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Sampling for Explosives Residues at Fort Greely, Alaska

Reconnaissance Visit July 2000

Marianne E. Walsh, Charles M. Collins, Charles H. Racine, Thomas F. Jenkins, Arthur B. Gelvin, and Thomas A. Ranney

November 2001

Abstract: Impact areas are lands used by the army for ordnance testing and training. The impact areas of Fort Greely, Alaska, are located on lands withdrawn from the public domain under the Military Lands Withdrawal Act (PL 106-65). The Army has pledged to implement a program to identify possible munitions contamination and evaluate the potential for surface water and groundwater contamination. Because of the large size (85,042 acres) of the impact areas, characterization of the contamination levels will be difficult. We have begun a multiphase sampling program at one impact area by first sampling locations that are likely to be contaminated and to identify locations that have the greatest potential to contaminate adjacent surface and groundwater. Based on a review of records at the Fort Greely Range Control and consultation with the Cold Regions Test Center (CRTC), we chose to sample the Washington Impact Area. We focused our sampling on surface soils and collected both composite (multi-increment) and discrete samples at locations of known firing events and from areas on the range that had evidence of range use. Evidence included cratering, pieces of munitions, or a designation as a firing point. Firing events included tests of 81-mm mortars, Tube-launched Optically tracked Wire-guided (TOW) missiles, 40-mm high-explosive cartridges, and Sense and Destroy Armor (SADARM). We detected explosives residue in 48% of the 107 soil samples we collected. RDX was the most frequently detected explosive (39%). Of the samples above the detection limit, median RDX concentration was only 0.021 µg/g. Low-order detonations accounted for four of the five highest RDX concentrations. TNT was the second most frequently detected explosive (21%). Median TNT concentration in samples where TNT was detected was only 0.004 µg/g. Low-order detonations produced the highest TNT concentration we found. The amino-dinitrotoluene transformation products of TNT were detected in about 10% of the samples. HMX was found in 11% of the samples. The analytes 2,4-DNT and NG were detected at a firing point and in a few samples on the Washington Impact Area. High-explosive projectiles that function properly appear to leave little residue in the surface soil. Low-order detonations, where only part of the high-explosive filler detonated leaving solid explosive composition in contact with surface soil, produced the highest soil concentrations observed. Also, firing points are sources of NG and 2,4-DNT. The greatest potential threat of contamination of surface and groundwater would be high numbers of low-order detonations or heavily used firing points located in groundwater recharge areas.

COVER: Washington Impact Area looking southwest with the Alaska Range in background.

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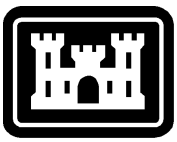

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November 2001

Prepared for
U.S. ARMY ALASKA

PREFACE

This report was prepared by Marianne E. Walsh, Chemical Engineer, Environmental Sciences Branch, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL), Engineer Research and Development Center (ERDC), Hanover, New Hampshire; Charles M. Collins, Research Physical Scientist, Environmental Sciences Branch, CRREL; Dr. Charles H. Racine, Ecologist, Environmental Sciences Branch, CRREL; Dr. Thomas F. Jenkins, Research Chemist, Environmental Sciences Branch, CRREL; Arthur B. Gelvin, Engineering Technician, Engineering Resources Branch, CRREL; and Thomas A. Ranney, Staff Scientist, Science and Technology Corporation, Hanover, New Hampshire.

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NOMENCLATURE

1,3-DNB	1,3-dinitrobenzene
2,4-DNT	2,4-dinitrotoluene
2-Am-DNT	2-amino-4,6-dinitrotoluene
3,5-DNA	3,5-dinitroaniline
4-Am-DNT	4-amino-2,6-dinitrotoluene
AcN	Acetonitrile
Am-DNTs	Amino-dinitrotoluenes
CRREL	Cold Regions Research and Engineering Laboratory
CRTC	Cold Regions Test Center
DODIC	Department of Defense Identification Code
ECD	Electron Capture Detector
EL	Environmental Laboratory
ERDC	Engineer Research and Development Center
GC-ECD	Gas chromatography-electron capture detection
GPS	Geographic Positioning System
HMX	1,3,5,7-octahydro-1,3,5,7-tetranitrotetrazocine
HPLC	High-performance liquid chromatography
NG	Nitroglycerin
PETN	Pentaerythritol tetranitrate
RDX	1,3,5-hexahydro-1,3,5-trinitro-1,3,5-triazine
SADARM	Sense and Destroy Armor
SARM	Standard Analytical Reference Materials
SPME	Solid-phase microextraction
TNB	1,3,5-trinitrobenzene
TNT	2,4,6-trinitrotoluene
TOW	Tube-launched Optically-tracked Wire-guided
USAEHA	U.S. Army Environmental Hygiene Agency
USARAK	U.S. Army Alaska
USCHPPM	U.S. Army Center for Health Promotion and Preventive Medicine (formerly USAEHA)
USGS	U.S. Geological Survey
UTM	Universal Transverse Mercator
UXO	Unexploded Explosive Ordnance
WES	Waterways Experiment Station
WP	White phosphorus
XRF	X-ray fluorescence

Sampling for Explosives Residues at Fort Greely, Alaska

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INTRODUCTION

Background

Fort Greely, Alaska, has an extensive complex of weapon training and testing impact areas located in the West Training Area, west of the main cantonment of Fort Greely. Of special interest are the 34,415 ha (85,042 acres) of high-hazard impact areas. These include the Washington and Mississippi Impact Areas located within the floodplain of the Delta River, the Delta Creek Impact Area located within the floodplain of Delta Creek, 20 km to west, and the Oklahoma Impact Area located just to the east of Delta Creek. The Mississippi and Washington Impact Areas are mainly used by the Army for mortar, artillery, and other similar indirect fire weapons systems. Washington Impact Area also is used by the Cold Regions Test Center for the test firing of a number of developmental weapons systems. Delta Creek Impact Area is used by the Army as an indirect fire impact area and by the Air Force as an aerial bombing range. The Oklahoma Impact Area is mainly used by the Air Force as an aerial bombing range. These impact areas are located on lands withdrawn from the public domain under the Military Lands Withdrawal Act (Public Law 106-65); the withdrawal of land was recently renewed. As part of the Environmental Impact Statement (U.S. Army 1999) prepared for the renewal, the Army has pledged to implement a program to identify possible munitions contamination and evaluate the potential for surface water and groundwater contamination.

Because of the large size (34,415 ha [85,042 acres]) of the impact areas, characterization of the contamination levels will be difficult. We proposed a multiphase sampling program in which we would first sample locations most likely to be contaminated at one impact area and identify locations that have the greatest potential to contaminate adjacent surface and groundwater. Based on this initial reconnaissance sampling program we would then develop comprehensive sampling and analysis protocols that can be applied to the additional impact areas of Fort Greely as part of a comprehensive explosive contaminant sampling and monitoring program.

During the summer of 2000, we began this process of developing a sampling program for the impact areas at Fort Greely. We started with an initial visit to review records at Fort Greely Range Control and at the Cold Regions Test Center (CRTC) to determine potential contaminants based on weapons fired and likely locations for an initial sampling program. Based on the records and recommendations by CRTC and Range Control, we decided to undertake the preliminary sampling program at Washington Impact Area. The use of this range by CRTC as a testing range has resulted in more precise records of what has been fired and more exact data on impact locations than is typically known on a training range. Because identification of nonfunctioning munitions was part of the test procedures, UXOs were carefully located, identified, and disposed of after each test, thus providing a safer environment for the sampling team as we developed sampling protocols. Also, Washington Impact Area offered the easiest access of any of the major impact ranges of Fort Greely, as it is accessible by vehicle from the main Fort Greely Cantonment area via gravel road. The environmental setting of Washington Impact Area, within the floodplain of a glacially fed, gravel-braided river, is similar to a number of other impact areas on Fort Greely. Therefore, environmental factors affecting the fate and transport of explosive contaminants on Washington Impact Area should also be applicable to most of the other impact areas on Fort Greely. Certain areas with similar environmental settings, such as Mississippi Impact Area, are not accessible to ground sampling because of the danger from numerous UXO. In those cases, we will have to make assumptions about

potential contamination based on the results from Washington Impact Area, comparisons of the use of the different areas based on the range records, and the differences or similarities in environmental conditions.

Environmental setting

Fort Greely covers about 267,000 ha (661,341 acres) near Delta Junction in Central or Interior Alaska. The area is located in the southeast corner of the Tanana-Kukodwim Lowlands Physiographic province (Wahrhaftig 1965) just north of and bordering the Alaska Range province. Elevations range from 400 to 1800 m, and because of its location just north of the Alaska range it has been glaciated and includes features such as glacial moraines, glaciofluvial sediments, and loess (Péwé and Holmes 1964, Church et al. 1965).

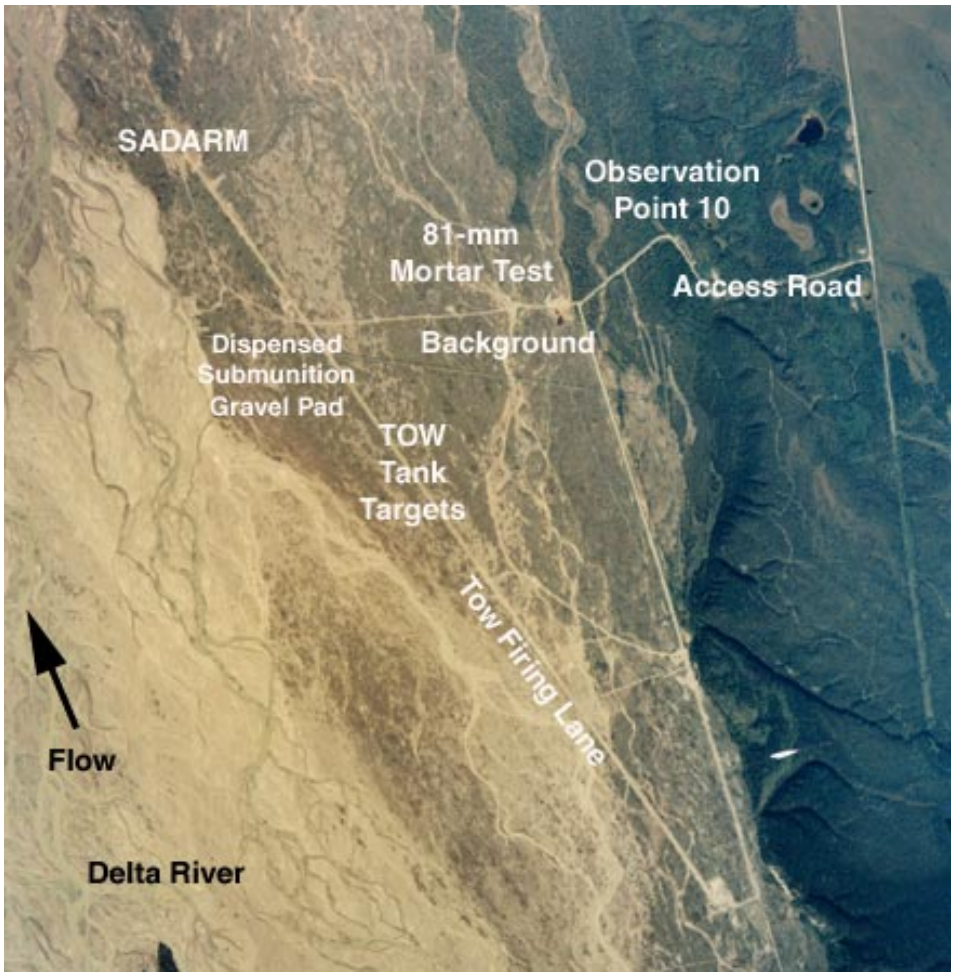
The Washington Range occupies about 1650 ha (4125 acres) along the Delta River (Fig. 1) and is located on the Mount Hayes D-4 Quad-SW. The study area, about one-half of the Washington Range or 800 ha (2000 acres), is located on a terrace elevated several meters above the active channel of the Delta River. The Delta River is a broad, gravel-braided glacial outwash system west of the main cantonment area of Fort Greely that flows from the Alaska Range northward to the Tanana River (Dingman et al. 1971). The terrace was most likely formed during a more active period of sedimentation and greater river discharge associated with a glacial surge of the Black Rapids Glacier during the 1930s. Soils of the terrace consist of alluvial silty, sandy gravel with cobble clasts up to 10 cm. There is a sporadic thin veneer of loess (wind-blown silt) in localized areas of the terrace. Also, within former channel swales there are deposits of silty sands of variable thickness. According to Jorgenson et al. (2001) permafrost is absent on these gravel bars due to groundwater activity but there are questions concerning the presence or absence of permafrost here.

The mean annual temperature at Fort Greely is –2.77°C. Important features of the environment at Fort Greely include strong winds, especially in the winter, which often sweep across the gravel bars and floodplain of the Delta River and move and deposit loess in the summer. Snow cover during the winter is most likely sparse due to the strong southerly winds that sweep down the Delta River (Benson 1972).

As floodplain terraces build up and are no longer flooded, vegetation develops according to a successional sequence. This sequence is fairly well known for the Tanana River (Viereck et al. 1993) but is clearly different on the Delta River where the substrate contains more gravel rather than the alluvial silts dominant on the Tanana River floodplains (Péwé and Reger 1983). The succession on these gravelly

a. View from Observation Point 10, Fort Greely, Alaska.

Figure 1. Washington Impact Area.



b. Aerial photo (28 August 1998) showing general locations of ordnance firing events where samples were collected.

Figure 1 *(cont'd).*

floodplains of the Delta River probably requires a much longer time for the development of forests (balsam poplar and white spruce), and at some stage grassy meadows appear to develop in places that are important grazing areas. Also, several legumes (*Hedysarum*, *Astragalus*, *Oxytropis*, *Avena*, *Dryas drumondii*, and *D. octopetala*) play a role in succession and willow is less important here than along the Tanana. Particularly striking on the Delta River floodplains is the abundance of silverberry shrubs (*Eleagnus commutata*).

The vegetation of the Delta River floodplain on the Washington Range was mapped by Holmes and Benninghoff (1957) using August 1948 aerial photos on the Mount Hayes D4-SW topographic map base. Several meadow areas were mapped here in the middle of the Delta River floodplain. Later Jorgenson et al. (2001) mapped the vegetation on Fort Greely and included the Washington Range as riverine gravelly barrens with species such as *Oxytropis campestris*, *Dryas durommondii*, *Potentilla multifica*, *Shepherdia canadensis*, *Eleagnus commutata*, *Potentilla fruticosa*, *Fragaria virginiana*, *Populus balsamifera*, and *Stereocaulon sp.*

Much of the terrace of the Washington Range, where we sampled for explosives, is bare gravel with localized areas of sparse shrubs mostly consisting of silverberry (Fig. 2 and 3). Vegetation cover was generally negatively correlated with gravel increasing where there is more sand and silt. Estimates of shrub cover (silverberry) in each of the four 3-m ×3-m sampled plots varied from 15 to 40%. The forb *Potentilla multifida* was also abundant and cover by both mosses (up to 70%) and lichens suggests that the gravels here were well stabilized with little flooding.

Figure 2. Typical soil substrate and vegetation (silverberry shrub and yellow goldenrod as well as moss cover) in 81-mm mortar fuse test location. Each blue flag marks a fin from a mortar projectile.

American Bison (*Bison bison*) are the most conspicuous grazers on the Washington Impact Area. According to the ADF & G Web site (http://www.state.ak.us/local/akpages/FISH.GAME/notebook/notehome.htm) they were introduced in the Big Delta area in the 1920s and the original herd of 20 increased to over 500 animals by 1982. They move far up the Delta River in early spring to secluded meadows where they calve and around August they travel back downstream, eventually moving into the Delta Junction Bison Range. They feed on gravel bars on the Washington Impact Area, where they graze on various grasses and forbs such as vetch, but also eat silverberry, which is common on the study area. We also observed ground squirrels (*Spermophilus parryii*).

The Lampkin Range is adjacent to an active side channel of the Delta River, about 10 km downstream of the Washington Impact Area. The Lampkin Range is used for various shorter-range direct-fire weapon systems. Firing points are located on elevated broad flat-topped gravel berms or platforms built on the vegetated floodplain along the right bank of the Delta River. Impact areas are to the southwest toward the Mississippi Impact Area, within the active channel system of the Delta River. For one particular test of 40-mm grenades undertaken by CRTC, a target berm was constructed on a river gravel bar approximately 100 m southwest of a firing point along the right bank of a side channel of the Delta River. The 3-m-high × 10-m-long target berm was constructed of silty, sandy gravel with clasts up to 10 cm.

Detailed information on the environment of Fort Greely may be obtained from the extensive field studies extending back to the 1950s when the Military Geology Branch of the USGS was contracted by the Corps of Engineers (WES) to conduct a terrain study of Fort Greely. A major summary and terrain study was produced in 1957 by Holmes and Benninghoff. This comprehensive study covered topography, geology, climate, hydrology, lakes, streams, soils and vegetation because these environmental factors influence training and testing activities on Fort Greely. Maps are included in volume 2 of the report and cover landforms (Mount Hayes D-4 and Big Delta A-4 [1:63,360]), geology–soils, and vegetation (Mount Hayes D-4 NE, NW, SE, SW [1:25,000]). Vegetation was mapped by Benninghoff from August 1948 aerial photos from U.S. Navy Mission BIG. More recently, from 1998 to 1999, CRREL and ABR, Inc. (Fairbanks, Alaska) conducted wildlife, plant, and vegetation inventories for the U.S. Army Alaska on Fort Greely (Jorgenson et al. 2001, Racine et al. 2001). Colorado State University also produced an Environmental Impact Statement for the USARAK for withdrawal of training lands, including Fort Greely.

a. Sampling grid encompassing the densest concentration of fins (Area Blue). The red flag shows the location of a low-order detonation of an 81-mm projectile.

b. Sampling grid with no fins (Area Yellow).

Figure 3. Sampling grids.

Range use

In order to identify contaminants of concern, we needed to know what munitions have been fired into the areas we planned to sample. We were given range records for Fort Greely from 1987 to 1999. Records of the exact types of ammunition used on the Washington Range and Impact Area are available from 1998. These records contain the Department of Defense Identification Code (DODIC) that facilitates retrieval of information about the various components of the ammunition (i.e., explosive fillers, primers, propellants, etc.). Range records from 1987 to 1997 do not list DODIC numbers, only "type of round," which does not identify the exact ammunition. From the most recent records, and the Munitions Item Disposition Action System (MIDAS) database (http://www.dac.army.mil/TD/Midas/Index.htm), we generated tables summarizing some of the ammunition components (Tables A1 and A2). The tables are incomplete because several of the munitions used on the Washington Impact Area are either of foreign origin or the nature of the components is restricted information. Munitions not in the MIDAS database are flagged in Table A2.

Munitions

TNT (2,4,6-trinitrotoluene) and RDX (hexahydro-1,3,5-trinitro-1,3,5-triazine) are the two most commonly used military explosives in projectiles, bombs, land mines, or other weapons (U.S. Army Materiel Command 1971, U.S. Army 1984). RDX is the explosive ingredient in Composition 4 (C4) that is used to detonate unexploded ordnance during range maintenance activities. HMX (octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine) is the explosive filler in many anti-tank weapons and it is an impurity in military-grade RDX. Nitroglycerin and 2,4-DNT (2,4-dinitrotoluene) are ingredients in propellants. Barium (Ba), lead (Pb), chromium (Cr), cadmium (Cd), zinc (Zn), and antimony (Sb) are metals used in various primers. Unlike the organic explosives listed above, metals have natural background concentrations.

Objective of sampling

Testing and training ranges are key elements in maintaining the capability and readiness of the U.S. Armed Forces. The potential for environmental impacts, including contamination of drinking water supplies, necessitates responsible management of these facilities in order to continue testing and training activities. Guidance for evaluation of the nature and extent of contamination and the fate of residues of energetic materials is inadequate to ensure sound management of ranges as sustainable resources. In the absence of guidance, facilities may be subject to more stringent and extensive site evaluation and remediation than may be necessary for responsible decision-making. The result is often higher-than-necessary expenditures of time and money, and insufficient data to address concerns of regulators and other interested parties. Range activities are susceptible to suspension in the absence of adequate scientific data to define potential affects on groundwater. For example, the possibility that groundwater was contaminated by training activities has resulted in suspension of training at the Massachusetts Military Reservation (USEPA 2000a).

The Center for Health Promotion and Preventive Medicine (USACHPPM, formerly the U.S. Army Environmental Hygiene Agency) has sampled surface water on several ranges, including Fort Greely. Little or no residue of explosives has been detected in these surveys. Because of the dangers associated with unexploded ordnance on firing ranges, extensive soil sampling on ranges is a relatively recent activity (Table 1). With the exception of HMX on anti-tank ranges (Jenkins et al. 1997, 1998; Thiboutot et al. 1998) and RDX on hand grenade ranges, explosives have either been undetectable or at very low concentrations in soils collected from impact areas. Nonetheless, the detection of RDX in groundwater at the Massachusetts Military Reservation has led to questions as to the source of the RDX. Is it from leaking unexploded ordnance, low-order detonations, or residue from thousands of properly functioning projectiles? Further sampling on ranges should help to answer this question.

Our objectives for the initial reconnaissance sampling program at Fort Greely were to

1. determine whether we could detect munitions residue in the soil of the Washington Impact Area;
2. determine what type of firing event or munition was associated with munitions residues detected;
3. test sampling methods appropriate for the soils and site conditions present;
4. acquire knowledge to assist us in developing sampling protocols to be applied in future to this and other impact areas on Fort Greely and elsewhere.

METHODS

We focused our sampling on surface soils and collected both composite (multi-increment) and discrete samples. Methods for forming the composite samples were tailored to each firing event as described below.

Sample locations were recorded using a Trimble GPS Pathfinder Pro XR system. The system uses real-time differential GPS to determine submeter (±20 cm)

Table 1. Summary of explosives detected by soil sampling on firing ranges.

Year	Range	Contaminants found	Source	Reference
1990–1994	Eagle River Flats, Fort Richardson, Alaska	2,4-DNT, TNT, RDX	From neighboring explosive ordnance disposal area	a, b
1995–1997	CFB Valcartier, CFB Dundurn, Western Area Training Center-Wainwright	HMX and TNT	Anti-Tank Rockets	c
1996	Canadian Forces Base Valcartier	HMX and TNT	Anti-Tank Rockets	c,d
1997	Fort Ord Anti-tank Range	HMX and TNT	Anti-Tank Rockets	e
1998	Wellington Anti-tank Firing Range (CFB Gagetown)	HMX and TNT	Light AntiTank Weapon Rocket	f
1998	Castle Grenade Range (CFB Gagetown)	RDX and TNT	Hand grenades	f
1998	CFB Chilliwack	RDX and HMX	Hand Grenades, C4, Anti-Tank Rockets	g
1999	Camp Shelby, Mississippi	NG and 2,4-DNT	Firing Point	h
2000	Fort Lewis Impact Area and Firing Point	2,4-DNT TNT	Firing Points Low-order detonations	i
2000	Fort Lewis Hand Grenade Range	TNT and RDX	Hand grenades	i
2000	Fort Richardson Hand Grenade Range	TNT and RDX	Hand grenades	i
1998–2000	Massachusetts Military Reservation	NG and 2,4-DNT	Firing Points	j
2000	Massachusetts Military Reservation	HMX, RDX, TNT, NG	Rockets	k

a. Racine et al. (1992)
b. USAEHA (1994b)
c. Thiboutout et al. (1998)
d. Jenkins et al. (1997)
e. Jenkins et al. (1998)
f. Dube et al. (1999)
g. Ampleman et al. (2000)
h. USACHPPM (2000)
i. Jenkins et al. (2001)
j. Ogden (2000)
k. USEPA (2000a)

accuracy for horizontal positioning. Universal Transverse Mercator (UTM) grid coordinates were determined for each sample or set of sample locations. Elevation data were also collected for each sample location. Because elevation data are not as precise as horizontal data using GPS systems, we also used a laser level to survey across the width of the terrace to determine elevational differences in the terrace and height above the active river channel.

ANALYTICAL METHODS

Explosives

Explosives were characterized using field and laboratory methods. Field procedures were the colorimetric Methods 8515 (Colorimetric Screening Method for Trinitrotoluene [TNT] in Soil), which detects TNT and other nitroaromatics, and 8510 (Field Method for the Determination of RDX in Soil), which detects RDX and other nitramines plus nitrate esters (USEPA 1996a, 2000b). We also used the Expray kit (EREZ Forensic Technologies, Israel) to identify explosive compositions found in the field.

Based on the results of previous sampling on training ranges (USACHPPM 2000) where most of the samples were non-detects when analyzed by Method 8330 (Nitroaromatics and Nitramines by High-Performance Liquid Chromatography [HPLC]) (USEPA 1994), we knew that we needed to use an analytical method that provided detection limits less than 0.2 µg/g. We used Method 8095 (Nitroaromatics and Nitramines by GC) (USEPA 2000c), which uses an electron capture detector and provides detection limits near 0.001 µg/g for TNT and RDX. The method detection limits for Method 8095

are 0.001 µg/g for the di- and trinitroaromatics, 0.003 µg/g for RDX, 0.025 µg/g for HMX, 0.01 µg/g for NG, and 0.02 µg/g for PETN. In this report, we report concentrations below the computed method detection limits if the concentrations were confirmed using a second GC column or using HPLC for HMX. We used Method 8330 (Nitroaromatics and Nitramines by High-Performance Liquid Chromatography [HPLC]) (USEPA 1994) when we found higher concentration samples (>0.2 µg/g) and to quantify the explosives components in low-order detonations.

White phosphorus

A limited number of samples were analyzed for white phosphorus using Method 7580 (White Phosphorus [P$_4$] by Solvent Extraction and Gas Chromatography) (USEPA 1996b).

Metals

Metals were determined in the field using a field-portable Niton Model XL-722S X-Ray Fluorescence Multi-Element Analyzer. Confirmatory analysis for antimony, cadmium, chromium, copper, lead, nickel, barium, and zinc was conducted on 50 samples at the Environmental Lab (Vicksburg, Mississippi) using Method 3050 (Acid Digestion of Sediments, Sludges, and Soils) and atomic absorption.

RESULTS

Known events

Mortar projectile impact zone

The first area we sampled was used in February 1992 to test the reliability of the M734 multi-option fuse. Forty-five 81-mm mortar projectiles were fired with their fuses set to proximity into a limited (100-m^2) target area. The projectile was an 81-mm M821E1, which is a U.S. version of the United Kingdom's M821 HE (high-explosive) cartridge (U.S. Army 1977). The complete round is made up of a fuse, four increment propellant charges, a fin assembly, ignition cartridge, and shell body. Unfortunately some of the information about this projectile is proprietary, but what we do know is given in Table 2.

We were able to locate the target area from the description of the firing point in the test report and the cluster of mortar projectile fins in a relatively small area (Fig. 2). We found 47 projectile fins, most of which were from 81-mm projectiles, and the remainder were from 60-mm projectiles. We don't know the source of the 60-mm projectile fins, but range records indicate that 60-mm smoke projectiles were frequently fired with 81-mm HE projectiles. We marked a 3-m × 3-m area encompassing the densest concentration of fins (Area Blue) and another 3-m × 3-m area nearby that contained no fins (Area Yellow) (Fig. 3). We also located a low-order detonation next to Area Blue (Fig. 3a). We sampled the explosive composition and the soil directly under the low-order detonation to a depth of 22 cm, the deepest we could reasonably dig through the cobbly substrate with a small shovel.

From each of these areas, we used a small shovel to collect soil at the nodes of a 1-m-square grid (Fig. 3b) to form a composite soil sample. We excluded rocks (particles >2 mm) from the samples by either sampling around them or picking them out. Three 120-mL subsamples were obtained by taking 30 random increments from the composite for subsequent laboratory analysis for explosives residues. The remainder of the sample was placed in a plastic bag for other analyses (XRF and field colorimetric methods).

In the field lab, we used colorimetric methods to test acetone extracts of the soil samples for nitroaromatics (Method 8515) and nitramines/nitrate esters (Method 8510). Method 8515 appeared to indicate the presence of nitroaromatic compounds. The initial background color of the acetone extract was yellow, and addition of the EnSys reagent (tetrabutyl ammonium hydroxide) resulted in an amber color. The color was more intense in the sample collected from the area without projectile fins. (Subsequent laboratory analysis showed that this color formation was due to the presence of elemental sulfur and sulfur compounds.) The following day, we marked out two additional 3-m × 3-m areas (labeled Areas Red and Pink) on either side of the two areas previously sampled in line with the firing point.

Using gas chromatography-µECD (Method 8095), we detected low (<1 µg/g) concentrations of RDX and HMX in the soil samples from the grid (Area Yellow) with no projectile fins (Fig. 4) that was located 6.5 m from the grid (Area Blue) with several projectile fins (Table 3). Some explosives residues were detected in each of the other three grids, but concentrations were much lower than in the Area Yellow and near the method detection limits.

The explosive composition from the low-order detonation was 66% RDX, 9% HMX, and 25% TNT (Table 4). This composition is more consistent with cyclotol (75% RDX and 25% TNT) rather than Composition B (60% RDX and 40% TNT). HMX is always present as an impurity in military-grade RDX; however, the proportion of HMX we found in this round is high. HMX is the least soluble of these three explosives, and preferential dissolution of RDX and TNT may account for the enrichment of HMX. The soil

Table 2. Components of M821E1 projectile (81-mm) with M734 fuse (DODIC C868).

M821E1 HE Cartridge		
Filler	Comp B (RDX and TNT)	2.05 lb
Ignition cartridge	M299: Black powder (charcoal, potassium nitrate, sulfur), M9 flake (ethyl centralite [0.75%], nitrocellulose [57.75%], nitroglycerin [40%], potassium nitrate [1.5%]), primer mix 70 (antimony sulfide [14.5%], lead thiocyanate [22.5%], potassium chlorate [53%], TNT [5%])	
Propellant charge	M220 (Unknown but probably double-base [nitrocellulose and nitroglycerin])	
Primer	M55 Perc (unknown)	
M734 Multi-option fuse		
Pellet booster comp	A5 (RDX (98.5%)and stearic acid (1.5%)	8 g
Lead charge	PBXN-5 (HMX 95% and Binder 5%)	152 mg
Detonator assembly	HMX (98%) and RDX (2%)	16 mg
	Lead azide	14 mg
Primer housing assembly	Lead azide	85 mg
	RDX	32.5 mg
	Primer mix and output mix NOL#130 (lead styphnate (40%), lead azide (20%), tetracene (5%), barium nitrate (20%), antimony sulfide (15%)	54.5 mg
	Output mix (lead azide (11%), zirconium (26%), lead dioxide (60.5%), viton (2.7%)	15 mg

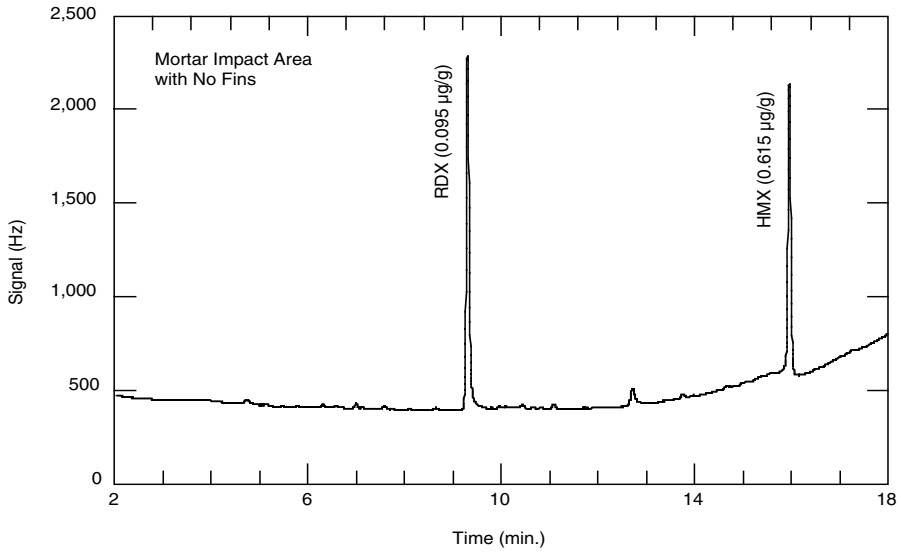


Figure 4. Chromatogram (GC-µECD) from the extract of surface soil collected in an area with no mortar projectile fins. Low concentrations of RDX and HMX were found a short distance from the impact point.

Table 3. Explosives residues detected in soil impacted by 81-mm HE projectiles. One composite sample was collected from each area and three soil subsamples were analyzed for explosives.

	Concentration (µg/g)		
	RDX	*HMX*	*TNT*
Area Blue (7 fins per 9 m^2)			
	0.002*	<d	<d
	<d	<d	<d
	<d	<d	<d
Area Yellow (no fins)			
	0.23	0.025	0.002
	0.31	0.36	<d
	0.095	0.62	<d
Area Red (closer to firing point)			
	<d	<d	<d
	<d	<d	<d
	0.002*	<d	0.007
Area Pink (farthest from firing point)			
	0.002*	<d	0.002
	0.002*	<d	<d
	0.003	<d	<d

*Detected but below method detection limit.

directly in contact with the explosive composition contained residues of RDX, HMX, and TNT (Fig. 5), and very low concentrations of the microbial transformation products of TNT, the two amino-dinitrotoluene isomers (Table 4). Concentrations dropped precipitously over a few centimeters; subsurface samples had trace (part per billion) concentrations of explosives residues, indicating that migration to groundwater is unlikely.

Metal concentrations (Table 5) were elevated in the composite sample from Area Red that was located between the concentration of fins (Area Blue) and the firing point. This sample had the highest concentration of chromium of all the samples analyzed for metals.

TOW missile targets

We next sampled around targets (Fig. 6) used in tests of TOW (Tube-launched Optically-tracked Wire-guided) missiles. There were 111 missiles (32 TOW 2, 69 TOW 2A, and 10 TOW 2B) tested in February 1995 and 69 missiles (10 TOW 2, 39 TOW 2A, and 20 TOW 2B) tested in 1996.

Table 4. Soil directly under 81-mm HE projectile low-order detonation. The explosive composition was determined to be 66% RDX, 9% HMX and 25% TNT.

	Concentration (µg/g)				
Depth	*RDX*	*HMX*	*TNT*	*4-Am-DNT*	*2-Am-DNT*
Surface	0.94	0.22	0.058	0.003	0.002
2–4 cm	0.005	<d	<d	<d	<d
10 –12 cm	0.014	0.002	0.002	<d	<d
20–22 cm	0.004	<d	<d	<d	<d

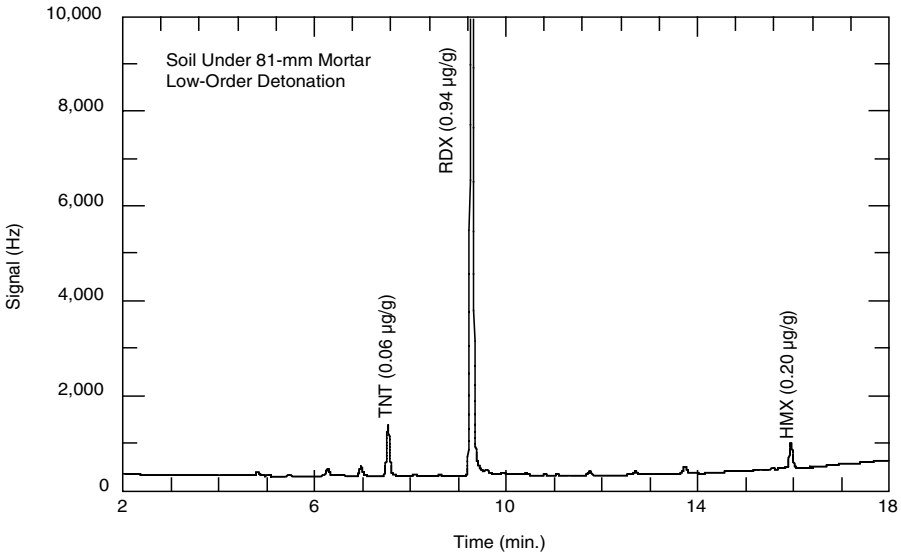


Figure 5. Chromatogram (GC-μECD) from the extract of surface soil collected under the low-order detonation of an 81-mm mortar projectile. The explosive composition was 66% RDX, 25% TNT, and 9% HMX, as determined by HPLC.

TOW missiles are anti-tank weapons. Information on the components of the TOW missile is restricted, but we do know that the explosive filler is LX-14 (HMX). Double-based propellant (nitrocellulose and nitroglycerin) launches the missile, then a solid propellant rocket motor ignites and burns out within 1.6 s of launch. The missile is guided by an operator who steers the missile to the target using wires that spool from the end of the missile.

We collected six discrete surface soil samples adjacent to each of two separate tank targets (Fig. 6). Then, composite samples, composed of seven subsamples each, were collected in duplicate in concentric circles around tank target #2 (Jenkins et al. 1998). The composite samples were collected from 5-m to 50-m distance from the tank target with a 5-m distance between each concentric circle.

The only explosive detected in surface soil next to the first tank target was RDX, which ranged from 0.002 to 0.17 µg/g (Table 6, Fig. 7). In surface soil immediately adjacent to the second tank target, RDX (<d to 0.031 µg/g) and PETN (<d to 0.20 µg/g) were detected. PETN is the explosive in detonation cord. HMX, RDX, and TNT were detected in one composite sample collected 10 m from the second tank target. Explosives were not detected in the more distant composite samples (15 to 50 m from the tank target).

In soil samples adjacent to both tank targets,

Table 5. Metals determined in soil from mortar firing test location.

	Concentration (µg/g)								
	*Fe**	*Zn*	*Pb*	*Ni*	*Cr*	*Cu*	*Ba*	*Sb*	*Cd*
Area Blue	20,600	56	8.2	26	18	32	482	<4.0	<0.5
Area Yellow	22,400	48	6.6	20	17	24	473	<4.0	<0.5
Area Red	38,600	98	12	45	45	55	789	<4.0	<0.5
Area Pink	23,000	60	7.7	22	17	28	528	<4.0	<0.5

*Iron and Barium were determined by XRF. The remaining metals were determined by atomic absorption.

Figure 6. Tank used as a target during TOW missile tests. Six discrete samples were collected adjacent to the tank, then a series of composite samples were collected radially around the tank out to 50 m at 5-m intervals.

concentrations of some metals were elevated (Table 7). Also, most of the detections of cadmium and the only detection of antimony (above detection limit) were in soils collected adjacent to these tank targets. Metal concentrations in composite samples 10 m or greater distance from tank target #2 were similar to naturally occurring concentrations (Gould et al. 1988).

SADARM tests

In the summer of 1998, reliability tests of SADARM (Sense and Destroy Armor) were conducted. The SADARM is a 155-mm projectile that contains two submunitions. The submunitions descend on a parachute while sensors (active and passive millimeter wave radar and infrared) scan for targets. Once a target is detected, an "explosively formed" penetrator is propelled through the top of the target.

Because SADARM is still under development, little information is available about its components. The penetrator is made of the heavy metal tantalum.

We located a revetment (Fig. 8) that concealed one of the target tanks during the tests. We collected one composite sample along the wall of the revetment and one from the floor of the revetment. Each composite sample was formed by taking a surface soil sample at about 1-m intervals in a line along the wall and from an approximate 1-m × 1-m grid along the floor. Near the revetment, we found a crater from which we collected surface soils from the bottom and rim and two composite samples collected from concentric circles 5-m and 10-m distance from the crater center.

RDX was the only explosive detected (0.002 µg/g) in the revetment (Table 8) and crater. It was detected at concentrations less than the method detection limit in the soils from the revetment floor, the crater rim, and 10 m from the crater. The metals zinc, lead, copper, chromium, and cadmium were detected at elevated concentrations in the revetment floor (Table 9).

40-mm impact berm and firing point

The final area sampled that was associated with a specific event was the impact berm for a test of 40-mm grenades. In November 1998, 1800 rounds were fired into a berm on the Lampkin Range (Fig. 1b). The berm was located in a now-active channel of the river downstream from an area with several targets (Fig. 9). The 40-mm rounds contain RDX as the explosive filler (Table 10). We also sampled the firing point from which these rounds were fired (Fig. 10). The propellant for this type of round is double-based (contains nitrocellulose and nitroglycerin).

Composite samples from the 40-mm impact berm were formed by collecting surface and subsurface soils at 1-m intervals along the face of the berm (Fig. 9). Method 8510 indicated the presence of nitramines and/or nitrate esters.

As determined by GC-µECD (Fig. 11), concentrations of RDX ranged from 0.004 to 0.17 µg/g in the

Table 6. Explosives residues detected around two tank targets used for TOW missile tests.

	Concentration (μg/g)				
	RDX	*HMX*	*TNT*	*NG*	*PETN*
Tank target #1					
Left rear	0.17	<d	<d	<d	<d
Left front	0.020	<d	<d	<d	<d
Front	0.002	<d	<d	<d	<d
Right front	0.050	<d	<d	<d	<d
Right rear	0.11	<d	<d	<d	<d
Rear	0.021	<d	<d	<d	<d
Tank target #2					
Left rear	0.026	<d	<d	0.005*	0.038
Left front	0.010	<d	<d	<d	<d
Front	0.023	<d	<d	<d	<d
Right front	0.012	<d	<d	<d	0.20
Right rear	<d	<d	<d	<d	<d
Rear	0.031	<d	<d	<d	<d
5 m out, replicate 1	0.002*	<d	<d	<d	0.007*
5 m out ,replicate 2	0.004	<d	<d	<d	<d
10 m out, replicate 1	0.002*	0.11	0.002	<d	<d
10 m out ,replicate 2	<d	<d	<d	<d	<d
15 m out, replicate 1	<d	<d	<d	<d	<d
15 m out, replicate 2	<d	<d	<d	<d	<d
20 m out ,replicate 1	<d	<d	<d	<d	<d
20 m out ,replicate 2	<d	<d	<d	<d	<d
25 m out ,replicate 1	<d	<d	<d	<d	<d
25 m out ,replicate 2	<d	<d	<d	<d	<d
30 m out, replicate 1	<d	<d	<d	<d	<d
30 m out ,replicate 2	<d	<d	<d	<d	<d
35 m out, replicate 1	<d	<d	<d	<d	<d
35 m out, replicate 2	<d	<d	<d	<d	<d
40 m out ,replicate 1	<d	<d	<d	<d	<d
40 m out, replicate 2	<d	<d	<d	<d	<d
45 m out ,replicate 1	<d	<d	<d	<d	<d
45 m out, replicate 2	<d	<d	<d	<d	<d
50 m out ,replicate 1	<d	<d	<d	<d	<d
50 m out, replicate 2	<d	<d	<d	<d	<d

*Detected but below method detection limit.

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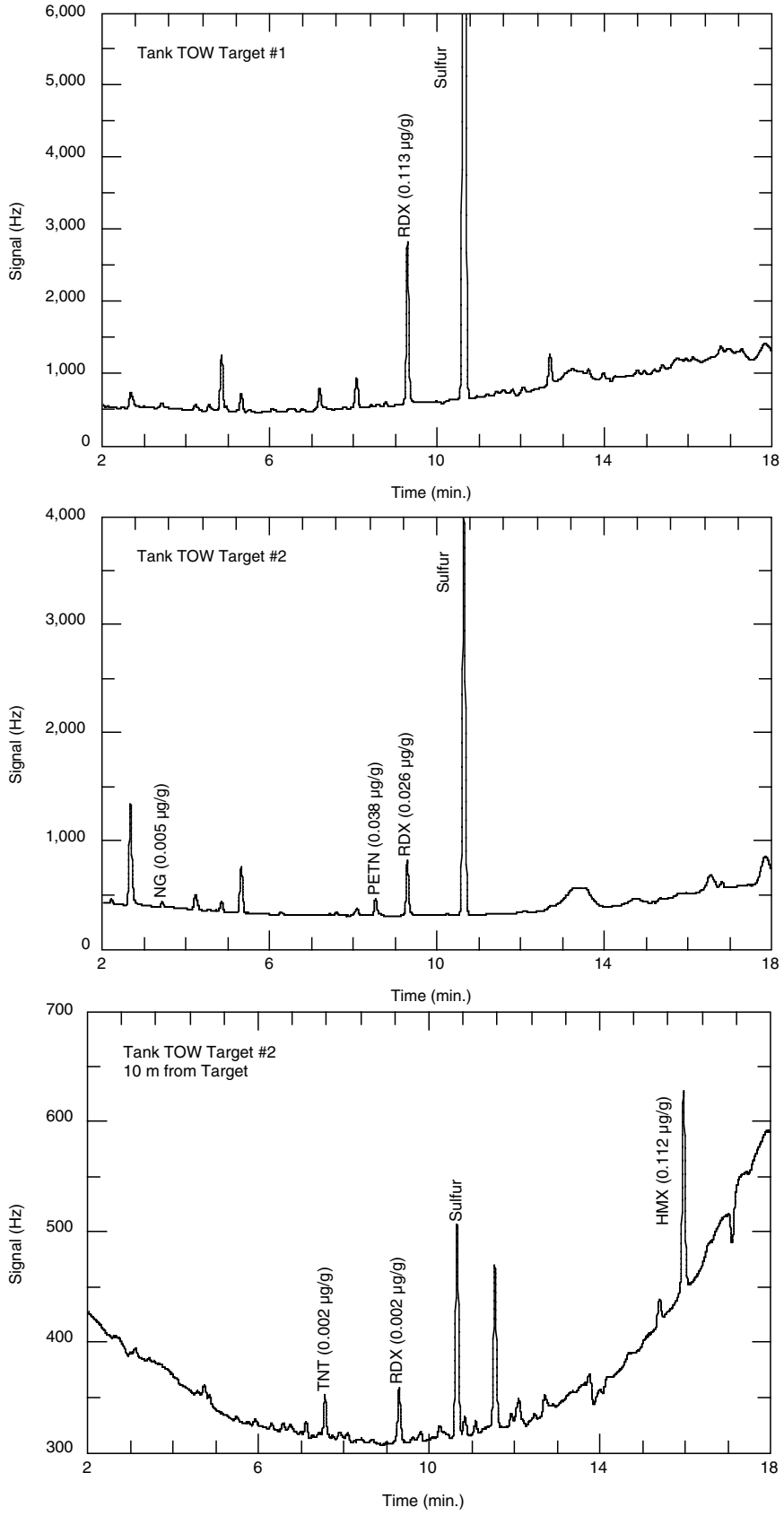

a. Tank TOW Target #1.

b. Tank TOW Target #2.

c. Tank TOW Target #2 10 m from target.

Figure 7. Chromatograms (GC-µECD) from the extracts of surface soil collected adjacent to targets used in TOW missile tests.

Table 7. Metals determined in soil around two tank targets used for TOW missile tests.

	Concentration (μg/g)								
	*Fe**	*Zn*	*Pb*	*Ni*	*Cr*	*Cu*	*Ba*	*Sb*	*Cd*
Target 1 Left rear	28,000	200	140	41	40	370	660	3.3	18
Target 1 Left front	25,000	150	17	28	24	56	550	1.3	0.43
Target 1 Right rront	23,000	300	57	45	42	260	540	2.7	2.9
Target 1 Rear	27,000	93	48	29	23	71	540	<4.0	2.9
Target 2 Rear	30,000	230	72	34	44	410	680	30	4.4
Target 2 Left front	26,000	110	19	27	25	89	490	<4.0	<0.5
Target 2 Right front	20,000	49	6.7	18	18	22	640	<4.0	<0.5
5 m out ,replicate 1	30,000	72	11	24	21	44	600	<4.0	<0.5
10 m out, replicate 1	32,000	55	7.0	23	19	35	500	<4.0	<0.5
15 m out, replicate 1	37,000	48	6.5	20	19	24	570	<4.0	<0.5
20 m out, replicate 1	36,000	52	8.3	22	19	27	630	<4.0	<0.5
25 m out, replicate 1	36,000	49	7.4	20	18	22	620	<4.0	<0.5
30 m out ,replicate 1	34,000	16	9.0	21	19	25	570	<4.0	<0.5
35 m out, replicate 1	33,000	50	8.8	23	18	20	560	<4.0	<0.5
40 m out ,replicate 1	33,000	51	7.1	20	17	25	550	<4.0	<0.5
45 m out ,replicate 1	29,000	52	11	22	19	26	580	<4.0	<0.5
50 m out, replicate 1	34,000	47	7.1	20	17	28	580	<4.0	<0.5

*Iron and barium were determined by XRF. The remaining metals were determined by atomic absorption.

Figure 8. Revetment that concealed one of the tank targets used in SADARM tests. We collected one composite sample along the wall of the revetment and one from the floor of the revetment.

Table 8. Explosives residues detected in soil from a revetment used to conceal a target in SADARM test.

	Concentration (μg/g)		
	RDX	*4-Am-DNT*	*2-Am-DNT*
Wall of SADARM revetment			
	<d	<d	<d
	<d	<d	<d
	<d	<d	<d
Floor soil of SADARM revetment			
	0.002*	<d	<d
	0.002*	0.001*	0.002
	0.002*	<d	<d
SADARM crater			
Crater bottom	<d	<d	<d
Crater rim	0.001*	<d	<d
5 m from crater	<d	<d	<d
10 m from crater	0.002*		

*Detected but below method detection limit.

Table 9. Metals determined in soil from a revetment used to conceal a target in SADARM test.

	Concentration (μg/g)								
	*Fe**	*Zn*	*Pb*	*Ni*	*Cr*	*Cu*	*Ba*	*Sb*	*Cd*
Wall of SADARM revetment	24,000	41	7.9	19	16	22	400	<4.0	<0.5
Floor soil of SADARM revetment	24,000	94	88	18	30	43	410	<4.0	1.2
5 m from crater	27,000	48	6.0	19	16	24	500	1.2	<0.5

*Iron and barium were determined by XRF. The remaining metals were determined by atomic absorption.

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Figure 9. Impact berm for 40-mm grenade test. In November 1998, 1800 rounds were fired into this berm on the Lampkin Range.

Table 10. Components of 40-mm grenades (CTG 40-mm HE M384, DODIC B470).

CTG CASE ASSY 40-mm M169	Case aluminum alloy (aluminum [80%], copper [0.95%], manganese [0.85%], chromium [0.4%]	3.05 oz
Filler	Comp A5: RDX (998.5%) and stearic acid (1.5%)	55 g
Primer perc #K90	Aluminum powder (5%), antimony sulfide (16%), barium nitrate (30%), lead styphnate (40%), tetracene (5%),	
Propellant charge M2	barium nitrate (1.4%), ethyl centralite (0.6%), graphite (0.6%), nitrocellulose (77.21%), nitroglycerin (19.44%), potassium nitrate (0.75%)	4.64 g
Primer	M55 perc	
Fuse		
Primer mix NOL #130*9	Antimony sulfide (15%), barium nitrate (20%), lead azide (20%), lead styphnate (40%), tetracene (5%)	0.23 g
	lead azide	0.79 gr*
	RDX	0.29 gr
Lead cup assy	Comp A5: RDX (98.5%) and stearic acid (1.5%)	2 gr

*gr = grain = 65 mg

Figure 10. Firing point for 40-mm grenade test. Targets for other firing events are seen in the background.

surface soil and 0.011 to 1.7 µg/g in the subsurface (Table 11). The highest concentrations were near the base of the berm. HMX was also detected above the method detection limit along the bottom half of the berm. Low concentrations of TNT and the amino-DNTs were also detected, probably associated with another firing event. A number of targets were located upstream from the berm (Fig. 9 and 10).

Concentrations of copper were elevated well above background in all of the samples from the berm (Table 12). The source of the copper was probably the grenade ogive (Fig. 12), which is 4% copper.

A composite sample from the 40-mm firing point was formed by collecting surface soil at 2-m intervals. No explosive or propellant residues were found in the soil at this firing point.

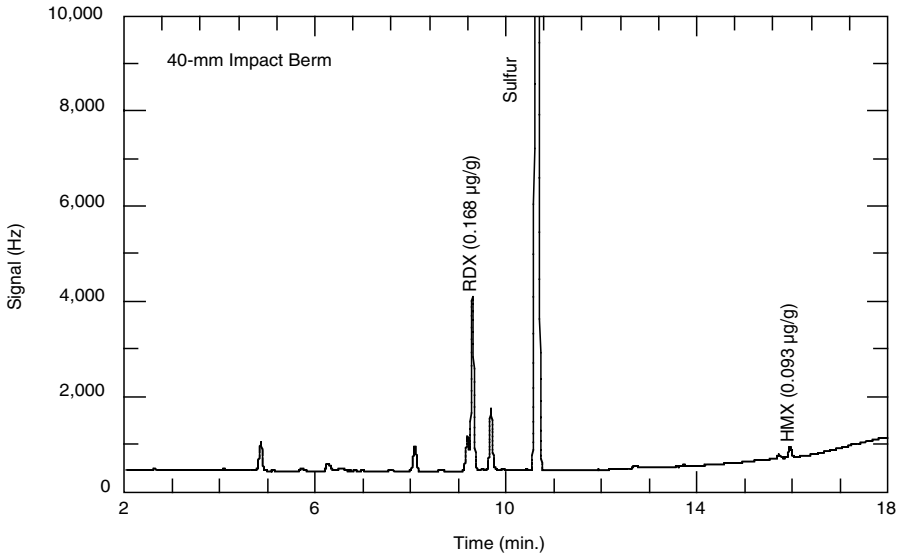


Figure 11. Chromatogram (GC-µECD) of solvent extract of surface soil collected 1 m up from berm base.

Table 11. Explosives residues detected in soil from a berm into which 1800 40-mm grenades were fired in November 1998.

Distance from base of berm		*Concentration (µg/g)*					
	Depth	*RDX*	*HMX*	*TNT*	*4-Am-DNT*	*2-Am-DNT*	*NG*
1 m	surface	0.17	0.093	0.002	<d	<d	<d
	subsurface	1.7	0.12	<d	<d	<d	<d
2 m	surface	0.086	0.014*	0.002	0.004	0.003	<d
	subsurface	0.076	0.033	0.002	<d	<d	<d
3 m	surface	0.037	<d	0.002	0.004	0.004	<d
	subsurface	0.021	0.008*	<d	<d	<d	<d
4 m	surface	0.022	<d	<d	<d	<d	<d
	subsurface	0.011	<d	<d	<d	<d	<d
Across top	surface	0.011	<d	<d	<d	<d	<d
	subsurface	0.004	<d	<d	<d	<d	<d
Firing point	surface	<d	<d	<d	<d	<d	<d
Cartridge case	surface	0.52 mg	4.6 mg	<d	<d	<d	650 mg

*Detected but below method detection limit.

We found an empty 40-mm cartridge (Fig. 12) from which we extracted RDX (0.52 µg), HMX (4.6 µg), and NG (650 µg) (Fig. 13).

Other events

In addition to soil samples associated with known firing events, we also collected samples from areas on the range that had evidence of range use. Evidence included cratering, pieces of munitions, or a designation as a firing point.

Range maintenance craters

We sampled three range maintenance craters: one near the mortar test area (Fig. 14), one near the TOW target tank, and one near the SADARM test. For each crater, samples were collected radially around the center, the rim, and surface soil up to 10-m distance.

Explosives residues were detected at all three craters at very low concentrations and with similar distribution patterns (Table 13). No explosives residues were detected in the centers (bottoms) of any of the craters. Rather, the residues were 10-m distance from the craters (Fig. 15). These results indicate that the centers of weathered craters are not the place to look for explosives residues if the objective of sampling is to determine whether any explosives residue is present in

Table 12. Metals determined in soil from a berm into which 1800 40-mm grenades were fired in November 1998.

		Concentration (µg/g)								
		*Fe**	*Zn*	*Pb*	*Ni*	*Cr*	*Cu*	*Ba**	*Sb*	*Cd*
1 m	surface	27,000	67	14	23	24	350	520	<4.0	<0.5
	subsurface	26,000	71	27	20	20	1,100	490	<4.0	<0.5
3 m	surface	30,000	45	6.8	29	25	150	500	<4.0	<0.5
	subsurface	28,000	46	8.2	33	30	160	500	<4.0	<0.5
4 m	subsurface	33,000	48	140	29	26	510	450	<4.0	<0.5
Firing point	surface	22,000	33	5.2	16	14	18	530	<4.0	<0.5

Figure 12. Cartridge case and ogive of a 40-mm grenade that contained residues of RDX, HMX, and NG.

a cratered area. Perhaps the pooling of water in craters allows more time for dissolution of the explosives, followed by either transformation or leaching of dissolved components.

Lampkin range firing point

Previous studies have shown that surface soils at firing points can be contaminated with residues of propellants (USAEHA 1994b, Ogden 2000, USCHPPM 2000, Jenkins et al. 2001). The Lampkin Range firing point has been used to fire a variety of weapons. Duplicate composite samples along this firing point were formed from surface soil collected at 2-m intervals (Fig. 16). NG (3.3 and 16.5 µg/g) and 2,4-DNT (0.005 and 0.044 µg/g) were detected in both composite samples (Fig. 17).

NG is an ingredient in double- and triple-based propellants and 2,4-DNT is added as a plasticizer to

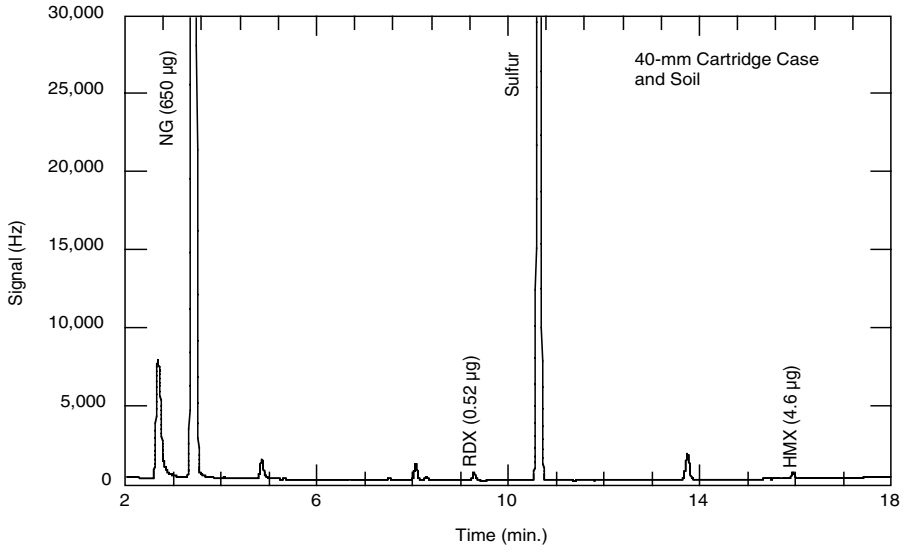


Figure 13. Chromatogram (GC-µECD) of solvent extract of empty 40-mm cartridge case found along firing point.

Figure 14. Range maintenance crater located near mortar test area.

Table 13. Explosives residues detected in three range maintenance craters.

		Concentration (µg/g)					
Event	*Location*	*RDX*	*HMX*	*TNT*	*4-Am-DNT*	*2-Am-DNT*	*NG*
Mortar	Center	<d	<d	<d	<d	<d	<d
	Rim	<d	<d	<d	<d	<d	<d
	5 m out	0.003	<d	0.008	<d	<d	<d
	10 m out	0.016	<d	0.007	0.001*	0.003	0.37
TOW	Center	<d	<d	<d	<d	<d	<d
	Rim	<d	<d	<d	<d	<d	<d
	1 m out	<d	<d	<d	<d	<d	<d
	3 m out	<d	<d	<d	<d	<d	<d
	10 m out	<d	<d	0.005	<d	<d	<d
SADARM	Center	<d	<d	<d	<d	<d	<d
	Rim	0.001*	<d	<d	<d	<d	<d
	5 m out	<d	<d	<d	<d	<d	<d
	10 m out	0.002*	<d	<d	<d	<d	<d

*Detected but below method detection limit.

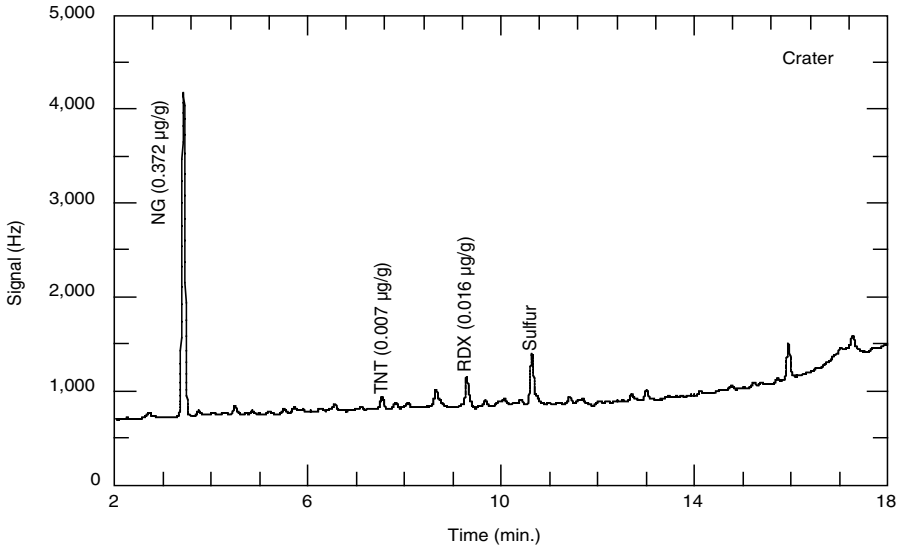


Figure 15. Chromatogram (GC-μECD) of solvent extract of soil collected 10 m from center of range maintenance crater.

single-base propellants. Single-base propellants are used with 60-mm mortars and 105-mm howitzers, double-base with 81-mm mortars and 40-mm grenades, and triple-base with 155-mm howitzers.

In addition to the point where weapons were fired, 2,4-DNT contamination may be found where excess single-base propellant has been burned directly on the soil surface (Racine et al. 1992).

Dispensed submunition gravel pad

We sampled a relatively unvegetated gravel pad that had pieces of 2.75-inch low-spin folding fin aircraft

Figure 16. Sampling soil at Lampkin Range firing point.

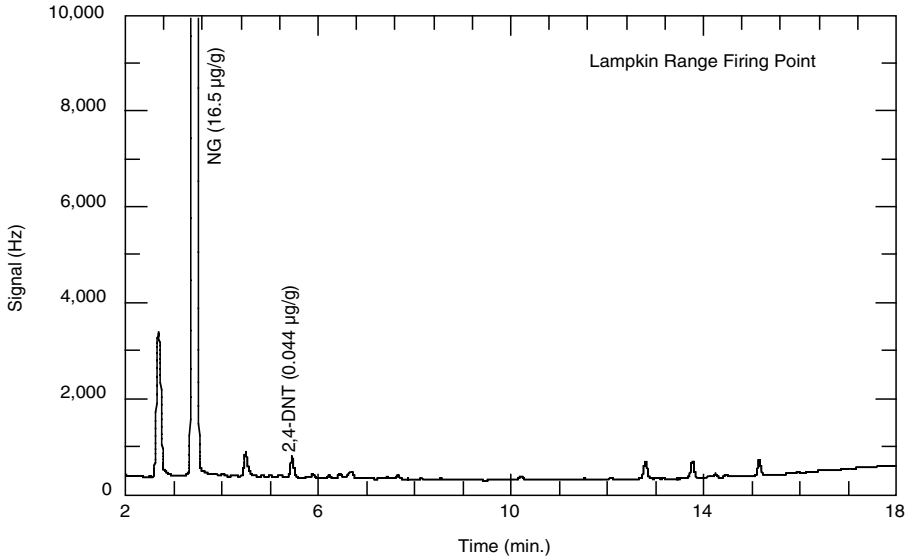


Figure 17. Chromatogram (GC-µECD) of solvent extract of soil collected at Lampkin Range firing point.

rockets and grenades (M39 and M43A1) scattered over the surface. The rockets appeared to be of various types. We were able to read the nomenclature on the side of one of the rocket pieces. It read WP M156, a rocket that originally contained 0.999 kg white phosphorus and 54.5 g Comp B (TNT and RDX) as the burster charge. The expended grenades we found were air-burst antipersonnel munitions (Fig. 18). These types of grenades contain propellant (M5 81.95% NC and 15% NG) that shoots a steel ball filled with Comp A5 (RDX), which then detonates about 5 ft above the impact point (U.S. Army 1977).

Figure 18. Grenades (M43A1 and M39) found scattered on a gravel pad on the Washington Impact Area.

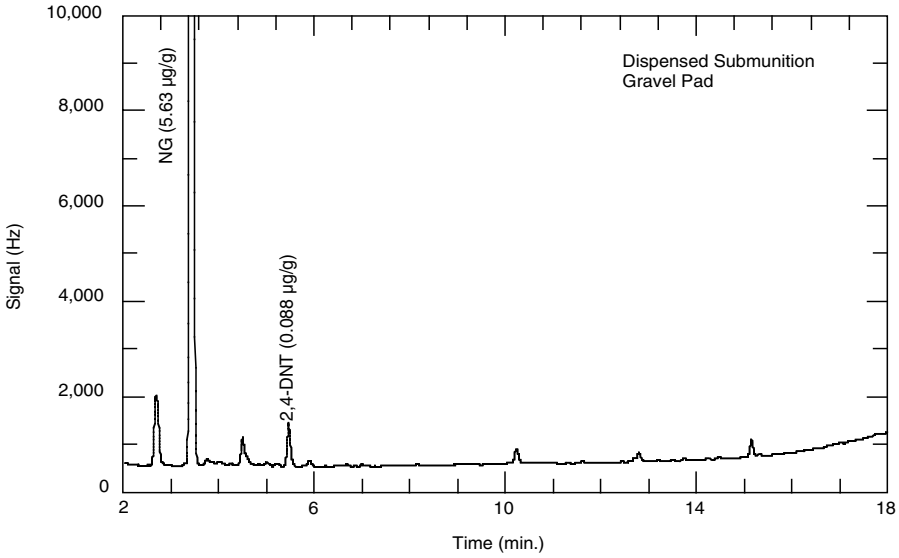


Figure 19. Chromatogram (GC-µECD) of solvent extract of soil collected on a gravel pad that had pieces of 2.75-in. low-spin folding fin aircraft rockets and grenades (M39 and M43A1) scattered over the surface.

To sample this area, each of the five-member sampling team randomly collected samples of surface soil to form five composite samples. The five composites were analyzed for explosives residues. Of these samples, two were blank, two contained 0.002 µg/g TNT, and one sample contained 5.6 µg/g NG and 0.088 µg/g 2,4-DNT (Fig. 19). The last sample had contamination similar to that found at the Lampkin Range Firing Point.

We also removed some soil from inside the expended WP M156 rocket and analyzed the soil for white phosphorus residues (USEPA 1996b). No white phosphorus residues were detected.

2.75-inch rocket warhead low-order detonation

Near the mortar test area, we found the remains of a 2.75-inch rocket warhead (U.S. Army 1981). We used the Expray kit to identify the explosive filler as Composition B (Fig. 20). Subsequent laboratory analysis showed that the composition was 57% RDX, 40% TNT, and 3% HMX.

We collected soil under the explosive to a depth of 10 cm. The highest concentrations of explosives residues found in all the samples we collected were in surface soil collected directly under this low-order detonation (Table 14, Fig. 21). Surface concentrations were 340 µg/g RDX, 40 µg/g HMX, 130 µg/g TNT,

Figure 20. Using the Expray kit to identify the explosive filler of a 2.75-in. rocket warhead as Composition B.

Table 14. Explosives detected in soil under a 2.75-in. rocket low-order detonation.

	Concentration (µg/g)							
Depth	*RDX*	*HMX*	*TNT*	*4-Am-DNT*	*2-Am-DNT*	*2,4-DNT*	*2,6-DNT*	*TNB*
Surface	340	40	130	1.0	0.84	0.036	0.016	0.17
2–5 cm	2.4	0.61	0.28	0.065	0.084	<d	<d	<d
5–7 cm	0.38	0.057	0.013	0.015	0.024	<d	<d	<d
10 cm	0.031	0.031	<d	0.003	0.007	<d	<d	<d

1.0 µg/g 4-Am-DNT, and 0.84 µg/g 2-Am-DNT. Subsurface soil at 10-cm depth contained 0.03 µg/g RDX, 0.03 µg/g HMX, 0.003 µg/g 4-Am-DNT, and 0.007 µg/g 2-Am-DNT. No TNT was detectable at 10-cm depth, indicating that migration was minimal. Given the large decrease in concentration over only 10-cm depth, migration of contaminants to groundwater is unlikely.

Red phosphorus pellets

We found a pile of red phosphorus pellets from a smoke grenade (Fig. 22). Nomenclature on the grenade was "GREN DSCHRG SMK SCR L8A3 VM GD 11/81 003." This kind of grenade is used to "provide a self-screening smoke capability for armored/tactical vehicles" (TM 43-0001-29 [U.S. Army 1994]). The grenade is filled with 360 grams of red phosphorus/butyl rubber 95/5 that is supposed to be ignited by the black powder burster charge. Red phosphorus is not toxic; however, it will contain traces of white phosphorus, which is very toxic by ingestion. We collected a few of the pellets and the surface soil under the pile of pellets. Using SW846 Method 7580, we performed a headspace SPME analysis of the pellets and analyzed the soil for white phosphorus residues. Although we detected white phosphorus in the vapor phase above the pellets, no white phosphorus residues were found in the soil.

Background

The last series of samples was not associated with a specific event or the appearance of range scrap. These samples were meant to provide background concentrations of metals and to provide information on what might be found using a grid node sampling approach. We collected a sample of surface soil every

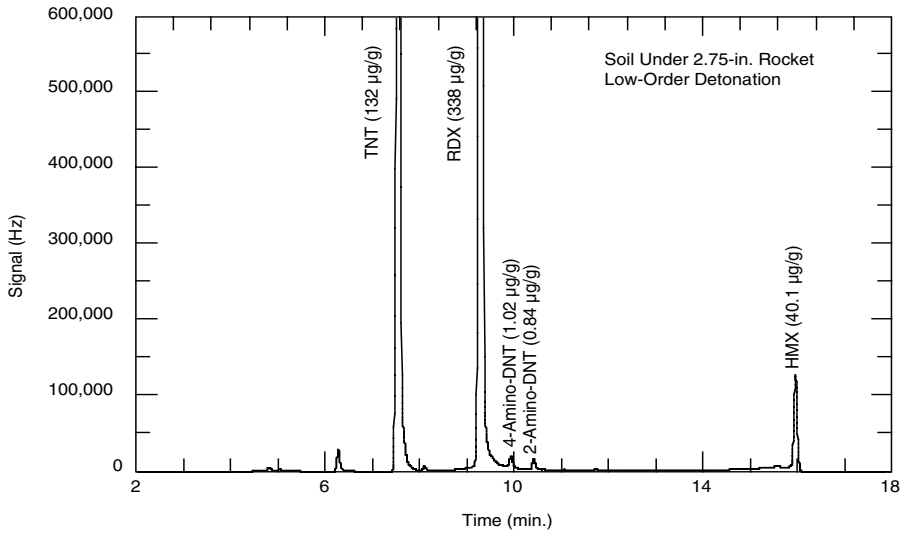


Figure 21. Chromatogram (GC-µECD) of solvent extract of soil collected under a 2.75-in. rocket warhead containing Composition B.

Figure 22. Red phosphorus pellets from an L8A3 smoke grenade.

50 m in a line paralleling the east–west access road. The line was approximately 15 m south of the road and we collected a total of 16 samples (Fig. 1b).

Low concentrations of RDX and TNT were detectable in several samples (Table 15), especially near the intersection with the TOW firing line. One sample had 9.5 µg/g 2,4-DNT and 0.42 µg/g 2,6-DNT. We suspect propellant burning was the source of these contaminants. Table 16 lists the concentrations of metals found in these samples.

Table 15. Explosives detected in discrete samples collected at 50-m intervals parallel to east–west road. Because these samples were not associated with a visually obvious range activity, we refer to these samples as "background."

Node (m)	*Concentration (µg/g)*						
	RDX	*HMX*	*TNT*	*4-Am-DNT*	*2-Am-DNT*	*2,4-DNT*	*2,6-DNT*
0	<d	<d	<d	<d	<d	<d	<d
50	<d	<d	<d	<d	<d	<d	<d
100	<d	<d	<d	<d	<d	<d	<d
150	<d	<d	<d	<d	<d	<d	<d
200	0.011	<d	0.004	0.002	0.005	<d	<d
250	0.002*	<d	<d	<d	<d	<d	<d
300	<d	<d	<d	<d	<d	<d	<d
350	<d	<d	<d	<d	<d	<d	<d
400	0.003	<d	0.010	<d	<d	<d	<d
450	0.007	<d	0.001	0.016	0.018	<d	<d
500	0.036	<d	0.012	0.005	0.013	9.5	0.42
550	0.014	0.004*	0.008	<d	<d	0.010	<d
600	0.001*	<d	<d	<d	<d	<d	<d
650	<d	<d	<d	<d	<d	<d	<d
700	<d	<d	<d	<d	<d	<d	<d
750	<d	<d	<d	<d	<d	<d	<d

*Detected but below method detection limit.

Table 16. Concentrations of metals in discrete samples collected at 50-m intervals parallel to east–west road.

Node (m)	Concentration (µg/g)								
	Fe*	Zn	Pb	Ni	Cr	Cu	Ba*	Sb	Cd
0	31,000	61	11	27	22	29	500	<4.0	<0.5
50	30,000	67	11	28	22	32	420	<4.0	<0.5
100	29,000	63	10	27	22	31	640	<4.0	<0.5
150	30,000	87	7.4	21	18	440	460	<4.0	<0.5
200	24,000	48	7.5	19	16	25	510	<4.0	<0.5
250	26,000	70	9.4	24	20	36	440	<4.0	<0.5
300	27,000	58	8.0	25	20	34	470	<4.0	<0.5
350	32,000	52	7.4	28	25	38	590	<4.0	<0.5
400	29,000	65	10	27	22	38	440	<4.0	<0.5
450	27,000	63	9.6	25	21	35	500	<4.0	<0.5
500	32,000	58	8.7	20	19	77	600	<4.0	<0.5
550	32,000	55	9.1	25	19	35	640	<4.0	<0.5
600	28,000	53	9.5	21	17	33	670	<4.0	<0.5
650	29,000	60	9.6	26	22	34	590	<4.0	<0.5
700	30,000	56	11	23	18	29	490	<4.0	<0.5
750	29,000	61	11	27	21	34	680	<4.0	<0.5

*Iron and barium were determined by XRF. The remaining metals were determined by atomic absorption.

DISCUSSION

Explosives residues

We detected explosives residues in 48% of the 107 soil samples we collected. RDX was the most frequently detected explosive (39%) (Table 17). Of the samples above the detection limit, median RDX concentration was only 0.021 µg/g (Fig. 23a). Soil samples collected under low-order detonations accounted for four of the five highest RDX concentrations. TNT was the second most frequently detected explosive (21%) (Table 17); concentrations were lower than RDX. Median TNT concentration in samples where TNT was detected was only 0.004 µg/g. Similar to RDX, soil samples collected beneath low-order detonations produced the highest TNT concentration observed (Fig. 23b). TNT is more readily biotransformed than RDX, and the transformation products of TNT were detected in about 10% of the samples. HMX was found in 11% of the samples. HMX is the least water-soluble of the explosives and is likely to persist in surface soils. However, its toxicity is low.

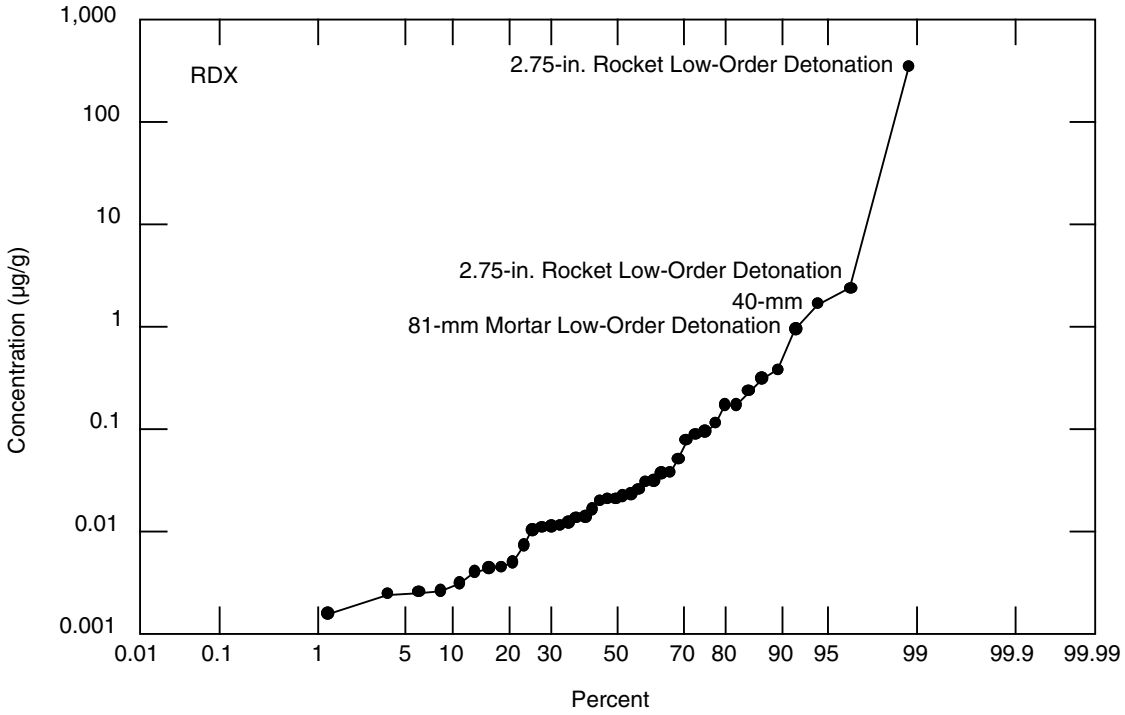
The analytes 2,4-DNT and NG were detected at the Lampkin Range firing point and in a few samples on the Washington Range. The highest concentration of 2,4-DNT we found was in a sample not associated with a known event. The likely source of the contamination was either firing using single-base propellant or burning of excess propellant.

Metals

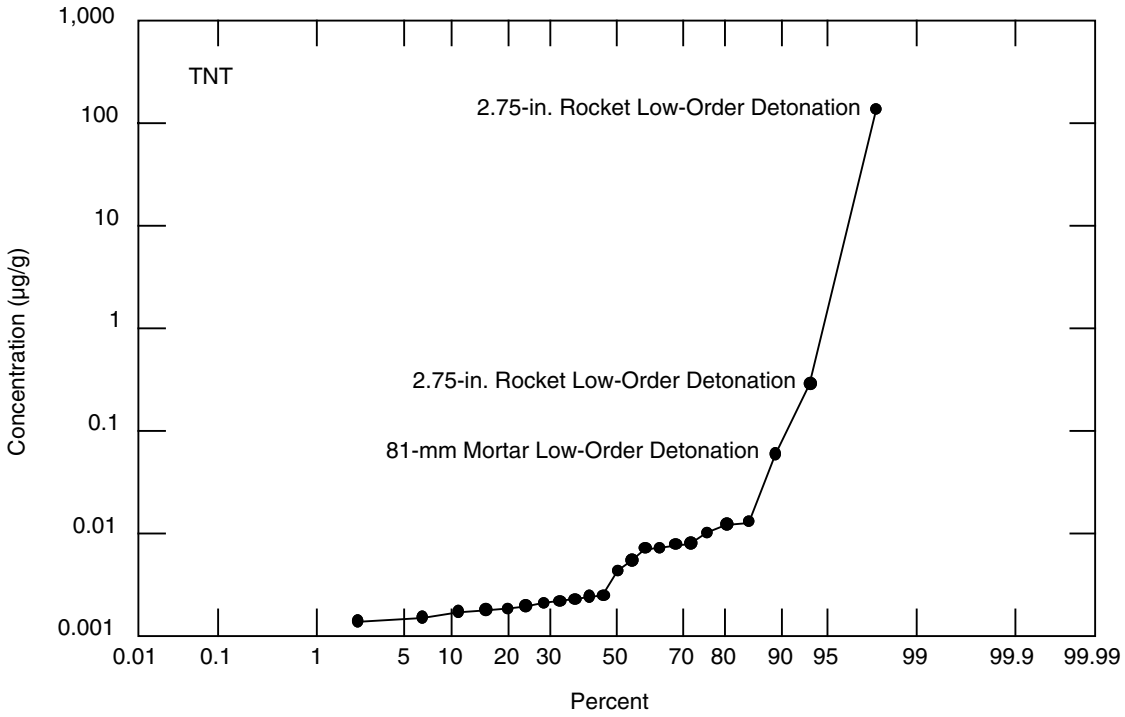
Unlike the explosives, metals have natural background concentrations. Probability plots help to show which samples contain abnormally high concentrations for a particular set of samples. For example, the 40-mm firing test resulted in increased levels of copper (Fig. 24). The TOW test increased

Table 17. Summary of explosives found in soil samples.

Analyte	Number of detections	Percent of sample collected	Median conc. of samples above detection limit (µg/g)	Maximum concentration (µg/g)
RDX	42	39	0.021	340
TNT	23	21	0.004	130
HMX	12	11	0.12	40
2-Am-DNT	12	11	0.006	0.84
4-Am-DNT	10	9	0.005	1.0
2,4-DNT	6	6		
NG	4	4		
2,6-DNT	2	2		
PETN	2	2		
TNB	1	1		
Tetryl	0	0		
DNB	0	0		

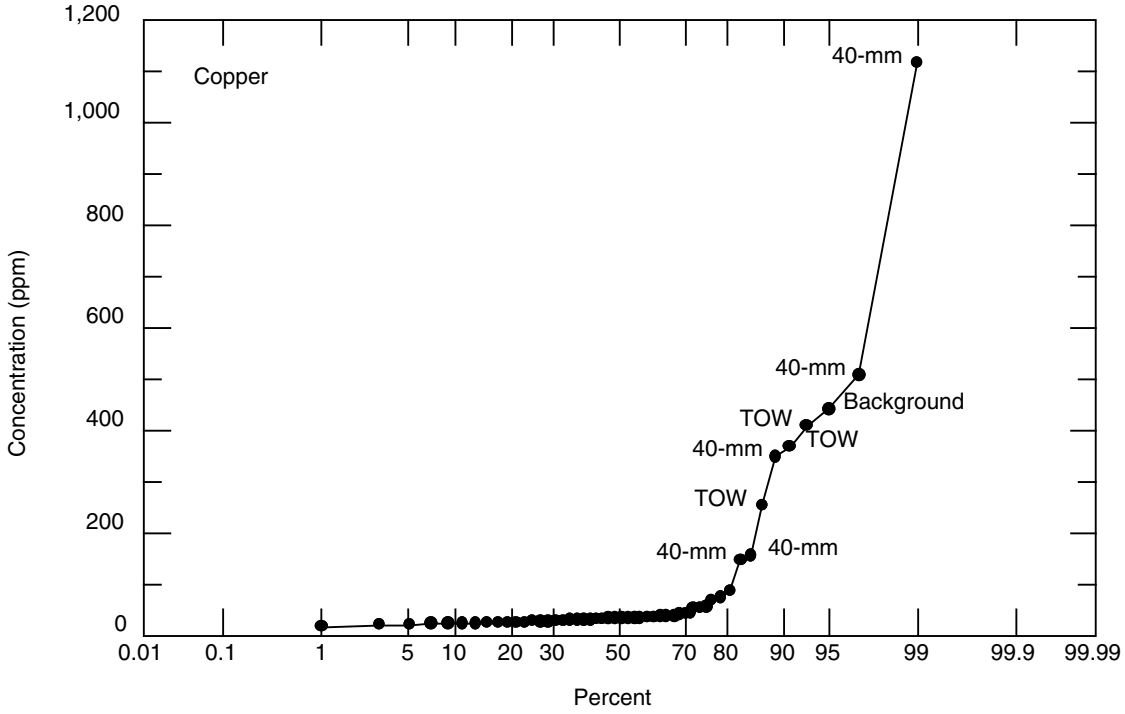


a. RDX concentrations. Median concentration was 0.021 µg/g. The four highest concentrations are labeled with the events associated with the soil sample.

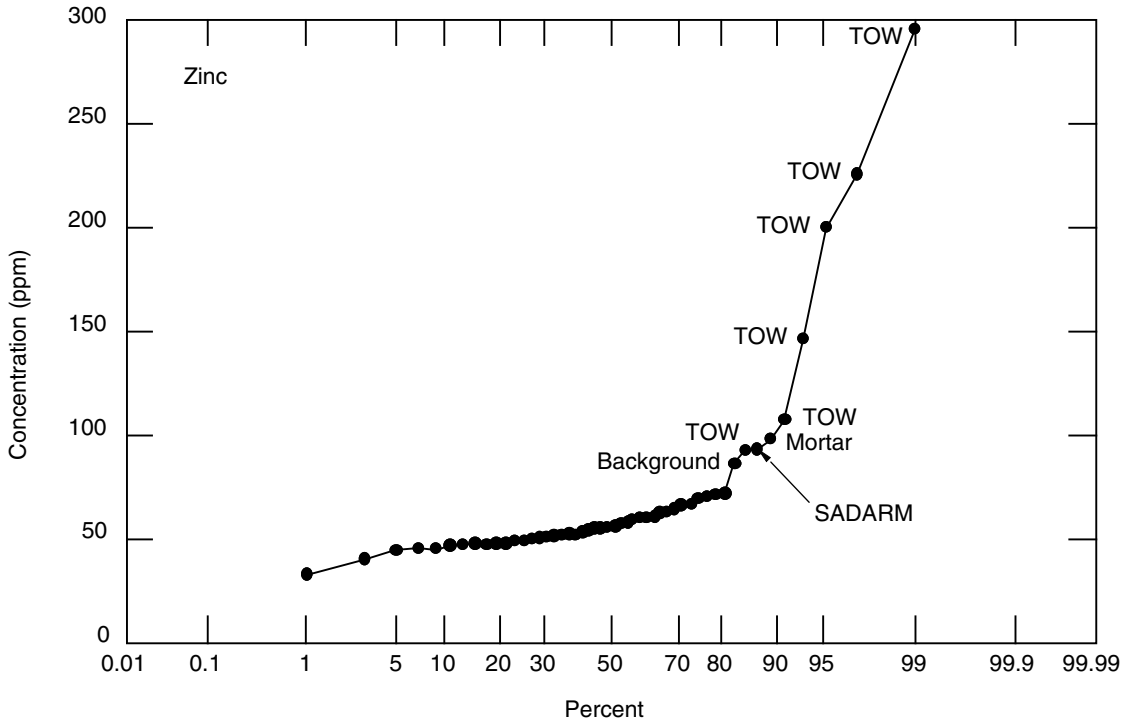


b. TNT concentrations. Median concentration was 0.004 µg/g. The three highest concentrations are labeled with the events associated with the soil sample.

Figure 23. Probability plots of RDX and TNT concentrations.

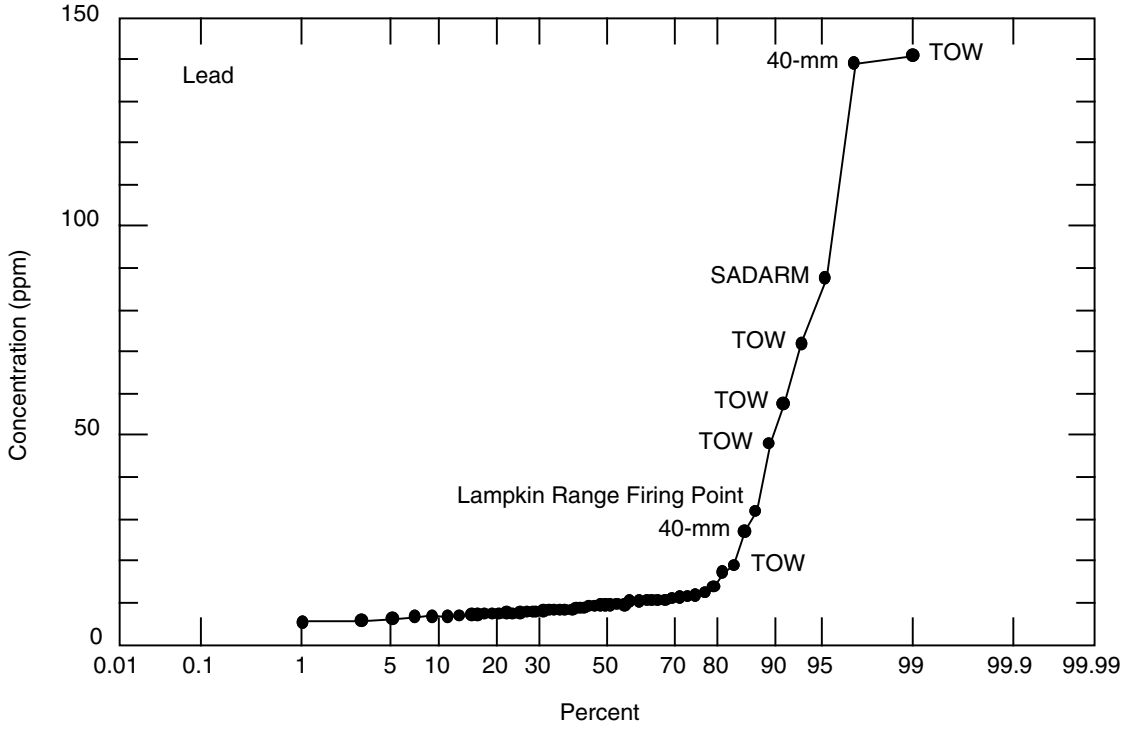


a. Copper

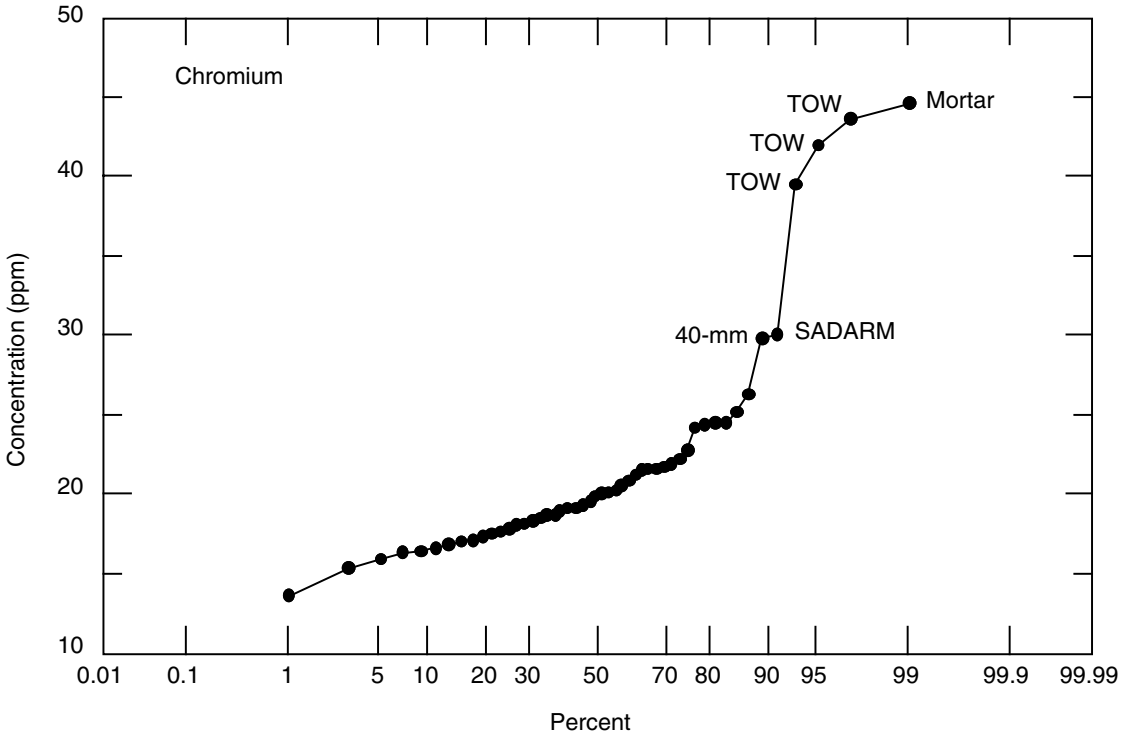


b. Zinc.

Figure 24. Probability plots of metal concentrations found in samples. The highest concentrations are labeled with the events associated with the soil sample. Normal (Gaussian) populations would fall on a straight line.



c. Lead.



d. Chromium.

Figure 24 *(cont'd)*. Probability plots of metal concentrations found in samples. The highest concentrations are labeled with the events associated with the soil sample. Normal (Gaussian) populations would fall on a straight line.

concentrations of copper, zinc, lead, chromium, and antimony above most of the other samples we collected (Fig. 24 and 25). Because these samples were collected adjacent to target tanks, source of the metal could have been either the missiles or the tank or both.

Comparison with current cleanup guidance

Action levels

Cleanup or action levels for contaminants in soil are site-specific and depend on several factors, including the characteristics of the soil, the mix of contaminants, potential receptors and exposure pathways, and potential for migration to groundwater. EPA Region III has developed a Risk-Based Concentration Table that may be used to screen sites not on the National Priority List. Tables 18 and 19 give levels for explosives residues and metals in industrial and residential soils.

Only one sample had RDX and TNT concentrations above the Risk-Based Concentrations for soil in a residential area, and that soil sample was in direct contact with unexploded Composition B from a low-order detonation. For some chemicals, the Risk-Based Concentration Table also gives soil screening levels for the protection of groundwater. Although values are not given for RDX and TNT, there are values for 2,4-DNT and 2,6-DNT (an impurity in military-grade TNT and 2,4-DNT). These values are 0.029 µg/g and 0.012 µg/g

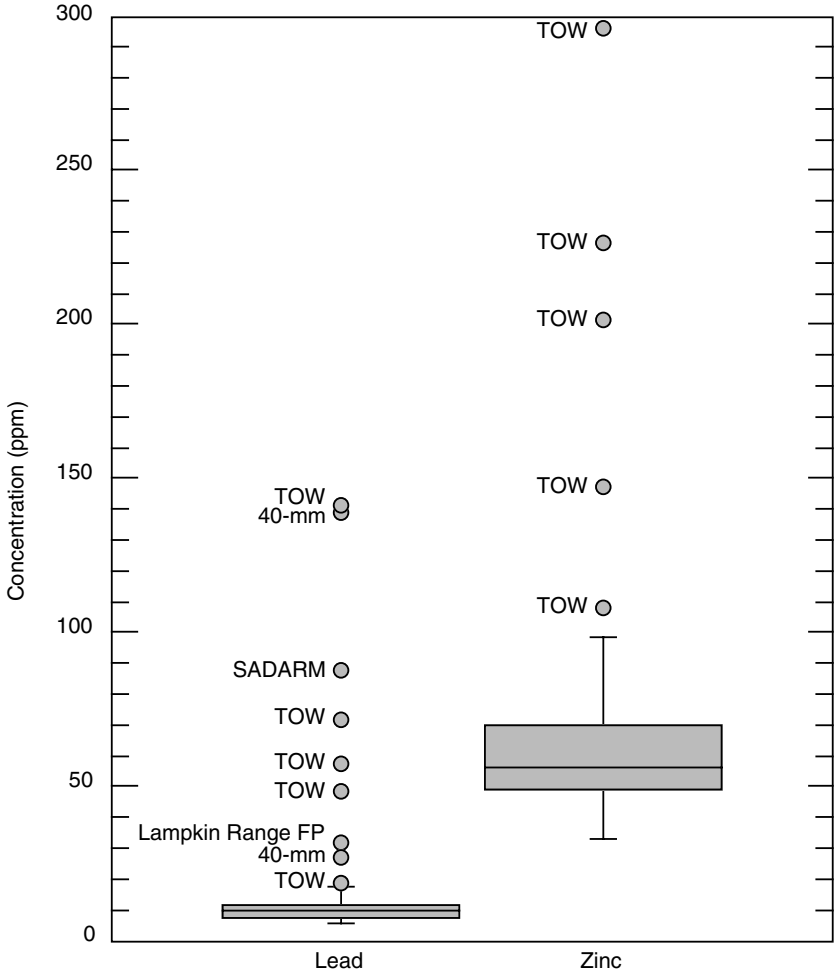


Figure 25. Box plots of lead and zinc concentrations showing which events resulted in increased metal concentrations. Each box encloses 50% of the data with the median value represented as a line in the box, the upper quartile as the top of the box and the lower quartile as the bottom of the box. The circles represent outliers, which are values greater than the sum of the upper quartile plus one and one-half times the difference between the upper and lower quartile.

Table 18. Risk-based concentrations in soil (μg/g) and maximum concentrations detected on the Washington Impact Area.

Analyte	Risk-based concentrations* Industrial	Residential	Max conc. detected	Event
TNT	190	21	130	Low-order detonation
RDX	52	5.8	340	Low-order detonation
HMX	10,000	3,900	40	Low-order detonation
NG	410	46	17	Firing point
2,4-DNT	4,100	160	9.5	Unknown

*http://www.epa.gov/reg3hwmd/risk/riskmenu.htm

for 2,4-DNT and 2,6-DNT, respectively, if the dilution attenuation factor is one, and 0.57 μg/g and 0.25 μg/g if the dilution attenuation factor is 20. The highest concentrations we found for these two analytes were 9.50 and 0.42 μg/g in a sample not associated with a known firing event.

Recommendations for future sampling plans

The sampling approach we used for this preliminary survey was biased because we are researching the sources of explosives residues in soils of impact areas. To accomplish this research we focused on low-order detonations and locations with written history or physical evidence of numerous high-order detonations. At each impact area that we visit in the future, we will continue this kind of biased sampling to further enhance our understanding of the relative importance of each potential source of contamination. Source areas must be identified prior to assessing the potential for migration to water. However, biased or authoritative sampling does not provide adequate baseline data to evaluate the extent of contamination, which usually requires a probabilistic sampling design to estimate mean concentrations

When designing a sampling plan to estimate mean concentrations of explosives in soil, the following

Table 19. Naturally occurring cleanup levels and maximum concentrations detected on the Washington Impact Area.

Element	Concentration (μg/g) Naturally occurring in U.S.* Soil	Naturally occurring in Alaska† Soil	Sediment	Alaska DEC cleanup levels Ingestion	Migration to groundwater	EPA risk based concentrations Industrial	Residential	Max. conc. detected (Event)
Antimony (Sb)	0.66			41	3.6	820	31	30 (TOW)
Barium (Ba)	580	595	811	7,100	1,100	140,000	5,500	790 (Crater)
Cadmium (Cd)	0.35	1.3	2.6	100	5	1,000	39	18 (TOW)
Chromium (Cr)	54	50 (t)	115(t)	510(+6)	26 (+6)	6,100 (+6)	230 (+6)	45 (Mortar)
Copper (Cu)	25	24	37			82,000	3,100	1,100 (Mortar)
Iron (Fe)	26,000	35,000	37,000			610,000	23,000	39,000 (Mortar)
Lead (Pb)	19	12	12	400 to 1,000				140 (TOW)
Nickel (Ni)	19	24	37	2,000	87	41,000	1,600	45 (TOW)
Zinc (Zn)	60	70	157	30,000	9,100	610,000	23,000	300 (TOW)

*Lower 48 states (Sposito 1989)
(t) total
(+6) oxidation state +6
†Gould et al. (1984, 1988)

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characteristics must be considered: explosives (with the exception of NG [melting point 13°C]) are solids at environmental temperatures; most explosives have low aqueous solubility; and they dissolve very slowly in water. As a result, the bulk of explosives residues tend to reside in the surface soil and are heterogeneously distributed over short distances.

Given these characteristics, and our objective to estimate mean explosives concentrations in surface soil, a multi-increment or composite sampling approach will be used. The detection limits provided by Method 8095 are sufficiently low to permit multi-increment sampling without concern for overlooking significant contamination sources. Based on data from the Washington Range and other impact areas, targets at which various munitions are fired will often have higher concentrations of contaminants than areas farther away (Jenkins et al. 1998). A stratified random sampling (Gilbert 1987) design could be used where these high-impact zones occupy one stratum, and the remainder of the impact area occupy another. In the sampling design illustrated in Figure 26, the impact area is divided into square grids from which duplicate multi-increment samples are collected. Superimposed on the square grid is the stratum containing the targets where multi-increment samples are formed from radial bands at various distances from each target. Such a design should provide sufficient data to assess the extent of contamination on an impact area.

CONCLUSIONS

This report summarizes a reconnaissance visit to an impact area on Fort Greely during the summer of 2000. This visit was the first sampling event in a multiphase program to develop sampling methods to assess the potential for surface and groundwater contamination from ordnance testing and training activities.

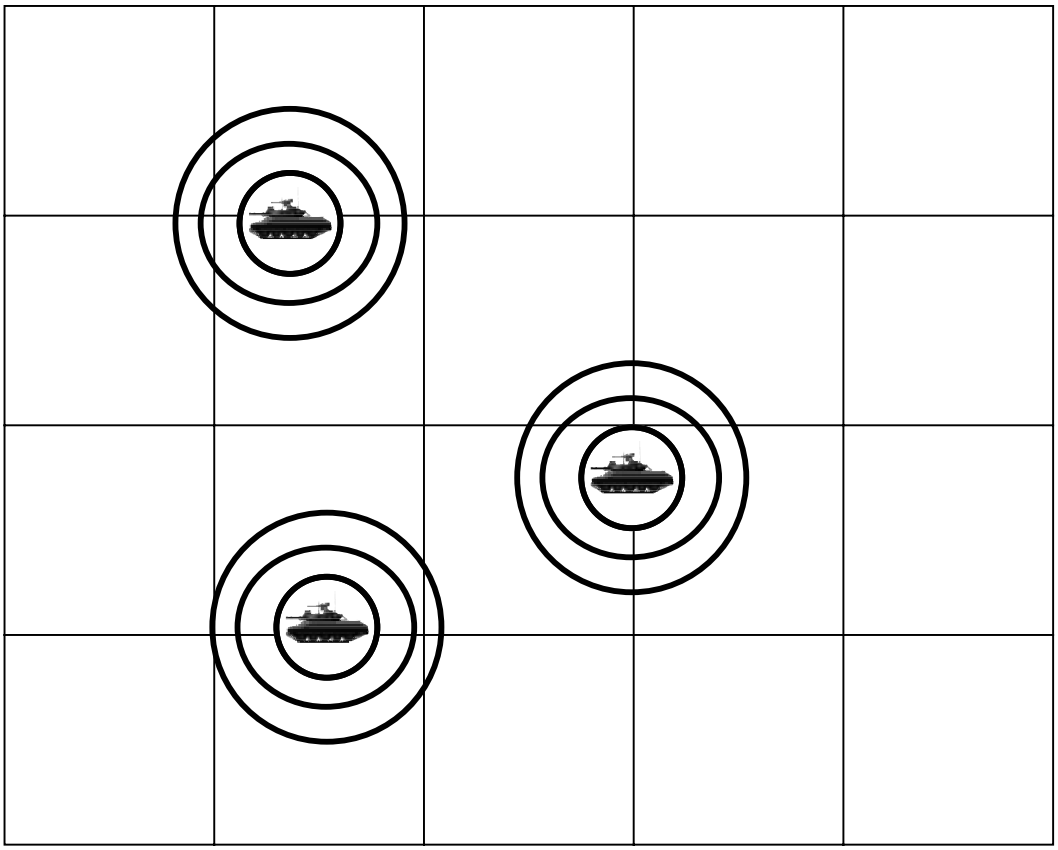

Figure 26. Conceptual illustration of a stratified sampling plan to estimate mean explosives concentrations in impact area surface soil. The impact area is divided into square grids from which duplicate multi-increment samples. The surface soils around targets, around where detonations are concentrated, are sampled in radial bands around each target.

High-explosive projectiles that function properly appear to leave little residue in the surface soil. RDX and HMX, which leave low but detectable residues, appear to leave more residue than TNT. The reason for the difference in residue levels between the nitramine (RDX and HMX) and nitroaromatic (TNT) explosives is unknown but may be due to degree of conversion in the detonation, water solubility differences, or environmental transformation pathways.

The median concentrations for RDX and TNT we detected in soils were only 0.021 and 0.004 µg/g, respectively. These low concentrations of explosives would have been non-detects using Method 8330, but were detectable using Method 8095. Also, field colorimetric procedures would not detect these low concentrations; rather, a field-portable gas chromatograph would be needed. Colorimetric field analysis of soil from the Washington Range revealed a problem with the commercial (EnSys) version of Method 8515. Elemental sulfur and sulfides yield a false positive for TNT with the EnSys reagent (tetrabutyl ammonium hydroxide) but not with the reagents (potassium hydroxide and sodium sulfite) originally recommended by Jenkins (1990).

Low-order detonations, where only part of the high-explosive filler detonated leaving solid explosive composition in contact with surface soil, produced the highest soil concentrations observed. On the Washington Range, the explosives did not appear to be migrating downward, probably because soils were frozen most of the year.

NG and 2,4-DNT residues from propellants were found in the soil at the Lampkin Range firing point. Washington Range firing points will be sampled in the future.

The greatest potential threat of contamination of surface and groundwater would be high numbers of low-order detonations or heavily used firing points located in groundwater recharge areas.

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APPENDIX A: CHEMICALS

Table A1. Chemicals found in ordnance listed in Table A2 (ammunition reported in Washington Range records for 1998–1999).

Chemical	*Formula*	*Registry number*
	a) Organic	
Acetone	CH_3COCH_3	67-64-1
Barium stearate	$C_{36}H_{70}O_4$•Ba	6865-35-6
Calcium resinate	Unspecified	9007-13-0
Calcium stearate	$C_{36}H_{70}O_4$•Ca	1592-23-0
Cobalt naphthenate	$Co(C_{11}H_{10}O_2)_2$	61789-51-3
Dibutylphthalate	C_6H_4-1,2-$[CO_2(CH_2)_3CH_3]_2$	84-74-2
Diethylphthalate	C_6H_4-1,2-$(CO_2C_2H_5)_2$	84-66-2
Dinitrotoluene	$C_7H_6N_2O_4$	121-14-2
Diphenylamine	$(C_6H_5)_2NH$	122-39-4
Ethyl centralite	$CO[N(C_2H_5)(C_6H_5)]_2$	85-98-3
Hexachloroethane	Cl_3CCCl_3	67-72-1
Hexanitrostilbene (HNS)	$[(NO_2)_3(C_6H_2)]C_2H_2[(NO_2)_3(C_6H_2)]$	20062-22-0
HMX	$C_4H_8N_8O_8$	2691-41-0
Laminac	$(C_8H_4O_3.C_4H_2O_3.C_3H_8O_2)n$	25037-66-5
Lecithin	$CH_2(R)CH(R')CH_2OPO(OH)O(CH_2)_2N(OH)(CH_2)_3$	8002-43-5
Lupersol (2-butanone-peroxide)	$C_8H_{16}O_4$	1338-23-4
Lead styphnate	$(NO_2)C_6H_2O$•Pb	15245-44-0
mono-Nitrotoluene	$C_3H_3C_6H_4NO_2$	88-72-2 (ortho)
Methyl acetate	$C_3H_6O_2$	79-20-9
Methyl centralite	$CO[N(CH_3)(C_6H_5)]_2$	611-92-7
Nitrocellulose	$[(CH_2ONO_2)C_5O(ONO_2)_2O]_n$	9004-70-0
Nitroglycerin	$C_3H_5(ONO_2)_3$	55-63-0
PETN	$C(CH_2ONO_2)_4$	78-11-5
Polyester adipate		
Polyethylene	$(C_2H_4)_n$	9002-88-4
Polyisobutylene	$(C_4H_8)_n$	9003-27-4
Polyvinyl chloride	$[CH_2CH(Cl)]_n$	9002-86-2
RDX	$C_3H_6N_6O_6$	121-82-4
Stearic acid	$C_{18}H_{36}O_2$	57-11-4
Tetracene	$C_2H_6N_{10}$•H_20	31330-63-9
Tetranitrocarbazole	$C_{12}H_5N_5O_8$	4543-33-3
Tetryl	$C_7H_5N_5O_8$	479-45-8
TNT	$(C_6H_2)(NO_2)_3CH_3$	118-96-7
Vinyl acetate	$C_4H_6O_2$	108-05-4
Vinyl alcohol (aka hydroxyethylene)	C_2H_4O	557-75-5
Wax	Unspecified	71808-29-2
	b) Inorganic	
Aluminum powder	Al	7429-90-5
Antimony	Sb	7440-36-0
Antimony sulfide (trisulfide)	Sb_2S_3	1345-04-6
Barium chromate	$BaCrO_4$	10294-40-3
Barium nitrate	$Ba(NO_3)_2$	10022-31-8
Boron amorphous powder	B	7440-42-8
Calcium carbonate	$CaCO_3$	471-34-1
Calcium chlorate	$Ca(ClO_3)_2$	10137-74-3
Calcium chloride	$CaCl_2$	10043-52-4
Calcium silicate	$CaSiO_3$	1344-95-2
Carborundum	CSi	409-21-2
Charcoal		16291-96-6
	Cr_2O_3	1308-38-9
Chromium oxide	CrO_3	1333-82-0
Coal		
Copper	Cu	7440-50-8
Diatomaceous earth		61790-53-2
Ferric oxide	Fe_2O_3	1309-37-1

Graphite	C	7782-42-5
Lead	Pb	7439-92-1
Lead azide	$Pb(N_3)_2$	13424-46-9
Lead carbonate	$PbCO_3$	13427-42-4
Lead chromate	$PbCrO_4$	7758-97-6
Lead dioxide	PbO_2	1309-60-0
Lead thiocyanate	$[Pb(NCS)_2]$	592-87-0
Magnesium powder	Mg	7439-95-4
Manganese powder	Mn	7439-96-5
Molybdenum trioxide	MoO_3	1313-27-5
Polysulfide	$[(S_x)_2-]$	9080-49-3
Potassium chlorate	$KClO_3$	3811-04-9
Potassium nitrate	KNO_3	7757-79-1
Potassium perchlorate	$ClHO_4$•K	7778-74-7
Potassium sulfate	K_2SO_4	7778-80-5
Silicon	Si	7440-21-3
Sodium nitrate	$NaNO_3$	7631-99-4
Sodium sulfate	Na_2SO_4	7757-82-6
Strontium nitrate	$Sr(NO_3)_2$	10042-76-9
Strontium peroxide	SrO_2	1314-18-7
Sulfur	S	7704-34-9
Titanium powder	Ti	7440-32-6
Tungsten	W	7440-33-7
Zinc oxide	ZnO	1314-13-2
Zirconium	Zr	7440-67-7
Zirconium hydride	ZrH_2	7704-99-6

Table A2. Ammunition listed on Washington Range records: Organic chemicals.

DODIC	Ammunition Name	Nomenclature	Rounds Fired	Acetone	Barium Stearate	Calcium Resinate	Calcium Stearate	Cobalt Naphthenate	Dibutylphthalate	Diethylphthalate	Dinitrotoluene	Diphenylamine	Ethyl Centralite	Hexachloroethane	Hexanitrostilbene (HNS)	HMX	Laminac (polyester resin)	Lecithin	Lupersol (2-butanone-peroxide)	Lead styphnate	meta-Nitrotoluene	Methyl Acetate	Methyl Centralite	Nitrocellulose	Nitroglycerin	PETN	Polyester Adipate	Polyethylene	Polyisobutylene	Polyvinyl Chloride	RDX	Stearic Acid	Tetracene	Tetranitrocarbazole	Tetryl	TNT	Vinyl Acetate	Vinyl Alcohol (aka hydroxyethylene)	Wax
A059	5.56M/M885	CTG 5.56MM BALL M855	232,060						X			X	X							X				X	X	X							X						
A060†	5.56MBLK	Blanks	11,225																																				
A064	5.56M4/1	CTG 5.56MM 4 BALL M855/1 TR M856 LNKD M2	3,800			X			X			X	X							X				X	X	X				X			X						
A066	5.56MBAL	CTG 5.56MM BALL M193	348,490						X			X	X							X			X	X	X	X							X						
A075	5.56MBLSAW	CTG 5.56MM BLK M200 LNKD	1,000						X			X	X							X				X	X	X													
A107	7.62M39BAL	CTG CAL .22 LR BALL	1,400									X								X				X	X		X						X						
A112	7.62MBM82	CTG 7.62MM BLK M82	20						X			X								X				X	X	X							X						
A127	7.62M,4/1	CTG 7.62MM 4 BALL M80/1 TR M62	1,700			X						X								X				X	X	X				X			X						
A131	7.62ML4/1	CTG 7.62MM 4 BALL M80/1 TR M62	1,000			X			X			X								X				X	X	X				X			X						
A135	7.62MBLK	Dummy Cartridge	450																																				
A171	7.62 MA	CTG 7.62MM MATCH M852	140						X		X	X								X				X	X								X						
A358	AT4 9MM	CTG 9MM Practice Tracer	15																																				
A360	9MMB	CTG 9MM Practice	1,650																																				
B470	40MM HE	CTG 40MM HE M384	1,800 (Lampkin Range)										X							X				X	X						X	X	X						
C226	81MMILLUM	CTG 81MM ILLUM M301 W/FUZE TIME M84	1							X			X											X	X									X		X			
C228	81MMHE	SHELL TRNG 81MM M68 MPTS W/O FIN ASSY	57																																				
C445	105MMHE	CTG 105MM HE M1 W/O FUZE	17		X				X		X	X												X											X				
D201†	TOWSIMBL		2																																				
D505	155MMILLUM	PROJ 155MM ILLUM M485E1	45																															X					
D539	155MMDUMMY	Dummy propelling charge, 155MM	14																																				
D544	155MM H	PROJ 155MM HE M107	335		X																															X			
G930	SMK HC|	GREN HAND SMK HC AN-M8	12	X										X								X													X	X	X	
K143	CLAYMORE	MINE APERS M18 W/ACCESSORIES	21	X							X										X			X					X		X			X	X			
K180	M15AT	MINE AT HEAVY M1	9																												X	X			X	X			
K181	M21MINE	MINE AT HEAVY M21	7															X		X				X							X	X	X					X
K250	M19MINE	MINE AT HEAVY M19 NON METALLIC	6																	X											X	X	X		X	X			
L314	STARGRN	SIGNAL ILLUM GRND M125A1	4					X									X		X	X						X				X			X	X			X		
M023	C4 1-1	CHG DEMO M112	1,237																										X		X								
M028	BANGTORP	DEMO KIT BANGALORE TORPEDO M1A2	41																												X					X			X
M039	40LB CR	CHG DEMO 40LB CRATERING	12															X													X	X				X			X
M130	BLCAPM6	CAP BLASTING ELECT M6	22				X																	X							X								
M131	BLCAPM7	CAP BLASTING NON ELECT M7	177																	X											X								
M148A†	JAVELIN		13																																				
M766	FUSE IG	IGN TIME BLASTING M60	104																	X					X								X			X			
M421†	SHAPCR40LB	CHARGE DEMOLITION 40 LB SHAPED	2																																				
M456	REINDET	CORD DETONATING	2,605																						X			X											
M670	TIMEFUSE	FUSE BLASTING TIME M700 4000 FT	218																									X											
M998	DEMO CH	CHG EXPL ORDNANCE DISPOSAL MK89 MOD0	12																												X								X
MD15†	DETCORD-15	CORD DETONATING	300																																				
MS52	CORDDET	CORD DETONATING	130												X																								
N335	FUSEM557	FUZE PD M557	2		X		X																					X							X	X			
PB25†	TOWHEAT		12																																				
PL23†	DRAGON	Guided Missile and Launcher, Surface Attack	2																																				
PL90†	STINGER	Guided Missile Subsystem, Intercept -Aerial	4																																				
PRIM†	PRIME		2																																				
XM898†	SADARM		48																																				

†Data not found.

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Table A2. Ammunition listed on Washington Range records: Inorganic.

DODIC	Ammunition Name	Nomenclature	Rounds Fired	Aluminum Powder	Antimony	Antimony Sulfide (trisulfide?)	Barium Chromate	Barium Nitrate	Boron Amorphous Powder	Calcium Carbonate	Calcium Chlorate	Calcium Chloride	Calcium Silicate	Carborundum	Charcoal	Chromium Oxide	Coal	Copper	Diatomaceous Earth	Ferric Oxide	Graphite	Lead	Lead Azide	Lead Carbonate	Lead Chromate	Lead Dioxide	Lead Thiocyanate	Magnesium Powder	Manganese Powder	Molybdenum Trioxide	Polysulfide	Potassium Chlorate	Potassium Nitrate	Potassium Perchlorate	Potassium Sulfate	Silicon	Sodium Nitrate	Sodium Sulfate	Strontium Nitrate	Strontium Peroxide	Sulfur	Titanium Powder	Tungsten (W)	Zinc Oxide	Zirconium	Zirconium Hydride
A059	5.56M/M885	CTG 5.56MM BALL M855	232,060	X	X	X		X		X								X			X	X															X								
A060†	5.56MBLK	Blanks	11,225																																											
A064	5.56M4/1	CTG 5.56MM 4 BALL M855/1 TR M856 LNKD M2	3,800	X	X	X		X		X								X			X	X							X								X	X	X						
A066	5.56MBAL	CTG 5.56MM BALL M193	348,490	X	X	X		X		X											X	X															X								
A075	5.56MBLSAW	CTG 5.56MM BLK M200 LNKD	1,000	X		X		X		X											X														X		X								
A107	7.62M39BAL	CTG CAL .22 LR BALL	1,400		X			X													X	X																							
A112	7.62MBM82	CTG 7.62MM BLK M82	20	X		X		X		X											X																X								
A127	7.62M,4/1	CTG 7.62MM 4 BALL M80/1 TR M62	1,700		X	X		X		X												X				X		X									X	X	X					X	
A131	7.62ML4/1	CTG 7.62MM 4 BALL M80/1 TR M62	1,000	X	X	X		X		X											X	X						X									X	X	X						
A135	7.62MBLK	Dummy Cartridge	450																																											
A171	7.62 MA	CTG 7.62MM MATCH M852	140	X	X	X		X		X											X	X											X		X			X							
A358	AT4 9MM	CTG 9MM Practice Tracer	15																																										
A360	9MMB	CTG 9MM Practice	1,650																																										
B470	40MM HE	CTG 40MM HE M384	1,800 (Lampkin Range)	X		X		X													X		X									X												
C226	81MMILLUM	CTG 81MM ILLUM M301 W/FUZE TIME M84	1			X		X	X						X		X										X	X				X	X			X	X			X				X
C228	81MMHE	SHELL TRNG 81MM M68 MPTS W/O FIN ASSY	57																																										
C445	105MMHE	CTG 105MM HE M1 W/O FUZE	17			X									X									X			X				X	X								X				
D201†	TOWSIMBL		2																																										
D505	155MMILLUM	PROJ 155MM ILLUM M485E1	45				X	X							X				X	X					X				X		X		X			X	X			X			X	X
D539	155MMDUMMY	Dummy propelling charge, 155MM	14																																										
D544	155MM H	PROJ 155MM HE M107	335																																										
G930	SMK HC|	GREN HAND SMK HC AN-M8	12	X			X	X							X				X	X					X		X		X			X	X	X		X						X	X	
K143	CLAYMORE	MINE APERS M18 W/ACCESSORIES	21																			X	X									X												
K180	M15AT	MINE AT HEAVY M1	9			X																	X				X					X												
K181	M21MINE	MINE AT HEAVY M21	7	X		X	X	X	X			X			X								X				X						X			X				X				
K250	M19MINE	MINE AT HEAVY M19 NON METALLIC	6			X		X					X										X				X					X												
L314	STARGRN	SIGNAL ILLUM GRND M125A1	4	X		X	X	X	X	X					X	X												X		X			X	X		X				X		X		X	X
M023	C4 1-1	CHG DEMO M112	1,237																																										
M028	BANGTORP	DEMO KIT BANGALORE TORPEDO M1A2	41										X																																
M039	40LB CR	CHG DEMO 40LB CRATERING	12	X								X	X																															
M130	BLCAPM6	CAP BLASTING ELECT M6	22																				X									X												
M131	BLCAPM7	CAP BLASTING NON ELECT M7	177																				X																					
M148A†	JAVELIN		13																																										
M766	FUSE IG	IGN TIME BLASTING M60	104	X		X		X			X																X																	
M421†	SHAPCR40LB	CHARGE DEMOLITION 40 LB SHAPED	2																																										
M456	REINDET	CORD DETONATING	2,605																																										
M670	TIMEFUSE	FUSE BLASTING TIME M700 4000 FT	218												X																		X									X				
M998	DEMO CH	CHG EXPL ORDNANCE DISPOSAL MK89 MOD0	12																																										
MD15†	DETCORD-15	CORD DETONATING	300																																										
MS52	CORDDET	CORD DETONATING	130																																										
N335	FUSEM557	FUZE PD M557	2			X								X	X						X		X				X					X	X								X				
PB25†	TOWHEAT		12																																										
PL23†	DRAGON	Guided Missile and Launcher, Surface Attack	2																																										
PL90†	STINGER	Guided Missile Subsystem, Intercept -Aerial	4																																										
PRIM†	PRIME		2																																										
XM898†	SADARM		48																																										
†Data not found.																																													

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Table A2. Ammunition listed on Washington Range records: Shell casings.

DODIC	Ammunition Name	Nomenclature	Rounds Fired	Aluminum	Beryllium	Bismuth	Boron	Cadmium	Cadmium Chromate	Carbon	Chromium	Cobalt	Copper	Iron	Lead	Magnesium	Manganese	Molybdenum	Nickel	Palladium	Phosphorus	Selenium	Silicon	Silver	Sulfur	Tin	Titanium	Vanadium	Zinc	Zinc Chromate	Zinc Phosphate	Vanadium
A059	5.56M/M885	CTG 5.56MM BALL M855	232,060							X			X	X	X		X				X				X				X			
A060†	5.56MBLK	Blanks	11,225																														
A064	5.56M4/1	CTG 5.56MM 4 BALL M855/1 TR M856 LNKD M27	3,800							X			X	X	X		X				X				X				X			
A066	5.56MBAL	CTG 5.56MM BALL M193	348,490										X	X	X														X			
A075	5.56MBLSAW	CTG 5.56MM BLK M200 LNKD	1,000										X	X	X														X			
A107	7.62M39BAL	CTG CAL .22 LR BALL	1,400										X	X	X														X			
A112	7.62MBM82	CTG 7.62MM BLK M82	20										X	X	X														X			
A127	7.62M,4/1	CTG 7.62MM 4 BALL M80/1 TR M62	1,700										X	X	X														X			
A131	7.62ML4/1	CTG 7.62MM 4 BALL M80/1 TR M62	1,000										X	X	X														X			
A135	7.62MBLK	Dummy Cartridge	450																														
A171	7.62 MA	CTG 7.62MM MATCH M852	140										X	X	X														X			
A358	AT4 9MM	CTG 9MM Practice Tracer	15																														
A360	9MMB	CTG 9MM Practice	1,650																														
B470	40MM HE	CTG 40MM HE M384	1,800 (Lampkin Range)	X	X	X	X	X		X	X	X	X	X	X	X	X				X	X	X		X	X	X		X			
C226	81MMILLUM	CTG 81MM ILLUM M301 W/FUZE TIME M84	1	X				X	X				X	X	X														X	X	X	
C228	81MMHE	SHELL TRNG 81MM M68 MPTS W/O FIN ASSY	57	X						X	X	X	X	X			X	X	X		X		X		X			X	X			
C445	105MMHE	CTG 105MM HE M1 W/O FUZE	17	X				X					X	X	X		X						X						X	X	X	
D201†	TOWSIMBL		2																														
D505	155MMILLUM	PROJ 155MM ILLUM M485E1	45	X					X				X													X			X	X		
D539	155MMDUMMY	Dummy propelling charge, 155MM	14																														
D544	155MM H	PROJ 155MM HE M107	335	X						X			X	X	X		X				X		X		X				X	X	X	
G930	SMK HC|	GREN HAND SMK HC AN-M8	12	X			X			X	X		X	X	X	X	X	X			X		X		X	X			X	X	X	
K143	CLAYMORE	MINE APERS M18 W/ACCESSORIES	21	X				X	X				X	X	X											X			X	X	X	
K180	M15AT	MINE AT HEAVY M1	9	X		X		X	X	X	X		X	X	X	X	X	X			X		X		X		X	X	X			
K181	M21MINE	MINE AT HEAVY M21	7	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X		X		X	X	X	X	X	X	X	X	X	X
K250	M19MINE	MINE AT HEAVY M19 NON METALLIC	6						X	X	X		X	X	X		X		X		X			X	X			X	X	X		
L314	STARGRN	SIGNAL ILLUM GRND M125A1	4										X	X					X										X			
M023	C4 1-1	CHG DEMO M112	1,237	X																												
M028	BANGTORP	DEMO KIT BANGALORE TORPEDO M1A2	41											X	X											X					X	
M039	40LB CR	CHG DEMO 40LB CRATERING	12	X										X	X								X			X			X		X	
M130	BLCAPM6	CAP BLASTING ELECT M6	22	X									X		X					X						X						
M131	BLCAPM7	CAP BLASTING NON ELECT M7	177	X																												
M148A†	JAVELIN		13																														
M766	FUSE IG	IGN TIME BLASTING M60	104						X				X	X	X				X										X	X	X	
M421†	SHAPCR40LB	CHARGE DEMOLITION 40 LB SHAPED	2																														
M456	REINDET	CORD DETONATING	2,605																														
M670	TIMEFUSE	FUSE BLASTING TIME M700 4000 FT	218																														
M998	DEMO CH	CHG EXPL ORDNANCE DISPOSAL MK89 MOD0	12																														
MD15†	DETCORD-15	CORD DETONATING	300																														
MS52	CORDDET	CORD DETONATING	130																														
N335	FUSEM557	FUZE PD M557	2	X					X				X	X					X										X	X		
PB25†	TOWHEAT		12																														
PL23†	DRAGON	Guided Missile and Launcher, Surface Attack	2																														
PL90†	STINGER	Guided Missile Subsystem, Intercept -Aerial	4																														
PRIM†	PRIME		2																														
XM898†	SADARM		48																														
†Data not found.																																	

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13. SUPPLEMENTARY NOTES

14. ABSTRACT

Impact areas are lands used by the army for ordnance testing and training. The impact areas of Fort Greely, Alaska, are located on lands withdrawn from the public domain under the Military Lands Withdrawal Act (PL 106-65). The Army has pledged to implement a program to identify possible munitions contamination and evaluate the potential for surface water and groundwater contamination. Because of the large size (85,042 acres) of the impact areas, characterization of the contamination levels will be difficult. We have begun a multiphase sampling program at one impact area by first sampling locations that are likely to be contaminated and to identify locations that have the greatest potential to contaminate adjacent surface and groundwater. Based on a review of records at the Fort Greely Range Control and consultation with the Cold Regions Test Center (CRTC), we chose to sample the Washington Impact Area. We focused our sampling on surface soils and collected both composite (multi-increment) and discrete samples at locations of known firing events and from areas on the range that had evidence of range use. Evidence included cratering, pieces of munitions, or a designation as a firing point. Firing events included tests of 81-mm mortars, Tube-launched Optically tracked Wire-guided (TOW) missiles, 40-mm high-explosive cartridges, and Sense and Destroy Armor (SADARM). We detected explosives residue in 48% of the 107 soil samples we collected. RDX was the most frequently detected explosive (39%). Of the samples above the detection limit, median RDX concentration was only 0.021 µg/g. Low-order detonations accounted for four of the five highest RDX concentrations. TNT was the second most frequently detected explosive (21%). Median TNT concentration in samples where TNT was detected was only 0.004 µg/g. Low-order detonations produced the highest TNT concentration we found. The amino-dinitrotoluene transformation products of TNT were detected in about 10% of the samples. HMX was found in 11% of the samples. The analytes 2,4-DNT and NG were detected at a firing point and in a few samples on the Washington Impact Area. High-explosive projectiles that function properly appear to leave little residue in the surface soil. Low-order detonations, where only part of the high-explosive filler detonated leaving solid explosive composition in contact with surface soil, produced the highest soil concentrations observed. Also, firing points are sources of NG and 2,4-DNT. The greatest potential threat of contamination of surface and groundwater would be high numbers of low-order detonations or heavily used firing points located in groundwater recharge areas.

15. SUBJECT TERMS

Explosives	Ranges	Sampling
Impact area	RDX	TNT

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