled.

Table A25. Surface concentrations of explosives residues from the detonation of 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, Vt., 1/16/2002.

Area: Soot plume 96 m^2; Crater 2.0 m^2 (3 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
S3-1	1.8	0.58	210	15
S3-2	3.7	0.67	31	11
S3-3	2.6	0.73	17	8.8
S3-4	2.8	0.73	6.4	3.4
S3-5	3.6	0.64	0.06	0.48
S3-6	2.2	0.63	0.65	1.3
S3-7	3.6	0.72	ND	ND
Crater	–	0.10*	13	16
Total mass (μg) deposited				
Without Crater (94 m^2)			3600	550
With Crater (96 m^2)			3600	580

* Estimated that 5% of the crater was sampled.

Table A26. Surface concentrations of explosives residues from the detonation of 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, Vt., 1/16/2002.

Area: Soot plume 208 m^2; Crater 1.5 m^2 (4 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
S4-1	8.2	1.00	230	62
S4-2	5.1	1.00	150	61
S4-3	2.0	1.00	79	27
S4-4	2.0	1.00	2.0	1.6
S4-5	3.6	1.00	0.07	ND
S4-6	2.1	1.00	6.8	3.8
S4-7	3.8	1.00	0.16	0.03
S4-8	1.7	1.00	2.4	2.0
Crater	–	0.075*	73	40
Total mass (μg) deposited				
Without Crater (206 m^2)			12,000	4100
With Crater (208 m^2)			12,000	4200

* Estimated that 5% of the crater was sampled.

Table A27. Surface concentrations of explosives residues from the detonation of 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, Vt., 2/15/2002.

Area: Soot plume 179 m^2; Crater 1.8 m^2 (5 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
S5-1	1.5	0.72	12	13
S5-2	2.3	1.05	32	23
S5-3	3.9	0.90	16	19
S5-4	1.6	0.80	15	17
S5-5	5.1	1.05	18	19
S5-6	6.8	0.90	38	37
S5-7	9.6	0.90	34	0.71
S5-8	6.4	0.90	11	9.5
Crater	–	0.090*	260	230
Total mass (μg) deposited				
Without Crater (177 m^2)			3900	3000
With Crater (179 m^2)			4400	3400

* Estimated that 5% of the crater was sampled.

Table A28. Surface concentrations of explosives residues from the detonation of 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, Vt., 2/15/2002.

Area: Soot plume 124 m^2; Crater 1.5 m^2 (6 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
S6-1	7.3	0.99	0.18	ND
S6-2	4.5	0.90	2.6	0.83
S6-3	3.3	0.99	7.5	4.4
S6-4	3.2	0.81	35	23
S6-5	5.0	0.83	36	31
S6-6	4.1	0.81	19	12
S6-7	2.0	0.81	80	42
Crater	–	0.15*	240	150
Total mass (μg) deposited				
Without Crater (122 m^2)			3100	2000
With Crater (124 m^2)			3500	2200

* Estimated that 10% of the crater was sampled.

Table A29. Surface concentrations of explosives residues from the detonation of 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, 2/15/2002.

Area: Soot plume 158 m^2; Crater 1.7 m^2 (7 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
S7-1	14.3	1.05	2.2	2.0
S7-2	10.0	0.81	11	9.8
S7-3	6.7	0.86	13	11
S7-4	3.8	0.86	28	21
S7-5	1.5	0.72	82	5.7
S7-6	2.3	0.81	30	31
Crater	–	0.17*	160	150
Total mass (μg) deposited				
Without Crater (156 m^2)			4300	2000
With Crater (158 m^2)			4600	2200

* Estimated that 10% of the crater was sampled.

Table A30. Surface concentrations of explosives residues from the detonation of a Claymore mine at Camp Ethan Allen, Vt., 2/2/02.

Area: Soot plume 127 m^2; Crater 1.3 m^2 (1 of 7).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
1	2.5	1	21	7.7
2	3.8	0.74	120	32
3	4.6	0.73	49	21
4	6.7	0.62	120	39
5	11	0.62	61	27
6	2.8	0.66	340	37
7	8.6	0.6	17	2.3
Crater	—	0.065*	240	49
Total mass (μg) deposited				
Without Crater (126 m^2)			13,000	3000
With Crater (127 m^2)			13,000	3100

* Estimated that 5% of the crater was sampled.

Table A31. Surface concentrations of explosives residues from the detonation of a Claymore mine at Camp Ethan Allen, Vt., 2/2/02.

Area: Soot plume 135 m^2; Crater 1.0 m^2 (2 of 7).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
1	3.1	0.66	120	34
2	4.9	0.54	35	12
3	6.4	0.66	46	22
4	8.3	0.79	30	20
5	10	0.73	3.2	3.1
6	3.0	0.81	74	5.9
7	5.8	0.86	9.1	4.5
Crater	—	0.05*	1300	120
Total mass (μg) deposited				
Without Crater (134 m^2)			6100	3000
With Crater (135 m^2)			7400	3100

* Estimated that 5% of the crater was sampled.

Table A32. Surface concentrations of explosives residues from the detonation of a Claymore mine at Camp Ethan Allen, Vt., 2/2/02.

Area: Soot plume 129 m^2; Crater 0.88 m^2 (3 of 7).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
1	1.9	1	11	13
2	1.7	1	66	41
3	3.0	1	3.8	4.6
4	5.2	1	2.0	1.6
5	5.5	1	1.6	2.8
6	3.5	1	28	30
7	5.5	1	27	21
8	7.1	1	20	28
9	9.1	1	4.0	6.2
10	12	1	0.75	0.17
11	4.5	1	11	17
12	9.1	1	0.11	0
Crater	—	0.044*	96	10
Total mass (μg) deposited				
Without Crater (128 m^2)			1900	1800
With Crater (129 m^2)			2000	1800

* Estimated that 5% of the crater was sampled.

Table A33. Surface concentrations of explosives residues from the detonation of a Claymore mine at Camp Ethan Allen, Vt., 2/2/02.

Area: Soot plume 117 m^2, Crater 2.1 m^2 (4 of 7).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
1	2.5	0.49	79	43
2	3.8	0.48	37	21
3	6.4	0.54	63	25
4	7.1	0.70	2.4	5.4
5	4.2	0.43	140	37
6	6.0	0.74	4.7	4.8
7	5.2	0.66	20	14
Crater	—	0.10*	1100	150
Total mass (μg) deposited				
Without Crater (115 m^2)			5700	2500
With Crater (117 m^2)			8000	2800

* Estimated that 5% of the crater was sampled.

Table A34. Surface concentrations of explosives residues from the detonation of a Claymore mine at Camp Ethan Allen, Vt., 2/2/02.

Area: Soot plume 107 m^2; Crater 1.0 m^2 (5 of 7).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
1	3.5	0.56	30	5.7
2	5.8	0.71	26	6.8
3	7.1	0.62	25	5.9
4	12	0.78	1.0	0.29
5	2.0	0.76	2.2	11
6	4.0	0.48	0.37	0
7	6.8	0.70	0	0
8	9.2	0.54	0	0
Crater	—	0.05*	1700	52
Total mass (μg) deposited				
Without Crater (106 m^2)			1100	390
With Crater (107 m^2)			2800	440

* Estimated that 5% of the crater was sampled.

Table A35. Surface concentrations of explosives residues from the detonation of a Claymore mine at Camp Ethan Allen, Vt., 2/2/02.

Area: Soot plume 118 m^2; Crater 1.2 m^2 (6 of 7).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
1	7.3	1	160	80
2	4.7	1	170	63
3	2.0	1	570	190
4	2.3	1	100	42
5	4.6	1	260	82
6	7.6	1	49	31
Crater	—	0.06*	520	41
Total mass (μg) deposited				
Without Crater (117 m^2)			26,000	9500
With Crater (118 m^2)			27,000	9500

* Estimated that 5% of the crater was sampled.

Table A36. Surface concentrations of explosives residues from the detonation of a Claymore mine at Camp Ethan Allen, Vt., 2/2/02.

Area: Soot plume 126 m^2; Crater 1.7 m^2 (7 of 7).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
1	2.5	0.56	190	56
2	3.8	0.75	520	130
3	6.4	0.61	89	25
4	7.1	0.52	98	43
5	4.2	0.30	31	12
6	6.0	0.66	7.2	0
7	5.2	0.74	15	6.0
Crater	—	0.085*	130	35
Total mass (μg) deposited				
Without Crater (124 m^2)			17,000	4800
With Crater (126 m^2)			17,000	4900

* Estimated that 5% of the crater was sampled.

Table A37. Surface concentrations of explosives residues from the detonation of a 155-mm howitzer round with a 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, Vt., 2/28/2002.

Area: Soot plume 496 m^2, Crater 1.0 m^2 (1 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)				
			TNT	TNB	2,4DNT	2AmDNT	4AmDNT
S1-1†	12.6	1.00	180,000	ND	300	ND	ND
S1-2	10.0	1.00	49,000	2600	230	ND	65
S1-3	8.3	1.00	170,000	1600	600	440	1000
S1-4	6.2	1.00	200,000	2800	780	920	1000
S1-5	3.8	1.00	530,000	1400	2600	2100	1100
S1-6	1.8	1.00	330,000	8300	2300	3800	2800
S1-7	2.0	1.00	19,000	630	310	410	500
S1-8	4.4	1.00	1000	110	51	60	110
S1-9	6.0	1.00	3200	380	51	34	41
S1-10	8.0	1.00	4300	ND	49	91	250
S1-11	1.5	1.00	1,300,000	2500	3700	8700	8100
S1-12	4.0	1.00	340,000	1000	2600	2000	4000
S1-13	6.6	1.00	140,000	50	400	230	920
S1-14	4.6	1.00	15,000	650	320	200	170
S1-15	6.8	1.00	21,000	350	150	170	220
Crater	–	1.0*	1,800,000	5800	3300	11,000	14,000
Total mass (g) deposited							
Without Crater (495 m^2)			110				
With Crater (496 m^2)			110				

† Sample (soot) used for TNT particle size classification.

* Estimated that 100% of the crater was sampled.

Table A38. Surface concentrations of explosives residues from the detonation of a 155-mm howitzer round with a 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, Vt., 2/28/2002.

Area: Soot plume 311 m^2; Crater 1.8 m^2 (2 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)				
			TNT	TNB	2,4DNT	2AmDNT	4AmDNT
S2-1	6.0	1.00	170,000	800	520	440	810
S2-2	3.3	0.70	120,000	4,900	730	180	120
S2-3	2.3	0.45	160,000	650	800	260	840
S2-4	3.8	0.74	32,000	230	330	200	220
S2-5	3.0	0.52	150	290	ND	ND	0.50
S2-6	4.6	0.52	650	210	60	ND	3.5
S2-7	3.9	0.48	69	190	0.89	7.9	10
S2-8	4.4	0.58	630,000	770	1,100	640	430
S2-9	7.0	0.90	440	ND	ND	ND	11
Crater	–	0.56*	200,000	1,900	430	150	ND
Total mass (g) deposited							
Without Crater (309 m^2)			38				
With Crater (311 m^2)			38				

* Estimated that 30% of the crater was sampled

Table A39. Surface concentrations of explosives residues from the detonation of a 155-mm howitzer round with a 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, Vt., 2/28/2002.

Area: Soot plume 345 m^2, Crater 1.7 m^2 (3 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)				
			TNT	TNB	2,4DNT	2AmDNT	4AmDNT
S3-1	8.0	0.68	750	110	ND	24	28
S3-2	5.9	0.56	41	21	ND	ND	ND
S3-3	4.4	0.49	42	37	ND	11	ND
S3-4	2.5	0.72	140	22	13	0.31	10
S3-5	1.3	0.60	51	ND	0.44	24	2.7
S3-6	2.0	0.52	3.7	ND	ND	58	1.4
S3-7	2.6	0.49	240	ND	0.42	57	22
S3-8	3.1	0.72	4.6	ND	1.2	ND	ND
S3-9	4.7	0.60	5.2	ND	ND	16	ND
S3-10	5.0	0.39	NA	NA	NA	NA	NA
S3-11	5.6	0.43	19	ND	ND	0.19	0.24
Crater	–	0.42*	17	ND	ND	28	ND
Total mass (μg) deposited							
Without Crater (343 m^2)			45,000				
With Crater (345 m^2)			45,000				

* Estimated that 25% of the crater was sampled.

Table A40. Surface concentrations of explosives residues from the detonation of a 155-mm howitzer round with a 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, Vt., 2/28/2002.

Area: Soot plume 344 m^2; Crater 0.56 m^2 (4 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)				
			TNT	TNB	2,4DNT	2AmDNT	4AmDNT
S4-1	0.6	0.64	0.47	ND	ND	ND	0.23
S4-2	6.6	0.55	0.82	ND	ND	10	ND
S4-3	9.1	0.68	ND	ND	ND	ND	ND
S4-4	6.0	0.72	1.5	ND	ND	ND	ND
S4-5	2.5	0.33	1.9	ND	ND	ND	0.21
S4-6	1.7	0.42	7.5	ND	ND	19	1.7
S4-7	4.8	0.55	0.39	ND	ND	ND	ND
S4-8	6.4	0.60	0.42	ND	ND	ND	ND
S4-9	4.0	0.63	0.22	ND	ND	ND	ND
Crater	–	0.56*	5.2	ND	ND	0.14	0.20
Total mass (μg) deposited							
Without Crater (343 m^2)			500				
With Crater (344 m^2)			510				

* Estimated that 100% of the crater was sampled

Table A41. Surface concentrations of explosives residues from the detonation of a 155-mm howitzer round with a 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, Vt., 2/28/2002.

Area: Soot plume 406 m^2; Crater 1.0 m^2 (5 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)				
			TNT	TNB	2,4DNT	2AmDNT	4AmDNT
S5-1	13.5	1.00	28,000	20	130	40	230
S5-2	11.5	1.00	7,300	31	130	180	380
S5-3	9.5	1.00	9,600	100	73	110	290
S5-4	7.5	1.00	15,000	120	10	50	180
S5-5	5.5	1.00	29,000	170	65	190	330
S5-6	3.5	1.00	7,000	94	64	230	260
S5-7	4.5	1.00	7,500	55	26	480	490
S5-8	6.5	1.00	17,000	290	36	ND	27
S5-9	8.5	1.00	5,300	210	140	23	31
S5-10	1.9	1.00	43,000	560	70	780	1,700
Crater	--	0.50*	38,000	430	8.3	82	87
Total mass (g) deposited							
Without Crater (405 m^2)			6.9				
With Crater (406 m^2)			6.9				

* Estimated that 50% of the crater was sampled.

Table A42. Surface concentrations of explosives residues from the detonation of a 155-mm howitzer round with a 1.25-lb (0.57-kg) block of C4 at Camp Ethan Allen, Vt., 2/28/2002.

Area: Soot plume 301 m^2; Crater 1.3 m^2 (6 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)				
			TNT	TNB	2,4DNT	2AmDNT	4AmDNT
S6-1	4.6	0.56	2.7	ND	ND	ND	ND
S6-2	4.0	0.56	0.46	ND	ND	ND	ND
S6-3	5.9	0.60	610	1.6	12	470	150
S6-4	7.4	0.80	16	30	7.4	ND	ND
S6-5	2.5	0.52	32	24	30	17	25
S6-6	2.5	0.60	210	ND	15	12	1.2
S6-7	2.7	0.56	5700	ND	150	120	62
S6-8	3.8	0.63	0.85	ND	0.34	ND	0.11
S6-9	5.5	0.60	21	23	26	ND	ND
S6-10	2.0	0.52	200	ND	18	16	11
Crater	--	0.13*	3.2	ND	ND	94	ND
Total mass (μg) deposited							
Without Crater (300 m^2)			200,000				
With Crater (301 m^2)			200,000				

* Estimated that 10% of the crater was sampled.

Table A43. Surface concentrations of explosives residues from the detonation of a 155-mm howitzer round with a 1.25-lb(0.57-kg) block of C4 at Camp Ethan Allen, Vt., 2/28/2002.

Area: Soot plume 473 m^2; Crater 2.2 m^2 (7 of 7)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)				
			TNT	TNB	2,4DNT	2AmDNT	4AmDNT
S7-1	6.9	0.64	22	ND	8.8	ND	0.14
S7-2	7.1	0.66	72	ND	ND	0.10	0.99
S7-3	7.8	0.55	710	33	7.8	51	100
S7-4	3.5	0.72	110	58	6.3	ND	ND
S7-5	3.1	0.75	0.39	ND	3.9	ND	ND
S7-6	6.5	0.56	110	20	9.4	0.069	0.72
S7-7	2.2	0.49	ND	ND	ND	ND	ND
S7-8	3.7	0.76	6.0	ND	ND	ND	ND
S7-9	8.6	0.52	560	54	ND	21	37
S7-10	9.2	0.60	230	ND	0.41	21	58
S7-11	7.9	0.48	27	ND	0.45	11	4.4
Crater	--	0.22*	0.91	ND	ND	ND	0.29
Total mass (μg) deposited							
Without Crater (473 m^2)			80,000				
With Crater (475 m^2)			80,000				

* Estimated that 10% of the crater was sampled.

Table A44. Surface concentrations of explosives residues from the detonation of a PMA 1A with a blasting cap at Camp Ethan Allen, Vt., 3/7/02.

Area: Soot plume 140 m^2; Crater 0.52 m^2 (1 of 2). North

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)
			TNT
1	3.2	0.63	13,000
2	2.7	0.70	78
3	3.5	0.66	14
4	3.0	0.65	68
5	1.1	0.85	810
6	1.5	0.84	74
7	2.5	0.64	16
Crater	—	0.052*	4700
Total mass (g) deposited			
Without Crater (139 m^2)			0.28
With Crater (140 m^2)			0.28

* Estimated that 10% of the crater was sampled.

Table A45. Surface concentrations of explosives residues from the detonation of PMA 1A with a blasting cap at Camp Ethan Allen, Vt., 3/7/02.

Area: Soot plume 147 m^2; Crater 0.38 m^2 (2 of 2). South

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)
			TNT
1	3.0	1.3	56
2	1.4	1.1	270
3	6.4	1	32,000
4	1.2	1	16,000
5	4.6	1	1.4
6	3.0	1.3	29
7	5.2	1	2,100
8	2.4	1.4	8,300
Crater		0.038*	69,000
Total mass (g) deposited			
Without Crater (147 m^2)			1.1
With Crater (147 m^2)			1.1

* Estimated that 10% of the crater was sampled.

Table A46. Surface concentrations of explosives residues from the detonation of a PMA 2 with a blasting cap at Camp Ethan Allen, Vt., 3/7/02.

Area: Soot plume 110 m^2; Crater 0.28 m^2 (1 of 2).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	TNT
1	3.0	1.4	6.0	78
2	1.4	1.4	5.2	0.41
3	6.4	1.2	6.5	0.066
4	1.2	1.1	6.7	18
5	4.6	1.6	4.7	8.9
Crater	—	0.028*	450	83
Total mass (mg) deposited				
Without Crater (110 m^2)			0.64	2.3
With Crater (110 m^2)			0.77	2.3

* Estimated that 10% of the crater was sampled.

Table A47. Surface concentrations of explosives residues from the detonation of a PMA 2 with a blasting cap at Camp Ethan Allen, Vt., 3/7/02.

Area: Soot plume 96 m^2; Crater 0.42 m^2 (2 of 2).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	TNT
1	2.6	1.4	33	580
2	2.6	1.5	24	2.1
3	2.0	1.3	15	5.2
4	4.0	1.6	23	0
5	1.5	1.2	19	370
6	3.6	1.2	0	45,000
7	1.2	1.7	6.9	5.0
8	3.5	1.4	6.7	16
Crater	—	0.042*	300	1000
Total mass (mg) deposited				
Without Crater (96 m^2)			1.5	550
With Crater (96 m^2)			1.6	550

* Estimated that 10% of the crater was sampled

Table A48. Surface concentrations of explosives residues from the detonation of a PPM 2 with 0.62 lb (0.28 kg) of C4 at Camp Ethan Allen, Vt., 3/7/02.

Area: Soot plume 149 m^2; Crater 0.78 m^2 (1 of 2).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)		
			RDX	HMX	TNT
1	2.6	0.81	40	25	8,700
2	3.4	0.55	140	0	610
3	3.3	0.68	310	52	2,000
4	3.2	0.68	79	14	2,100
5	1.6	0.68	1300	220	4,500
6	1.2	0.60	290	41	28,000
7	1.2	0.67	60	22	220
Crater	—	0.039*	2400	1100	110,000
Total mass (mg) deposited					
Without Crater (148 m^2)			47	7.9	980
With Crater (149 m^2)			49	8.8	1100

* Estimated that 5% of the crater was sampled.

Table A49. Surface concentrations of explosives residues from the detonation of a PPM 2 with 0.62 lb (0.28 kg) of C4 at Camp Ethan Allen, Vt., 3/7/02.

Area: Soot plume 157 m^2; Crater 1.0 m^2 (2 of 2).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)		
			RDX	HMX	TNT
1	5.0	1	78	0	14,000
2	2.9	1	220	0	61,000
3	1.5	1	580	0	100,000
4	1.2	1	690	0	96,000
5	2.8	1	260	61	28,000
6	1.6	1	230	0	28,000
7	3.4	1	110	0	10,000
8	1.3	1	1.3	0	450
Crater	—	0.05*	2100	0	1,300,000
Total mass (mg) deposited					
Without Crater (156 m^2)			42	—	6600
With Crater (157 m^2)			44	—	7900

* Estimated that 5% of the crater was sampled

Table A50. Surface concentrations of explosives residues from the detonation of a VS 50 with 0.62 lb (0.28 kg) of C4 at Camp Ethan Allen, Vt., 3/7/02.

Area: Soot plume 108 m^2; Crater 0.70 m^2 (1 of 2).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
1	3.0	0.72	1300	64
2	2.2	0.76	4800	90
3	3.0	0.50	130	4.1
4	1.9	0.68	730	36
5	1.1	0.64	2,300	160
6	3.5	0.60	37	0.94
7	3.0	0.78	97	0
8	1.1	0.54	1200	40
Crater	—	0.035*	45,000	4400
Total mass (mg) deposited				
Without Crater (107 m^2)			140	5.3
With Crater (108 m^2)			170	8.4

* Estimated that 5% of the crater was sampled.

Table A51. Surface concentrations of explosives residues from the detonation of a VS 50 with 0.65 lb (0.28 kg) of C4 at Camp Ethan Allen, Vt., 3/7/02.

Area: Soot plume 121 m^2; Crater 1.0 m^2 (2 of 2).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
1	—	1	330	0
2	—	1	95	0
3	—	1	1400	42
4	—	1	220	52
5	—	1	220	25
6	—	1	540	20
7	—	1	26	5.7
8	—	1	3100	57
Crater	—	0.05	16,000	450
Total mass (mg) deposited				
Without Crater (107 m^2)			89	3.0
With Crater (108 m^2)			100	3.4

* Estimated that 5% of the crater was sampled.

Table A52. Surface concentrations of explosives residues from the live fire detonation of an 81-mm mortar round at Ft. Richardson, Alaska, 3/13/2002.

Area: Soot plume 230 m^2; Crater 5.8 m^2 (1 of 2)

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)					
			RDX	TNT	2,4DNT	2,6DNT	2AmDNT	4AmDNT
S1-1	5.3	1	2.4	2.6	0.72	0.48	ND	ND
S1-2	3.0	1	11	1.6	2.8	1.9	2.2	3.9
S1-3	2.4	1	21	8.0	4.9	2.0	4.8	13
S1-4	5.2	1	19	14	4.1	1.6	4.3	7.1
S1-5	3.4	1	3.9	1.0	1.9	0.49	2.6	4.1
S1-6	5.2	1	52	36	15	6.2	12	19
S1-7	7	1	28	23	5.6	0.16	1.8	11
S1-8	9.2	1	1.1	0.17	1.1	0.31	2.4	4.0
S1-9	7.3	1	33	0.72	4.7	3.2	3.8	15
S1-10	7.3	1	20	22	7.9	4.7	13	54
S1-12	4.4	1.7	56	12	9.8	4.2	8.1	29
S1-13	4.4	1.4	39	0.19	4.8	2.8	5.1	12
S1-13A	9.0	1	19	7.5	3.5	1.4	5.5	7.6
S1-Crater	—	0.58*	16	1.8	4.2	1.4	2.6	19
Total mass (μg) deposited								
Without Crater (224 m^2)			5300	2200	1100	510	1100	3100
With Crater (230 m^2)			5400	2200	1100	520	1100	3300

Note: Sample S1-11 lost.

* Estimated that 10% of the crater was sampled.

Table A53. Surface concentrations of explosives residues from the live fire detonation of thirteen 81-mm mortar rounds at Ft. Richardson, Alaska, 3/13/2002. Plumes for rounds designated 2 through 14 overlapped.

Area: 13 overlapping Soot plumes 1670 m^2; Craters: 8.4, 8.1, 8.4, 8.7, 7.6, 7.0, 8.1, 6.5, 6.8, 7.8, 9.2, 5.2, 7.1 m^2 (2 of 2)

Sample	Sample area (m^2)	($\mu g/m^2$)					
		RDX	TNT	2,4DNT	2,6DNT	2AmDNT	4AmDNT
S2-1	0.87	18	15	3.7	1.8	2.2	4.0
S2-2	0.96	48	2.2	10	5.1	7.2	29
S2-3	0.92	52	4.0	8.2	15	7.2	10
S2-4	0.90	110	17	39	17	67	210
S2-5	1	80	2.1	14	10	19	39
S2-6	1	170	4.2	24	17	18	70
S2-7	0.94	130	0.89	20	14	19	97
S2-8	1	78	0.07	8.1	7.2	3.5	8.5
S2-9	0.93	23	1.9	9.1	4.5	9.0	27

Sample	Sample area (m^2)	($\mu g/m^2$)					
		RDX	TNT	2,4DNT	2,6DNT	2AmDNT	4AmDNT
S2-10	0.87	120	3.4	20	17	15	97
S2-11	0.84	77	4.7	12	5.4	15	39
S2-12	1	66	ND	16	8.0	11	35
S2-13	1	61	6.1	17	6.7	18	25
S2-14	1	59	3.3	11	4.5	5.8	15
S2-15	0.92	37	37	4.8	1.8	2.6	4.6
S2-16	1	33	20	6.0	2.9	3.7	15
S2-17	1	53	1.7	7.2	4.8	3.9	15
S2-18	1	87	1.6	11	7.7	8.4	32
S2-19	1	86	0.64	15	11	15	42
S2-20	1	140	1.7	23	16	18	68
S2-21	1	50	ND	10	5.1	8.0	18
S2-22	1	56	1.2	17	8.5	21	51
S2-23	1	79	0.87	10	8.8	7.4	40
S2-24	1	37	14	7.0	2.5	7.6	15
S2-25	1	64	8.9	8.9	4.4	10	26
S2-26	1	72	50	10	4.1	14	27
S2-27	1	78	28	8.1	3.9	8.0	23
S2-28	1	88	12	14	5.6	30	50
S2-29	1	76	0.85	11	9.8	9.4	20
S2-30	1	74	2.8	10	9.2	19	68
S2-31	1	38	1.1	13	6.6	17	54
S2-32	1	140	3.4	21	11	12	64
S2-33	1	78	0.95	14	8.3	9.4	18
S2-34	1	48	0.26	4.6	2.7	2.5	5.3
S2-35	1	120	2.8	25	15	27	75
S2-36	1	160	1.4	22	14	23	40
S2-38	1	34	1.7	7.8	3.9	6.8	15
S2-39	1	19	0.58	4.3	2.4	3.1	10
S2-40	1	84	1.7	8.0	6.2	4.8	22
S2-41	1	12	25	4.3	1.7	4.2	3.1
S2-42	1	55	59	11	4.5	7.8	17
S2-43	1	68	22	16	6.0	10	32
S2-11A-D	34	33	0.39	7.5	5.4	15	39
S2-Crater #1	0.84*	21	4.9	3.4	1.3	3.3	5.0
S2-Crater #2	0.81*	61	0.50	5.5	3.8	8.2	17
S2-Crater #3	0.84*	42	0.90	6.3	2.3	9.5	20
S2-Crater #4	0.87*	21	0.60	5.7	2.4	13	25

Sample	Sample area (m^2)	($\mu g/m^2$)					
		RDX	TNT	2,4DNT	2,6DNT	2AmDNT	4AmDNT
S2-Crater #6	0.7*	55	0.60	9.3	6.3	21	50
S2-Crater #7	0.81*	23	14	5.0	1.9	8.9	21
S2-Crater #8	0.65*	74	3.1	20	6.1	77	100
S2-Crater #9	0.68*	52	0.50	15	7.6	31	50
S2-Crater #10	0.78*	52	0.70	7.7	4.7	6.6	10
S2-Crater #11	0.92*	87	4.4	13	4.8	7.5	11
S2-Crater #12	0.52*	23	8.2	10	4.8	26	42
S2-Crater #13	0.71*	48	0.60	16	6.5	23	74
Total mass (g) deposited							
Without Crater (1570 m^2)		110	13	20	12	20	60
With Crater (1670 m^2)		110	13	21	12	22	63
Average mass (μg) deposited per round							
Without Crater (1570 m^2)		8500	1000	1500	920	1500	4600
With Crater (1670 m^2)		8500	1000	1600	920	1700	4800

Note: Samples S2-37 and S2-Crater #5 were lost.

* Estimated that 10% of the crater was sampled.

Table A54. Surface concentrations of explosives residues from the live fire detonation of a 105-mm howitzer round at Ft. Richardson, Alaska, 3/14/2002.

Area: Soot plume 590 m^2; Crater 7.7 m^2 (1 of 13).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	TNT
S1-1	4.8	1	0.32 j	0.63
S1-2	5.3	1	0.06 j	0.1 j
S1-3	6.1	1	0.02 j	0.13 j
S1-4	9.9	1	0.25 j	0.22
S1-5	9.9	1	0.07 j	0.22 j
S1-6	9.5	1	0.16 j	0.13 j
S1-7	9.1	1	0.13 j	0.14 j
S1-Crater	—	0.77*	ND	0.12 j
Total mass (μg) deposited				
Without Crater (582 m^2)			84	130
With Crater (590 m^2)			84	130

* Estimated that 10% of the crater was sampled.

j Concentration at or below estimated detection level.

Table A55. Surface concentrations of explosives residues from the live fire detonation of two 105-mm howitzer rounds at Ft. Richardson, Alaska, 3/14/2002. Plumes for rounds designated 2 and 3 overlapped.

Area: two overlapping Soot plume 780 m^2; Crater 9.8 & 8.8 m^2 (2 and 3 of 13).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	TNT
S2-1	6.2	1	0.01 j	0.10 j
S2-2	5.8	1	0.11 j	0.22 j
S2-3	5.7	1	0.06 j	0.35
S2-4	5.2	1	0.23 j	0.44
S2-5	4.7	1	0.50	1.0
S2-6	7.8	1	0.73	0.24
S2-7	12	1	ND	0.15 j
S2-8	10	1	0.05 j	0.46
S2-9	9.5	1	0.18	0.13 j
S2-10	9.3	1	0.43	0.34
S2-11	13	1	0.19	0.20 j
S2-12	10	1	0.21	0.42
S2-13	10	1	0.35	0.28
S2-14	8.9	1	0.20	0.22
S2-15	14	1	0.15	0.93
S2-Crater	—	0.98*	0.08 j	0.27
S3-Crater	—	0.88*	0.002 j	0.001 j
Total mass (μg) deposited				
Without Craters (760 m^2)			170	290
With Crater (780 m^2)			170	290
Total mass (μg) deposited per round				
With Crater (780 m^2)			85	140

* Estimated that 10% of the crater was sampled.

j Concentration at or below estimated detection level.

Table A56. Surface concentrations of explosives residues from the live fire detonation of a 105-mm howitzer round at Ft. Richardson, Alaska, 3/14/2002.

Area: Soot plume 780 m^2, Crater 9.4 m^2 (4 of 13).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	TNT
S4-1	3.9	1	0.41	0.49
S4-2	5.1	1	ND	0.39
S4-3	11	1	ND	ND
S4-4	10	1	ND	0.32
S4-5	11	1	ND	0.19 j
S4-6	17	1	0.39	0.46
S4-7	17	1	0.29	0.09 j
S4-8	16	1	0.71	0.25 j
S4-Crater	—	0.94*	0.02 j	0.03 j
Total mass (μg) deposited:				
Without Crater (770 m^2)			170	210
With Crater (780 m^2)			170	210

* Estimated that 10% of the crater was sampled.

j Concentration at or below estimated detection level.

Table A57. Surface concentrations of explosives residues from the live fire detonation of four 105-mm howitzer rounds at Ft. Richardson, Alaska, 3/14/2002. Plumes for rounds designated 5 through 8 overlapped.

Area: Four overlapping Soot plumes 1880 m^2; Craters 9.1, 7.2, 11.8 & 8.4 m^2 (5, 6, 7 and 8 of 13).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	TNT
S7-1	1.9	1	0.34	0.92
S7-2	4	1	0.28	0.85
S7-3	4.1	1	0.08 j	0.18 j
S7-4	5.5	1	0.20 j	0.22 j
S7-5	9.4	1	0.49	0.29
S7-6	11	1	ND	0.42
S7-7	13	1	ND	ND
S7-8	14	1	ND	0.38
S7-9	12	1	ND	ND
S7-10	12	1	ND	0.31
S7-11	16	1	0.08 j	0.21
S7-12	19	1	0.10 j	0.32
S7-13	7.7	1	0.31	ND
S7-14	12	1	0.19	0.31
S7-15	12	1	0.24 j	3.3
S7-16	17	1	0.21 j	4.9
S7-17	19	1	0.05 j	0.19 j
S7-18	18	1	0.08 j	ND
S7-19	16	1	0.10	0.08 j
S7-20	20	1	0.13	0.58
S7-21	21	1	0.19	0.34
S7-22	26	1	0.01 j	ND
S7-23	26	1	0.06 j	0.44
S7-24	27	1	0.74	0.33 j
S7-25	14	1	0.32	0.52
S7-26	15	1	0.65	0.61
S7-27	18	1	0.13	1.1
S7-28	21	1	0.59	0.02 j
S7-29	25	1	ND	0.43
S7-30	20	1	ND	0.15
S7-31	26	1	ND	0.23
S5-Crater	—	0.91*	ND	ND
S6-Crater	—	0.72*	0.003 j	0.18 j
S7-Crater	—	1.18*	ND	0.11 j
S8-Crater	—	0.84*	ND	ND

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	TNT
Total mass (μg) deposited				
Without Crater (1840 m^2)			330	1000
With Crater (1880 m^2)			330	1000
Total mass (μg) deposited per round				
With Crater (1880 m^2)			82	250

* Estimated that 10% of the crater was sampled.
j Concentration at or below estimated detection level.

Table A58. Surface concentrations of explosives residues from the live fire detonation of a 105-mm howitzer round at Ft. Richardson, Alaska, 3/14/2002.

Area: Soot plume 290 m^2; Crater 10.3 m^2 (9 of 13).

Sample	Distance to Crater (m)	Samplearea (m^2)	($\mu g/m^2$)	
			RDX	TNT
S9-1	1.4	1	0.06 j	ND
S9-2	3.2	1	0.25	ND
S9-3	2.6	1	ND	ND
S9-4	3.2	1	0.06 j	0.03 j
S9-5	3.8	1	0.06 j	0.05 j
S9-6	4.4	1	ND	0.08 j
S9-7	6.3	1	0.05 j	0.09 j
S9-8	5.3	1	0.05 j	0.42
S9-9	7.1	1	0.09	0.21
S9-10	7.2	1	0.03 j	0.32
S9-11	6.8	1	0.35	0.79
S9-12	10	1	0.03 j	0.27
S9-13	11	1	0.04 j	ND
S9-14	12	1	0.26 j	0.25
S9-15	6.9	1	0.23 j	0.03 j
S9-16	9.1	1	ND	0.29
S9-17	11	1	0.06 j	0.02 j
S9-18	13	1	0.03 j	ND
S9-19	13	1	0.19	0.07
S9-20	14	1	ND	0.15 j
S9-21	17	1	0.09	0.16 j
S9-22	16	1	0.02 j	0.14 j
S9-Crater	—	1.0*	ND	ND
Total mass (μg) deposited				
Without Crater (280 m^2)			25	43
With Crater (290 m^2)			25	43

* Estimated that 10% of the crater was sampled.
j Concentration at or below estimated detection level.

Table A59. Surface concentrations of explosives residues from the live fire detonation of a 105-mm howitzer round at Ft. Richardson, Alaska, 3/14/2002.

Area: Soot plume 500 m^2; Crater 10.3 m^2 (10 of 13).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	TNT
S10-1	3.2	1	0.60	0.72
S10-2	4.7	1	0.03 j	0.37
S10-3	7.2	1	0.05	0.34
S10-4	10	1	0.06	0.29
S10-5	13	1	0.04	0.20
S10-6	7.1	1	0.03 j	0.16 j
S10-7A	NR**	103	0.008	ND
S10-7B	NR	103	0.020	0.014
S10-7C	NR	103	0.011	0.048
S10-8	NR	15.5	0.09	ND
S10-Crater	—	1.0*	ND	ND
Total mass (μg) deposited				
Without Crater (490 m^2)			56	130
With Crater (500 m^2)			56	130

* Estimated that 10% of the crater was sampled.

** Not recorded.

j Concentration at or below estimated detection level.

Table A60. Surface concentrations of explosives residues from the live fire detonation of a 105-mm howitzer round at Ft. Richardson, Alaska, 3/14/2002.

Area: Soot plume 460 m^2; Crater 7.6 m^2 (11 of 13).

Sample	Distance to Crater (m)	Samplearea (m^2)	($\mu g/m^2$)	
			RDX	TNT
S11-1	3.8	1	0.88	0.01 j
S11-2	5.8	1	1.1	ND
S11-3	14	1	ND	0.22
S11-4	9.4	1	0.02 j	0.001 j
S11-5	14	1	2.0	0.08 j
S11-6	18	1	0.12	0.02 j
S11-7	13	1	0.37	0.01 j
S11-8	18	1	0.14	0.18 j
S11-Crater	—	0.76*	ND	0.31
Total mass (μg) deposited				
Without Crater (450 m^2)			260	29
With Crater (460 m^2)			260	31

* Estimated that 10% of the crater was sampled.

j Concentration at or below estimated detection level.

Table A61. Surface concentrations of explosives residues from the live fire detonation of a 105-mm howitzer round at Ft. Richardson, Alaska, 3/14/2002.

Area: Soot plume 540 m^2; Crater 7.7 m^2 (12 of 13).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	TNT
S12-1	3.8	1	0.07 j	0.39
S12-2	6.8	1	0.13 j	0.47
S12-3	4.9	1	0.27	0.40
S12-4	7.2	1	0.26	0.27
S12-5	8.9	1	0.03 j	0.02 j
S12-6	10.5	1	0.31 j	0.31
S12-7	11	1	0.04 j	0.59
S12-8	13.8	1	0.45	0.01 j
S12-Crater	—	0.77*	0.02 j	0.001 j
Total mass (μg) deposited				
Without Crater (530 m^2)			100	160
With Crater (540 m^2)			100	160

* Estimated that 10% of the crater was sampled.

j Concentration at or below estimated detection level.

Table A62. Surface concentrations of explosives residues from the live fire detonation of a 105-mm howitzer round at Ft. Richardson, Alaska, 3/14/2002.

Area: Soot plume 550 m^2, Crater 9.6 m^2 (13 of 13).

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	TNT
S13-1	5.7	1	ND	0.15
S13-2	6.6	1	0.24	0.66
S13-3	6.5	1	ND	0.88
S13-4	11	1	0.09	0.30
S13-5	11.8	1	ND	0.35
S13-6	12.2	1	0.09	0.03 j
S13-Crater	—	0.96*	0.02	0.25
Total mass (μg) deposited				
Without Crater (540 m^2)			38	210
With Crater (550 m^2)			38	210

* Estimated that 10% of the crater was sampled.

j Concentration at or below estimated detection level.

Table A63. Surface concentrations of explosives residues from the detonation of a Bangalore Torpedo at Ft. Richardson, AK, 3/26/02.

Area: Soot plume 1067 m^2; Crater 1.6 m^2.

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
1	12	2	22	10
2	17	2	11	5.8
3	5.4	1.5	90	26
4	1.6	1	240	49
5	5.9	1	170	24
6	10	4	14	1.7
7	8.0	1	46	12
Crater	—	0.16*	1.8	58
Total mass (mg) deposited				
Without Crater (1065 m^2)			90	20
With Crater (1067 m^2)			90	20

* Estimated that 10% of the crater was sampled.

Table A64. Surface concentrations of explosives residues from the detonation of a Shape Charge at Ft. Richardson, AK, 3/26/02

Area: Soot plume 1540 m^2; crater 0.71 m^2.

Sample	Distance to Crater (m)	Sample area (m^2)	($\mu g/m^2$)	
			RDX	HMX
1	9.4	2	250	36
2	4.9	1	3600	440
3	1.9	1	12,000	120
4	6.0	1	94	26
5	12	1	2.5	0
6	16	1	1.4	0
7	21	1.5	4.3	0
8	14	1	3000	370
9	9.6	1	800	30
10	7.7	1.5	7700	1200
Crater	—	0.071*	210	140
Total mass (μg) deposited				
Without Crater (1539 m^2)			4,200.000	—
With Crater (1540 m^2)			4,200,000	—

* Estimated that 10% of the crater was sampled.

APPENDIX B: CALCULATIONS

Step 1. Calculate area covered by soot.

The area of the soot plume was usually established with the geographical information system (GIS), by walking the perimeter and recording locations under an area function. In the few cases where this system was not available, or for all of the craters, the diameter was measured and the area of a circle was calculated. When plumes over lapped the area was reported on a per round basis.

$$\text{Area} = \pi r^2$$

Step 2. Calculate amount of explosives residues in a surface snow sample.

Soot

The soot and debris trapped on the glass fiber filter after passing the entire melted sample through a vacuum filtration system was extracted with acetonitrile. The volume of extractant was multiplied by the concentration to determine the mass of explosives in the soot. If more than one vessel (soxhlet extraction thimble) was needed for a given sample then the masses were added together.

$$\text{Ex. } 0.025 \text{ mg RDX/L} \times 0.145 \text{ L} = 3.6 \ \mu\text{g RDX}$$

Melt

The total snow melt volume was recorded, and then a 500 mL portion was passed through a solid phase extraction cartridge. The explosives sorbed to the solid support were extracted with 5.00 mL of acetonitrile, for a 100 fold pre-concentration factor. To calculate the mass of explosives in the snow melt the concentration measured was divided by 100 then multiplied by the total melt volume.

$$\text{Ex. } 0.055 \text{ mg RDX/L} \div 100 \times 4.22\text{L} = 2.3 \ \mu\text{g RDX}$$

Step 3. Calculate the mass of explosives per meter squared of a sample (i.e., surface concentration)

The mass of an analyte determined for the soot and melt fraction for a given sample was added together and divided by the surface area sampled.

Ex. 3.6 μg RDX (soot) + 2.3 μg RDX (snow melt) ÷ 0.78 m^2 = 7.6 μg RDX/m^2

Step 4. Mean surface concentration.

The mean surface concentration for a given analyte was established for the samples obtained within a soot plume. In the case of overlapping plumes the mean per round was determined. The mass of explosives in the crater was not used to determine the mean surface concentration.

Step 5. Mass Deposited.

The mass deposited was determined by multiplying the mean surface concentration per round by the total plume (or in the case of overlapping plumes, the plume area per round) area not including the crater, then adding the mass of analyte determined for the crater (or for the mean of the craters, when plumes overlapped). The example is for a Hand Grenade:

0.58 μg RDX/m^2 (mean surface conc.) × 99 m^2 (area without crater) + 1.7 μg RDX/m^2 × 1.0 m^2 (area of crater) = 59 μg RDX

Step 6. Percent Deposited.

The mass deposited was divided by the total mass of analyte in the muntion detonated, including the explosives in the demolition munition used for blow-in-place operations (see Table 3).

Step 7. Estimated mean soil concentration.

Once the snow melted the mean explosives residue concentrations in the soil (1.7 g/cm^3 density) beneath the plumes was estimated by dividing the mean surface concentration by an area one meter square by 0.5 cm depth.

Ex. 0.73 μg RDX/m^2 ÷ (100 cm x 100 cm x 0.5 cm) × 1.7g/cm3 = 0.000086 μg/g

or 0.086 μg/kg

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14. ABSTRACT

Snow was used as a collection medium to examine explosives residues following the high-order detonation of various military munitions. After detonation, a set of large (1-m^2) samples of residue-covered snow were collected, processed, and analyzed for explosives without cross contamination from previous detonations and other potential matrix interferences. Trials were performed to quantify explosives residues following the detonation of 60-, 81-, and 120-mm mortar rounds, 105- and 155-mm howitzer rounds, M67 hand grenades, 40-mm rifle grenades, blocks of C4, several different types of land mines, bangalore torpedoes, and a shaped demolition charge. Munitions were detonated following both common military live-fire and blow-in-place techniques. When possible, the same munition was detonated several times using the same conditions to provide a more reliable estimation of the percentage of high explosives that were deposited on the snow surface. In addition to using the snow surface as a collection medium, aluminum trays and steel plates were used in some of the detonation trials.

The blowing in place of TNT-filled munitions often resulted in the deposition of near-percent levels of TNT from the main charge that was estimated to lead to mg/kg concentrations in surface soils. When we observed high concentrations of TNT in residue samples, often 2,4-DNT, 2,6-DNT, TNB, 2-ADNT, and 4-ADNT were also present at much lower concentrations. In contrast, the percentage of high explosives deposited from live-fire detonations of Comp-B-filled howitzer rounds, mortar rounds, and hand grenades was always less than 0.002%, leading to low µg/kg or ng/kg surface soil concentrations. Overall residue deposition from live-fire--high-order detonations was much lower than for munitions destroyed using blow-in-place techniques. Detonation residues for other munitions that were evaluated fell between these two ranges. Residues from blown-in-place detonations collected on pre-positioned aluminum trays and steel plates showed concentrations similar to the adjacent snow surfaces, and for one detonation allowed for an energetic particle size distribution analysis.

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