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Development of Environmental Data for Navy, Air Force, and Marine Munitions

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Development of Environmental Data for Navy, Air Force, and Marine Munitions

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Abstract: Use of conventional weapons and explosives in live-fire military training can lead to release of munitions constituent residues, which can migrate to groundwater and drinking water sources. The extent to which major energetic constituents (RDX, HMX, TNT, and perchlorate) are present at military installations is being analyzed and assessed. Studies of the presence of energetic materials on US Army live-fire training sites have increased our understanding of the environmental fate and transport of energetic constituent residues. This study is intended to expand existing information concerning Army installations to Navy, Marine Corps, and Air Force facilities by relating munitions constituent database information with training allocations and recorded range munitions usage. Munition usage projections from training allocations and range records help identify probable presence of energetic residues and allow for prioritization of sites for further analysis and investigation. Data from this study suggest Air Force, Navy, and Marine training in the continental United States involves use of munitions containing quantities of RDX, HMX, TNT, and perchlorate comparable to Army usage on an annual basis. Based on field studies of numerous Army ranges, there is a high probability of introduction of RDX, HMX, TNT, and perchlorate residues into the environment at Air Force, Navy, and Marine ranges as well.

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Nomenclature

AFB	US Air Force Base
Comp	Composition
CRE	Comprehensive Range Evaluation
DAC	Defense Ammunition Center
DNT	Dinitrotoluene
DoD	US Department of Defense
DODIC	Department of Defense Identification Code
HE	High explosive
HMX	Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine
IRIS	Integrated Risk Info System
MIDAS	Munitions Item Disposition Action System
NCEA	Non-Combat Expenditure Allowances
NSN	National Stock Number
PBX	Plastic bonded explosive
RCA	Range Condition Assessments
RDX	Hexahydro-1,3,5-trinitro-1,3,5-triazine
RfD	Chronic oral exposure
SERDP	Strategic Environmental Research and Development Program
TNT	2,4,6-trinitrotoluene
US	United States
USEPA	US Environmental Protection Agency

Preface

This report was prepared by Jay L. Clausen, Research Physical Scientist, Biogeochemical Sciences Branch (ESB), and Constance L. Scott, Staff Scientist, Remote Sensing and Geographic Information Systems and Water Resources Branch, Cold Regions Research and Engineering Laboratory (CRREL), US Army Engineer Research and Development Center (ERDC), Hanover, New Hampshire, and by Dr. Randall J. Cramer, Senior Technologist, Applied Technology Directorate, Indian Head Division, Naval Warfare Center, Indian Head, Maryland.

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Antonio J. Palazzo and Michael G. Ferrick, ESB, CRREL, provided technical reviews.

This report was prepared under the general supervision of Terrance M. Sobecki, Branch Chief, ESB, CRREL; Dr. Lance D. Hansen, Deputy Director, CRREL; and Dr. Robert E. Davis, Director, CRREL.

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

Unit Conversion Factors

Multiply	By	To obtain
feet	0.3048	meters
inches	0.0254	meters
pounds (mass)	0.45359237	kilograms
tons (2,000 pounds, mass)	907.1847	kilograms

1 Introduction

Military testing and training ranges are vital for preparing military troops for combat and maintaining readiness. Range managers must determine the use of training range activities on these lands so that operations proceed without the environmental consequences associated with repeated release of undesirable residues. There are increasing concerns that a reduction in US military readiness will result if training range usage is restricted. For example, the Massachusetts Military Reservation had training curtailed in 1999 by the US Environmental Protection Agency (USEPA) because of concern over the release of energetic residues and other constituents into the environment as a function of Army National Guard training. In 2003, the Navy closed the training site at Vieques, Puerto Rico, as a result of political pressure resulting from a perception that routine training activities resulted in undesirable environmental impacts.

Recent research funded by the Strategic Environmental Research and Development Program (SERDP) project CP-1155, "Distribution and Fate of Energetics on DoD Test and Training Ranges," revealed the presence of energetic residues at numerous Army military installations (Jenkins et al. 2005, Pennington et al. 2006). They identified the types of munitions used on Army training ranges along with their related constituents, linking usage with energetic residues found in soil at the installations. The SERDP project CP-1155 study, along with other studies, found hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX), 2,4,6-trinitrotoluene (TNT), dinitrotoluenes (DNTs), perchlorate, di-n-butyl phthalate, N-nitrosodiphenylamine, and some metals are introduced into the environment at Army installations during training (Pennington et al. 2006, 2005, 2004, 2003, 2002a, 2002b; Jenkins et al. 2005, 2001a; Clausen et al. 2004). Perchlorate, RDX, and HMX, and to a lesser degree TNT and DNT, are particularly problematic due to their mobility potential from soil to surface water and groundwater.

A study of the munitions used by the Navy, Air Force, and Marines and the energetic compounds present has not been conducted. Consequently, the extent of energetic residues at Navy, Air Force, and Marine installations because of training and the impact on nearby water resources is unknown.

2 Objective

The objective of this study is to provide a greater level of understanding of the potential for deposition of energetic residues on Air Force, Navy, and Marine ranges and to identify those constituents posing an environmental concern. Specific tasks are to 1) identify Navy, Air Force, and Marine munitions used for training, 2) determine the associated energetic compounds for each munition item, and 3) assess which energetic compounds pose a potential threat to the environment through evaluation of their usage, fate and transport, and toxicological properties.

In the case of Army and Marine Corps ranges, deposition of energetic residues occurs at the impact areas as well as at firing points. Because the Marines train with the same weapon systems as the Army, the exception being some small arms systems, the energetic compounds of concern are the same for both services. Previous work on Army ranges identified RDX, HMX, TNT, and perchlorate as the principal energetic compounds of concern (Pennington et al. 2006, 2005, 2004, 2003, 2002a, 2002b; Jenkins et al. 2005, 2001a; Clausen et al. 2004). Therefore, RDX, HMX, TNT, and perchlorate are the focus in our assessment of Marine Corps ranges.

In contrast, firing of Air Force munitions is primarily from airborne platforms, with the exception of land-based missiles and test ranges. Consequently, the number of land firing points is more limited than at Army or Marine installations. Similarly, the Navy fires most of its munitions from sea-based platforms and therefore land-based firing points largely do not exist, with the exception of test ranges located on land. For these reasons, this report focuses on high explosive (HE) fillers in Air Force and Navy munitions and not propellants. The one exception is perchlorate, which is the principal propellant in most Navy and Air Force weapons systems. In addition to perchlorate usage in propellant, perchlorate is a principal component in simulators, illumination rounds, and signaling devices, such as flares and smokes.

Our initial survey found more than 500 constituents present in the Air Force, Navy, and Marine Corps munition HE fillers. Therefore, there was a need to limit the number of constituents. As previously mentioned, Army studies (Pennington et al. 2006, 2005, 2004, 2003, 2002a, 2002b; Jenkins et al. 2005, 2001a; Clausen et al. 2004) identified RDX, HMX, TNT, and perchlorate as the primary energetic compounds of concern. A survey by the Air Force identified 24 constituents of concern for its range assessments with emphasis placed on evaluating the presence of RDX, HMX, TNT, and perchlorate (Cooper 2006). The three HE (RDX, HMX, and TNT) make up the bulk of the HE formulations (Table 1).

Table 1. Examples of explosive formulations.

High-explosive name	Filler material	Mixture (% by weight)
Composition A	RDX/wax	91/9
Composition B	RDX/TNT/wax	59.5/39.5/1
Composition C4	RDX/polyisobutylene/ motor oil/ethylhexyl sebacate	91/2.1/1.6/5.3
Octol	HMX/TNT	70/30
Tritonal	TNT/aluminum	80/20
PB XN-109	RDX/aluminum/HTPB[1]/ dioctyl adipate/other[2]	64/20/16/7.3/1
LX-14	HMX/estane	95.5/4.5
PB XN-5	HMX/Viton A	95/5

[1] HTPB: Hydroxyl terminated polybutediene

[2] Other compounds at less than 1% include N N2-hydroxethyl, 2-2-methylenebis, and triphenylbismuth.

Although significant quantities of aluminum are used with TNT in tritonal, aluminum and the other metals are not part of this study. The original SERDP Statement of Need for Development of Environmental Data for Navy, Air Force, and Marine Munitions specified a focus on energetic materials.

3 Background

Live-fire training is a necessary component of readiness for the armed forces of the United States. To sustain long-term use of Department of Defense (DoD) training ranges, each installation must comply with environmental regulations ensuring human health and the environment are not compromised. In particular, DoD must ensure live-fire training does not produce residues migrating beyond installation boundaries at concentrations impairing the use of ground and surface water resources by the surrounding communities.

When SERDP initiated project CP-1155, "Distribution and Fate of Energetics on DoD Test and Training Ranges," in 2000, very little information was available describing the nature and extent of residual energetics on Army weapons testing and training ranges. Suspension of Army training occurred at Camp Edwards in 1999 as a precaution in the absence of data. The threat of similar actions at other sites critical to military readiness mandates addressing issues associated with range residues. In response, research began through SERDP project CP-1155 and the US Army's Environmental Quality Technology program. Over the course of these projects, a substantial amount of information was gathered on the presence of energetics on Army ranges (Pennington et al. 2006, 2005, 2004, 2003, 2002a, 2002b; Jenkins et al. 2005, 2001a). Also, site-specific studies funded by the National Guard Bureau (Clausen et al. 2004; AMEC 2004, 2001a, 2001b; Ogden 1999a, 1998a), US Army Alaska (Walsh et al. 2005a, 2005b, 2004, 2001) and others (Hewitt et al. 2005, 2003; Thiboutot et al. 2004, 2003a, 2000a, 2000b, 1998; Ampleman et al. 2003a, 2003b, 2000, 1998; USCHPMM 2003; Dube et al. 1999; Martel et al. 1998) have added to our understanding of the presence of energetic residues at military installations. A limited amount of sampling also has been conducted at one Marine Corps site in the United States (Jenkins et al. 2004a), two Air Force sites in the United States (Pennington et al. 2006), and one Air Force site in Canada (Ampleman et al. 2003b).

To ensure long-term viability of operational ranges while protecting human health and the environment, DoD issued a directive to establish policy and assign responsibility to protect DoD personnel and the public from explosive hazards on operational ranges and to assess and minimize environmental impact of munitions use (US DoD 2004). The DoD components or commands are to each establish and implement procedures to assess the environmental impacts of munitions use on their ranges. All the services have since put forward their respective range assessment programs: The US Army Operational Range Assessment Program (US Army 2005), the US Air Force Operational Range Assessment Program (Cooper 2006), the US Navy Range Sustainment and Environmental Program Assessment (Holmes 2006), and the Marine Corps Environmental Vulnerability Assessment (Morefield 2006).

Although the operational range assessment programs may differ among the military services in some of the procedural aspects, such as their monitoring and reporting processes, all are focused on answering the question: is off-range migration, or a potential for migration of munitions constituents, an unacceptable risk to human health and the environment? These programs contain the elements of a qualitative evaluation. If needed, performance of a more rigorous and quantitative data gathering process, including sampling, analysis, and fate and transport modeling, supports a risk assessment.

Assessment of the environmental impact of munitions use on ranges, including the potential off-range migration of munitions constituents, is important in addressing serious encroachment issues and is a necessary part of the overall national objective for sustainable ranges (US DoD 2006). The Navy began its Range Condition Assessments (RCA) at several ranges in 2003 and the Marine Corps has a process in place to begin conducting assessments. The Air Force implemented its investigation process and the Army has completed Regional Range Assessments on some of its installations. These programs have just started and data on munitions residues on ranges are still very limited.

4 Munitions Constituents

As indicated in Section 2, the principal energetic compounds used in most conventional weapons include RDX, HMX, TNT, and perchlorate (Fig. 1). A summary of the physical, chemical, and fate-and-transport properties of RDX, HMX, TNT, and perchlorate follows.

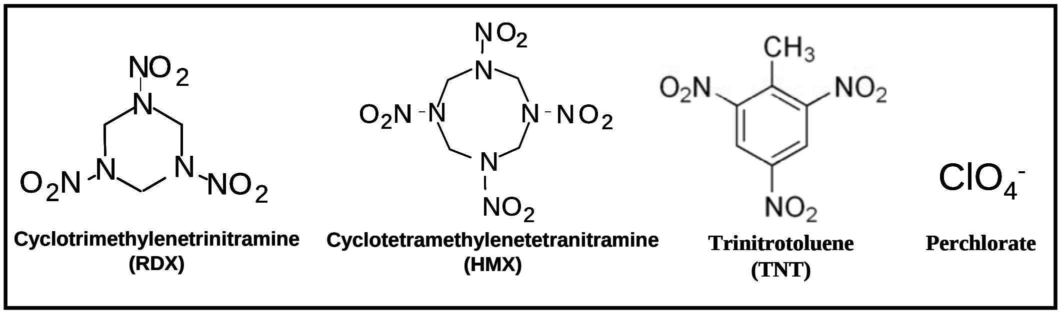

Figure 1. Chemical structures of energetic compounds included in this study.

RDX (Hexahydro-1,3,5-trinitro-1,3,5-triazine)

RDX is a white crystalline, relatively insensitive explosive material compatible with many binder and plasticizing ingredients and is widely used in a number of military explosive formulations: Composition A (Comp A), Comp B, C4, H-6, and HBX. It is a major component in many plastic bonded explosives (PBXs) (Table 1).

RDX belongs to a class of compounds known as nitramines and has low water solubility (42 mg/L at 20°C), dissolves slowly into aqueous solution, has a low vapor pressure, and a low affinity for hydrophobic substances (McGrath 1995). Although some studies report RDX sorption on sediments and clays (Myers et al. 1998, Xue et al. 1995, Leggett 1985), many have indicated limited RDX retention in most soils. McGrath (1995) reported RDX passes through laboratory columns with minimal retardation and reduction, and Pennington et al. (1995) found RDX readily leached from clay loams and soils collected from several different sites. Laboratory investigations employing a variety of soils ranging from clay to sandy loam found less than two percent of RDX bound as a non-extractable residue (Cataldo et al. 1990).

The natural degradation rate of RDX can range from months on most soils (Jenkins et al. 2003) to years in an arid climate (Rodacy and Leslie 1992).

RDX transformation is minimal in most environments and the belief is formation of the nitrosamine intermediates under certain conditions is genotoxic (Major et al. 2002). The RDX degradation products have been widely studied with the conclusion they are extremely unstable and hydrolyze in water (Hawari et al. 2001; Price et al. 1998; McCormick et al. 1984a, 1984b).

The relatively slow dissolution of RDX, which is a function of the contact time between the RDX particles and the infiltrating precipitation, limits migration to groundwater. RDX has a slow dissolution rate but once dissolved is persistent and mobile. If incompletely combusted, RDX residues produced through munitions use find their way to soil at military sites (Hewitt et al. 2005, 2003). The propensity for RDX to be relatively mobile through soil raises the potential for its off-range migration to groundwater or other water sources.

HMX (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)

HMX, a white crystalline solid having higher energy and density than RDX, is used in HE explosive formulations such as LX-14 and PBX9501.

Most studies indicate sorption of HMX on soil is not a significant process. McGrath (1995) reported HMX passed through laboratory columns with minimal retardation, and Checkai (1993a, 1993b, 1993c) reported HMX was highly mobile in soils with low clay content. Such results are consistent with studies by Pennington et al. (1995), who found HMX leached from clay loam soils from several sites.

HMX transformation occurs primarily under anaerobic conditions (Price et al. 1998, McCormick et al. 1984b). Rodacy and Leslie (1992) found the half-life of HMX is 39 years based on work by DuBois and Baytos (1972) in an arid environment, but HMX does not degrade as readily as does RDX in most conditions. Like RDX, HMX undergoes ring cleavage and extensive mineralization (60 percent with anaerobic sludge). However, identification of the transformation pathway with respect to microbial populations and enzymes is uncertain. Nevertheless, it is clear that once the ring cleaves, the transformation products are thermally unstable and hydrolyze readily in water. The latter abiotic reactions compete with biotic reactions during biodegradation and complicate evaluations of the transformation process at the microbial level. Hence, the actual fate of HMX in terms of natural attenuation remains uncertain and laboratory studies may not be applicable to the field where conditions are more complex (Hawari et al. 2001).

Migration of HMX to groundwater, limited by its slow dissolution rate, which is a function of contact time between the HMX particulate and infiltrating precipitation, is much slower than RDX; sorption to soil is not an important process at most sites.

TNT (2,4,6-trinitrotoluene)

TNT is a stable, insensitive, and inexpensive HE used for many years in almost all forms of conventional weapons: gun ammunition, grenades, mortars, bomblets, general purpose Mark 80 series bombs, rockets, and missile warheads.

Soils have a high capacity for rapid sorption of TNT (Greene et al. 1985, McGrath 1995, Willis 2002); however, TNT retention is insignificant for sand (Myers et al. 1998). Soils low in clay and organic matter sorb very little TNT. Another difficulty in describing and predicting TNT soil sorption rates is that degradation products compete with the parent compound for sorption sites (Brannon et al. 1992) and may be irreversibly bound (Harvey et al. 1990).

Many microorganisms aid in the transformation of TNT in both surface water and groundwater (Spanggord et al. 1980). Therefore, in most situations TNT not sorbed onto soil transforms rapidly. The half-life of TNT added to soils as an aqueous solution occurs in several days (Jenkins et al. 2000).

Since TNT transformation is rapid in most soil and aquifer systems, its presence is typically restricted to areas near its introduction to the environment. The major fate-and-transport processes for TNT in soil and groundwater are dissolution, adsorption, abiotic transformation, biotransformation, diffusion, advection, and hydrodynamic dispersion (Townsend and Meyers 1996, McGrath 1995). The transformation rates are sufficiently fast at most sites, thereby preventing contamination of the vadose zone or groundwater. In the case of impact areas, the majority of the TNT transformation occurs in the surface soil with only small quantities reaching groundwater.

Perchlorate (ClO_4^-)

Introduction of perchlorate (ClO4–) into the environment is in the form of solid salts of ammonium, potassium, or sodium perchlorate. Ammonium and potassium perchlorate used include the oxidizer component and primary ingredient of solid propellants, igniters, rockets, missiles, and fireworks. Flares, smokes, tracers, and other pyrotechnics also contain perchlorate.

The perchlorate ion, a strong oxidant, is kinetically stable and not reactive when dissolved in water under environmental conditions. Reduction of the chlorine in perchlorate from the +7 oxidation state to the chloride ion (–1 oxidation state) does not occur readily (Urbansky 1998). A high input of energy (e.g., heat, light, or physical shock) or the presence of a catalyst is necessary to initiate significant reduction. This high activation energy offers an advantage for the stable use of perchlorate salts in munitions and fireworks, but such chemical stability also results in environmental persistence.

Bacteria capable of perchlorate degradation are widely distributed in nature (Coates et al. 1999, Logan et al. 2001, Tipton et al. 2003). Furthermore, biostimulation of naturally occurring microorganisms to initiate in-situ bioremediation of groundwater containing perchlorate has been demonstrated (Cramer et al. 2004).

Perchlorates are also highly soluble, and the ions have a limited tendency to interact with other dissolved chemical species or to adsorb to aquifer materials under typical environmental conditions. Consequently, the controlling mechanism for fate-and-transport of perchlorate released to soils and water is through physical rather than chemical or biological processes. Because of perchlorate's high solubility and mobility, the expectation is for rapid leaching of perchlorate out of the soil. Once dissolved in water, perchlorate retardation via sorption is insignificant.

Munitions Constituents Toxicity

The health assessment information and toxicity levels for RDX, HMX, TNT, and perchlorate are included in the USEPA Integrated Risk Information System (IRIS) and presented in Table 2 (USEPA 2006). The noncarcinogenic reference dose for chronic oral exposure (RfD) for perchlorate is the updated value based on the Greer et al. (2002) study and the recommendation made by the National Research Council report (NRC 2005).

The RfD for RDX in this IRIS information is based on assessments of much earlier studies (last revised 02/01/1993); results from new studies conducted by the US Army Center for Health Promotion and Preventive Medicine have led to a reevaluation and a reassessment of the carcinogenicity of RDX, and evidence for a reduced cancer risk have prompted a proposal to remove the oral slope factor. Studies now continue on evaluating the noncarcinogenic effects. Future data may have significant influence upon the uncertainty factors used in determining the RfD.

Table 2. Integrated Risk Information System (IRIS) munitions constituents toxicity information. (From http://www.epa.gov/iris.)

Munitions constituent	Chronic oral exposure RfD (mg/kg-day)	Carcinogenicity (US EPA Guidelines 1986)	Oral slope factor (per mg/kg-day)
RDX	0.003	C (Possible human carcinogen)	0.11
HMX	0.05	D (Not classified as to human carcinogenicity)	—
TNT	0.0005	C (Possible human carcinogen)	0.03
Perchlorate	0.0007	Not likely to pose a risk of thyroid cancer in humans	—

5 Data Sources

The range use criteria set forth for this study included 1) a US controlled land range, 2) capable of live-fire testing, and 3) located in the United States. Investigation of a wide variety of data sources led to identification of the munitions used by the Air Force, Navy, and Marines, as well as the munitions constituents present in the ordnance items. Information obtained on munition usage came from range managers as well as through contacts at the Pentagon. This report includes information on munitions use and training volumes for the Air Force, Navy, and Marines, and identified 13 Air Force, six Navy, and three Marine Corps training ranges in CONUS, plus Alaska and Hawaii.

Munition compound content information obtained used the Munitions Items Disposition Action System (MIDAS), a database linked to and accessed through the Defense Ammunition Center (DAC) Web site (MIDAS 2006). Development of MIDAS supports the military's demilitarization program and includes munitions for all services. A complete breakdown of all components of the munition by weight is available. Although MIDAS does not include a complete inventory of all currently used munitions or those used in the past, items are being added continuously. More recently, the environmental community has been accessing information on the constituents present in munitions using MIDAS. However, MIDAS allows data access only through pre-set routines; therefore, the utility is limited in the searches performed and the data output format. Consequently, performing some general queries is unsupported, e.g., making a list of all constituents present in Navy, Air Force, and Marine munitions. Several options to search the MIDAS database are available; the detailed usage option provides a spreadsheet with the following columns: munition national stock number (NSN), Department of Defense Identification Code (DODIC), munition nomenclature, and net explosive weight per unit in pounds of the explosive ingredient or the compound searched.

Air Force Munition Usage

Information requested for Air Force training range munition usage in CONUS (continental United States), Alaska, and Hawaii in this report came from various Air Force range managers through a Range Policy and Programming Officer at the Pentagon. The information requested included the munitions used on the range (excluding small arms munitions), NSN, and DODIC for each of the munitions used, the quantity of each item used per year, 10-year usage projection, and system(s) using the munition item. Table 3 lists the Air Force ranges that provided information and are, therefore, included in this report.

Table 3. Air Force ranges included in this study.

Range name	Major command	Location	Base assigned
Dare County	ACC	NC	Seymour-Johnson AFB
Holloman Range Complex	ACC	NM	Holloman AFB
Melrose	ACC	NM	Cannon AFB
Mountain Home Range Complex (consolidates data from Saylor Creek Range and Juniper Butte Range	ACC	ID	Mountain Home AFB
Nevada Test and Training Range (NTTR)	ACC	NV	Nellis AFB
Poinsett	ACC	SC	Shaw AFB
Utah Test and Training Range (UTTR)	ACC	UT	Hill AFB
Barry M. Goldwater Range (BMGR)	AETC	AZ	Luke AFB
Edwards	AFMC	CA	Edwards AFB
Eglin	AFMC	FL	Eglin AFB
Elmendorf	PACAF	AK	Elmendorf AFB
Eilson	PACAF	AK	Eilson
Barking Sands	PACAF	HI	Bonham AFB

ACC....... Air Combat Command
AETC..... Air Education and Training Command
AFMC.... Air Force Materiel Command
PACAF... Pacific Air Forces

The 13 Air Force ranges in Table 3 represent those installations providing information on munition usage. Five additional Air Combat Command ranges not included were Avon Park, Belle Fourche, Grand Bay, Lone Star, and Snyder. Avon Park and Grand Bay provided no information, and Bell Fourche, Lone Star, and Snyder are no-drop ranges. There may be an additional dozen or more ranges within CONUS used by the Air Force. Therefore, the munition usage records obtained may represent a portion of the total Air Force training expenditure. However, discussion with Air Force personnel and documentation (Global Security 2006) suggests the 13 ranges identified capture the major CONUS training facilities under the Air Combat Command (ACC), Air Education and Training Command

(AETC), Air Force Materiel Command (AFMC), and Pacific Air Forces (PACAF). This study does not include munitions used in training at Air National Guard or Air Force Reserve ranges. The capability of the ranges to provide information varied greatly. Table 4 contains an outline of the reports received and the information included in each report.

Table 4. Air Force installation information received.

Folder name and ranges included	Munition NSNs included	Munition DODICs included	Nomenclature	Years included	Projections	Comments
AK-HI Eilson, Elmendorf, Barking Sands	Not valid #s	No	Yes	FY 2004 and 2005	10 years	
BMGR Barry M. Goldwater	Most	Most	Yes	CY 2003–05	No	
Edwards	Some*	Some*	Yes	CY 2004 and 05	FY 2006–10	
Eglin	Many	Most	Yes	FY 2003, 04, and 05	No	
Langley Dare County, Holloman, Mountain Home, Melrose, Poinsett, NTTR, UTTR	No	No	Yes	2003–05†	10 years†	A data list containing thousands of munitions with NSNs and DODICs also was provided, but with very different nomenclature than the range info.

* Projection data included NWSNs and DODICs, other data did not.

† Melrose included 2005 only and had no projections.

Navy/Marine Corps Munition Usage

Sites potentially impacted by energetic residues resulting from munitions use in training exercises came from the list of the Navy training ranges listed in the 2006 Sustainable Range Report (US DoD 2006a). Of the 25 Navy range complexes listed in the report, six sites met the range use criteria set forth for this study. The selected sites, listed in Table 5, were cross-referenced with the execution status of Navy range complexes currently under the Navy Range Sustainability Environmental Program Assessment (RSEPA) (Holmes 2006).

Table 5. Navy range complexes potentially impacted by energetic residues resulting from training activities.

El Centro Range Complex
Fallon Range Training Complex (FRTC)
Hawaiian Island Range Complex
Jacksonville Range Complex
Southern California Range Complex (SOCAL)
Virginia Capes (VACAPES) Range

The following Marine Corps facilities also conduct live-fire training: Marine Corps Air Ground Combat Center Twentynine Palms, Camp Lejeune, and Camp Pendleton.

The basis for projections of munition usage are the non-combat expenditure allowances (NCEA) from 2006 through 2015 for the Department of the Navy, a list obtained from the Naval Ordnance Safety and Security Activity, and the Navy's Ordnance Environmental Support Office (Urbansky 2006). Use of the NCEA list was a consequence of being unable to locate training use records. Projections of munition usage may be different from actual training usage. Our assumption is the annual projected usage derived from a 10-year average is similar to the actual usage within the past several years.

The NCEA spreadsheet includes 2,215 items with the following ordnance and training information: the Naval Ammunitions Logistics Codes (NALC), the munitions nomenclature, the training allocation claimant (at the command level), and the 10-year (FY06 through FY15) use projections in number of units. Table 6 lists the Navy and Marine claimants used for determining the non-combat projected munition expenditures.

Integration of Data

Different approaches were utilized to integrate the munitions usage data with the munitions constituents present for Air Force, Navy, and Marine ordnance items. For the Air Force assessment, our approach relied on using NSN and DODIC numbers, where provided, to identify the munitions and to link with the MIDAS database to identify the munitions constituents. A similar approach used for the Navy and Marine information relied upon use of the NCEA number to look up the munition items, applying a

DODIC number, and then cross-referencing with the NALC in order to look up the item in MIDAS.

Table 6. Claimant list for Navy and Marine non-combat expenditure allowance.

COMNAVAIRSYSCOM: Naval Air Systems Command
COMNAVRESFOR: Naval Reserve
COMPACFLT: Commander Pacific Fleet
FLTFORCOM: Fleet Forces Command (formerly CINCLANTFLT)
NAVSURFWARCENDDIV: Naval Surface Warfare Center
NRL: Naval Research Laboratory
NETC: Naval Education and Training Command
NAVSTKAIRWARCEN: Naval Strike Warfare Center

The process used to quantify the HMX, RDX, TNT, and perchlorate contained in the munitions used on training range munitions was as follows:

1. Obtain from range personnel information on the munitions used on each range, including DODIC, NSN, or NALC numbers.

2. Perform a detailed usage search on each of the four compounds generating a munitions list. Included on the munitions list are the NSN, DODIC, or NALC numbers, munitions descriptor, and mass in pounds of the four compounds of interest.

3. Match the DODIC, NSN, and NALC numbers for the munition items used on the range with DODIC, NSN, and NALC information from the MIDAS detailed usage lists using the Excel VLOOKUP function, a command that searches a table-array against a reference set for matching values.

4. Multiply the quantity of the compound in a given munition with the quantity of munitions used on a particular range in order to obtain the total quantity of energetic material for a given year.

As shown in Table 4, many of the Air Force ranges did not supply DODIC or NSN information for the munitions used and much of the range information nomenclature is dissimilar to the nomenclature used within MIDAS. In such cases, information from ranges with NSN/DODIC information was used to find a probable match. If no match was found but the nomenclature was sufficient to do so, a value was assigned based on the most commonly found configuration for that particular munition. In some instances, a munition item was not included due to the level of uncertainty as to the identity of the item. Also, an assessment conducted using munition usage data from Eglin AFB involved using the NSN and DODIC numbers individually to see whether they yielded equivalent results. In most cases, the results from the two sets of data did not match. This is possible because often there is more than one NSN associated with a given DODIC and a single DODIC may be associated with several different configurations of the same munition, further illustrating the difficulty in achieving precise data.

Table 7 illustrates the importance of including more than just the munition nomenclature in any type of munitions recordkeeping. For both the 2000- and 500-pound general purpose Mark 84 bombs, there are two configurations with identical or nearly identical nomenclature, which can be distinguished only by the DODIC number. Without this information or an NSN, it is difficult to determine whether the munition item contained RDX. For example, the general purpose 2000-pound Mark 84 bomb can contain either a Comp B filler (RDX and TNT) or TNT. When the specific configuration of a weapons system could not be determined, the configuration with the greater mass of HE filler or the greatest use was assumed. Because of the nomenclature issues, the total quantity of explosive material contained in the munitions used in training is an estimate.

Table 7. Air Force munitions containing large quantities of RDX, TNT, and perchlorate.

Munition item	DODIC	RDX (lb)	TNT (lb)	Perchlorate (lb)
Bomb general purpose 2000-lb MK84 MOD2	F128	426.20	275.94	
Bomb general purpose 2000-lb MK84 MOD4	F275		752.00	
Bomb general purpose 1000-lb MK83 MOD4	E509	200.70	129.94	
Bomb general purpose 500-lb MK82 MOD1	E480	86.59	56.06	
Bomb general purpose 500-lb MK82 MOD1	E485		153.60	
Bomb general purpose 250-lb MK81 MOD1	E466	45.10		
Bomb 2000-lb 109/B Penetrator	F140		428.00	
Warhead AGM-65A (Maverick)	V437	50.58	33.58	
Rocket POD 298-mm practice	H185			896.44
Rocket POD 298-mm tactical	H104			896.44

After sorting the Navy/Marine data by claimant command, the munition nomenclature and the munition items, of which many had various names, were grouped and represented under general headings (gun ammunition, grenades, bomblets, bombs, rocket warheads, and so forth). The result is a summary of navy munitions usage planned for training, and a total amount of explosive planned for training over the next 10 years directly relatable to the training command.

6 Results

Data on actual munition expenditures were obtained from 13 Air Force ranges along with 10-year projections for the Navy and Marine Corps munition usage. Most of the 13 Air Force ranges provided data on munition use in 2005, with some providing data for 2003, 2004, and 10-year projections. For comparisons between the services, the 2005 Air Force data were selected. The Navy and Marine Corps 10-year projections on munition usage were averaged to come up with an annual usage rate. Finally, we obtained 2005 usage records for the Army for comparison (Table 8).

Table 8. Total energetic material usage (pounds) in munitions by service for training in 2005.

Munition constituent	Army [1]	Air Force [2]	Navy [3]	Marines [3]
RDX	2.5 E6	2.5 E6	1.8 E6	2.7 E6
HMX	1.2 E4	6.0 E2	6.4 E3	2.5 E4
TNT	2.3 E6	1.8 E6	5.2 E5	9.0 E5
Perchlorate	2.5 E6	7.3 E5	3.9 E3	6.6 E4

[1] Based on munitions records obtained for 2005 for CONUS, as well as Alaska, Hawaii, Korea, and Germany training ranges.

[2] Based on munitions records obtained for 2005 for CONUS training ranges.

[3] Based on annual rate derived from a 10-year average of projected munition expenditures for training.

The purpose for including the Army data is for a point of comparison with the other services. Since 2001, the Army has collected training usage data on munition items on an annual basis for CONUS (including Alaska and Hawaii), Germany, and Korea ranges. Unfortunately, separation of CONUS information from Germany and Korea is not possible. Cross-referencing the Army munition data with MIDAS allowed for determining the usage of RDX, HMX, TNT, and perchlorate in pounds for 2001 through 2005 (Table 9). The usage for 2005 is comparable to the five-year average.

Table 9. Comparison of RDX, HMX, TNT, and perchlorate usage (pounds) on Army training ranges for 2001 through 2005.

Munition constituent	2001	2002	2003	2004	2005	Average
HMX	3.2 E3	2.9 E3	2.6 E3	1.4 E3	1.3 E4	4.5 E3
Perchlorate	3.1 E6	3.8 E6	3.6 E6	3.1 E6	2.6 E6	3.2 E6
RDX	2.9 E6	2.9 E6	2.2 E6	1.6 E6	2.5 E6	2.4 E6
TNT	3.4 E6	3.2 E6	2.6 E6	1.6 E6	2.3 E6	2.6 E6

Given the large number of munition items used in training, a comprehensive list of items is not provided. However, the number of items used has been cross-referenced with the mass of RDX, HMX, TNT, and perchlorate in each item to determine the total quantity used in training (Table 8). All of the services appear to have comparable quantities of RDX use, i.e., in the neighborhood of 2 to 2.5 million pounds per year. Note that the record of Army usage of RDX, HMX, TNT, and perchlorate includes training in Korea and Germany as well as CONUS plus Alaska and Hawaii. Consequently, the actual energetic material usage in CONUS is less than that listed in Table 8. HMX usage by the Marines is comparable to the Army, with the Navy and Air Force using lesser amounts. The quantity of HMX used in training is less than RDX, TNT, and perchlorate. The Air Force usage of TNT is comparable to the Army, with the Navy and Marines using lesser amounts. The Army has the highest usage of perchlorate, with the Air Force, Marines, and Navy, respectively, using lesser amounts.

Air Force

Munition usage records provided by the 13 Air Force installations are identified in the preceding section and records on quantity of RDX, HMX, TNT, and perchlorate are provided by installation in Appendix A. The quantities are listed by year (calendar year or fiscal year, as indicated) and include actual and projected-use information where provided.

RDX and TNT had the highest HE usage on Air Force training ranges. The ranges with the highest usage of ordnance containing RDX were, in order, Nevada Test and Training Range (NTTR), Utah Test and Training Range (UTTR), Eilson Range, and Barry M. Goldwater Range (BMGR) (Appendix A). Ordnance containing TNT was most heavily used at NTTR, UTTR, Eilson Range, Edwards AFB, and Eglin AFB, in order of quantity of usage (Appendix A)

Overall, HMX had the lowest mass of material associated with ordnance items used on the various ranges. The highest usage was 873 pounds at Eglin AFB. The next lowest usage was of perchlorate with the highest usage also at Eglin AFB. At Barking Sands Range located on Bonham AFB and Mountain Home Range Complex at Mountain Home AFB, no munition items were used that contained the four energetic compounds. The 10-year projection of munition use at these same installations also does not include HMX. Therefore, no tables are included for these ranges (Appendix A).

NTTR and UTTR have a level of munitions use that translates into large quantities of RDX and TNT on an annual basis, but these two ranges also are the two largest in terms of acreage.

The Air Force munition items with the largest quantity of RDX were the general purpose bombs and Maverick warhead. Similarly, the greatest quantities of TNT can be found in the general purpose bombs, penetrator bomb, and Maverick warhead. This trend changes with perchlorate, where the largest quantity comes from the rocket PODS used at Eglin AFB. HMX was not included due to the relatively low quantities in any particular munitions item (Appendix A).

Navy/Marines

Information on past or current ordnance usage (FY2005 or 06) for the Navy/Marines was not located; however, a summary of the type of munition and corresponding explosives projected to be used over the next 10 years for the Navy training was available (Table 10). It is uncertain how the projected munition usage compares with past or current usage levels. However, it is our assumption that usage of a similar type of ordnance in the past to the projected use in the next 10 years is appropriate. Therefore, energetic compounds identified in our 10-year projection are likely to be similar to those compounds used in the recent past, i.e., last 10 years. A 10-year average calculated from the data in Table 10 is the basis for the annual usage provided in Table 8.

As expected, RDX and TNT usage is in the millions of pounds because of the wide use of munitions containing Comp B (RDX/TNT/wax) as the HE filler in gun ammunition, rockets, warheads, and bomblets and due to the use of the HE filler PBXN-109 (RDX/aluminum/hydroxyl-terminated butadiene) in the large Mark 80 series bombs. Perchlorate usage estimates include approximately 200 tons contributed from Jet-Assisted Take-Off (JATO) rockets. Overall HMX usage in relationship is low, although 40 percent comes from small cartridge actuated devices (CAD).

Table 10. Projected Navy munitions usage over the next 10 years.

Munition type	RDX (lb)	HMX (lb)	TNT (lb)	Perchlorate (lb)
Med caliber	85,834	1,520	6,241	1,608
Grenade fuzes				118
Grenades			810	
Bomblets	3,098	1,758	90,871	
Bombs	17,149,810		4,719,780	
5"/54 projectiles	98,915	184		
JATO rockets				340,078
Rocket WHs	297,678		1,965	
Impulse cartridges		109		
Flares				4,686
Detonators	149	120		
Demolition charges	452,657		160,287	
UW charges			76,537	32,160
Test charges	130,735		124,303	
Cutters	199,090		1,008	
Smokey Sams				5,364
Simulants				5,389
CADs		2,703		728
10-year total	18,417,966	6,395	5,181,801	390,131

A similar compilation for Marine Corps training shown in Table 11 reflects the large use of RDX and TNT in projectiles, warheads, bomblets, and bombs. The perchlorate data are consistent with the Marine Corps heavy use of tracers and pyrotechnics, and ground activities such as usage of the Smokey Sam rocket simulator, intended to produce a highly visible thick white smoke when fired to simulate surface-to-air missile.

Table 11. Projected Marine Corps munition usage over the next 10 years.

Munition type	RDX (lb)	HMX (lb)	TNT (lb)	Perchlorate (lb)
Med caliber	38,009	15,958	562	38,817
Grenade fuzes				
Grenades				
Bomblets	3,447	8,942	4,650	
Bombs	27,426,714		8,544,803	
5"/54 projectiles	4,300			
JATO rockets				14,580
Rocket WHs	270,919		368,763	
Impulse cartridges		268		114
Flares				1,154
Detonators				
Demolition charges				
UW charges				
Cutters				
Smokey Sams				11,214
Simulants				
CADs				
10-year total	27,743,389	25,168	8,918,778	65,880

Breakout of information on munition type allocated to each training command for munitions containing RDX, HMX, TNT, and perchlorate for the Navy and Marine munitions is provided in Appendices B through E.

7 Discussion

To place the quantity of RDX, HMX, TNT, and perchlorate used in training on an annual basis by the Air Force, Navy, and Marines into perspective, it is useful to compare the data with Army usage (Table 8) first and discuss findings at Army ranges. Because many of the Air Force, Navy, and Marine munitions contain the same or similar HE formulations as Army munitions, the Army installations are a useful analogue for what can be expected at the other military services installations.

More than 25 Army installations studied for the presence of energetic residues on a variety of ranges—artillery, mortar, anti-tank rocket impact areas, anti-tank rocket, grenade, open burn/open detonation (OB/OD), and EOD demolition areas—indicated the presence of RDX, HMX, and TNT (Jenkins et al. 2005, 2004b; Pennington et al. 2006, 2005, 2004, 2003, 2002a, 2002b; AMEC 2001c, 2001d; Hewitt et al. 2005, 2003; Ampleman et al. 2003a, 2003b, 2000, 1998; Thiboutot et al. 2004, 2003a, 2000a, 2000b, 1998; Walsh et al. 2005a, 2005b, 2004, 2001; USCHPMM 2003; Ogden 1998a; Dube et al. 1999; Martel et al. 1998). The concentration of RDX, HMX, and TNT in surface soils has varied from low parts-per-billion to percent levels as exhibited by chunks of HE on the ground surface. The predominant energetic compounds observed have been RDX and TNT with lesser amounts of HMX; this is consistent with the use of Comp B as the HE filler in the majority of the Army munitions. As indicated in Table 1, Comp B consists of a 60:40 mixture of RDX:TNT with up to 10 percent HMX by weight as an impurity in the RDX. In contrast, the presence of perchlorate in soils on Army ranges has not been widely studied. Limited studies at Camp Edwards have indicated the presence of low levels of perchlorate in surface soils of an impact area and OB/OD site (Clausen et al. 2004). However, the fate-and-transport properties of perchlorate are such that, except for dry climates, its presence in surface soils is unexpected to any significant degree.

Work by Hewitt et al. (2005, 2003) has demonstrated low-order detonation of munitions are the primary source for introduction of RDX, HMX, and TNT into the environment, with cracked or ruptured UXO providing lesser amounts of residues. The contamination manifests itself in surface soil as a heterogeneous, diffuse, low-concentration, distributed source term. High-explosive residues are present on the soil surface as solid particulates and undergo slow dissolution; therefore the source is persistent, remaining in soil for years to come. Hewitt et al. (2005, 2003) also have shown high-order detonations do not distribute enough energetic residues to be of concern.

Evidence of contamination of surface or groundwater at Army ranges is generally lacking since few surface water or groundwater studies have been undertaken. Fate-and-transport properties of RDX, HMX, and perchlorate favor their transport from soil to water (see Section 4). This propensity for transport is supported by the few groundwater and surface water studies conducted where RDX, HMX, and perchlorate have been observed associated with impact areas and OB/OD sites (Pennington et al. 2006; Lewis et al. 2005; Clausen et al. 2004; AMEC, 2004, 2001d; Thiboutot et al. 2003b; Mailloux et al. 2002; Jenkins et al. 2001; Martel et al. 1999, 1998; Ampleman et al. 2004, 1998; Ogden 1998b; CH2M Hill 1997; Simmers et al. 1997).

As discussed in Section 4, transformation and sorptive processes in most cases will limit the movement of TNT. The fate-and-transport properties of TNT favor its sorption and transformation within shallow surface soil, so even though TNT may be present in surface soil, its presence in groundwater is likely limited. However, at military installations with low organic carbon or shallow groundwater depths, there is an increased probability of TNT in groundwater. Locations with concentrated activities such as OB/OD sites will have the highest probability of TNT and its degradation products, the aminodinitrotoluenes (aDNTs), being present in soil and groundwater. However, even if TNT and aDNTs reach groundwater, sorption to aquifer material continues, as do transformation processes limiting their mobility (AMEC 2004, 2001d). Therefore, the presence of TNT in groundwater is limited from its introduction point to a few hundred or thousand feet.

Air Force

As shown in Figure 2, two energetic compounds present to the greatest extent in ordnance items used on Air Force training ranges are RDX and TNT. Much of the RDX and TNT is attributable to large bombs (Appendix A). The quantities of RDX and TNT can be as high as one to two million pounds per year for large ranges such as NTTR and can range into the tens of million pounds for multiple year totals (Appendix A; Figure 3). The quantities of RDX and TNT used in munitions during training in 2005 are comparable to those used by the Army (Table 8). Three ranges (NTTR, UTTR, and Eielson AFB) are responsible for most of the total use of RDX and TNT in 2005 (Appendix A). Recall that the Army totals include training in Germany and Korea, so the CONUS totals (including Alaska and Hawaii) are likely lower. From the earlier discussion, RDX and TNT residues are present at Army ranges. Therefore, there is a high probability that RDX and TNT residues are present at Air Force bombing ranges, resulting from use of munitions containing Comp B and tritonal fillers. RDX and TNT also can be expected in soils where OB/OD or EOD training activities take place (Clausen et al. 2004).

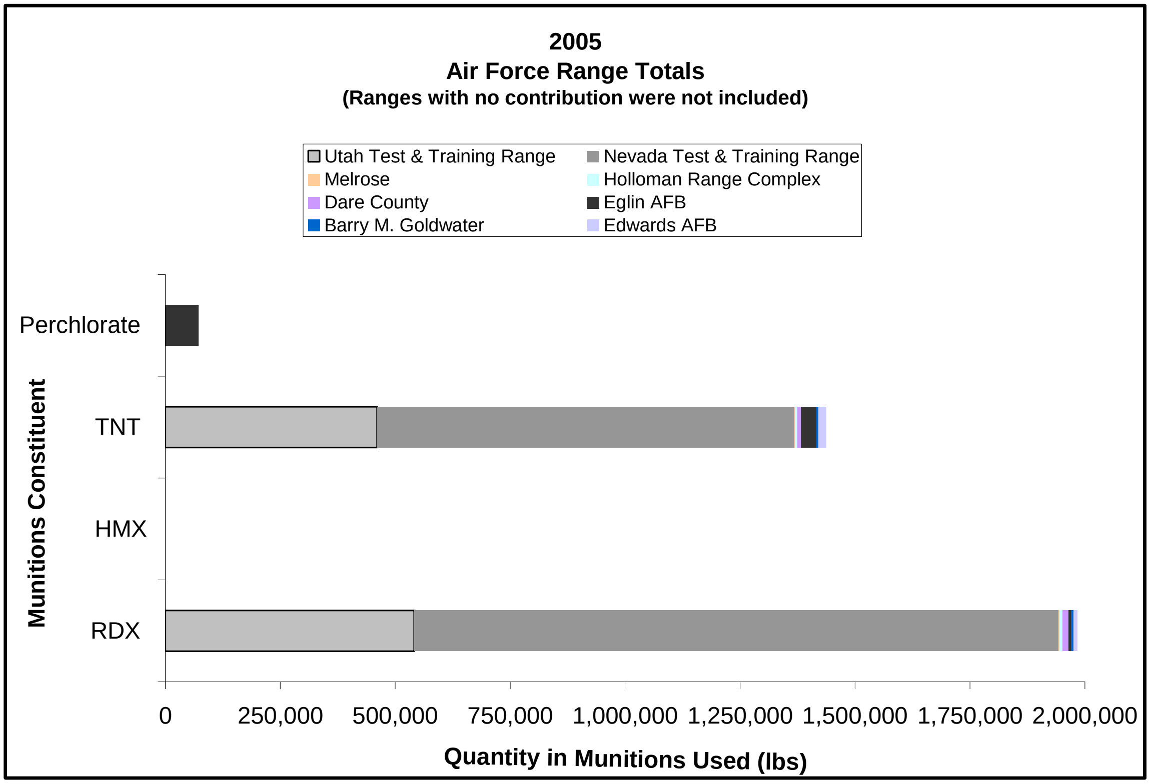

Figure 2. Constituent totals for 2005 Air Force range munitions usage.

The concern for groundwater and surface water impacts is primarily with RDX. The presence or absence in water will be a function of the depth to groundwater, degree of surface water drainage, soil characteristics, meteorological conditions, etc. However, those sites with fixed targets, shallow depth to groundwater, and high annual precipitation are sites having a high probability for movement of RDX from soil to water, such as Barking Sands Range, Dare County Range, Eglin AFB, Eielson AFB, Elmendorf AFB, and Poinsett Range. In contrast, those sites with little precipitation and significant depths to groundwater, such as NTTR and UTTR, have a low probability of surface water or groundwater impacts. Based on the few Army studies conducted, the probability of TNT or its degradation products being present in surface water and groundwater on bombing ranges is low. There is a moderate probability of TNT in surface water or groundwater at OB/OD or EOD training sites. However, even when present, rapid attenuation of TNT via transformation and sorptive processes limits movement to a few thousand feet at most (AMEC 2004, 2001d).

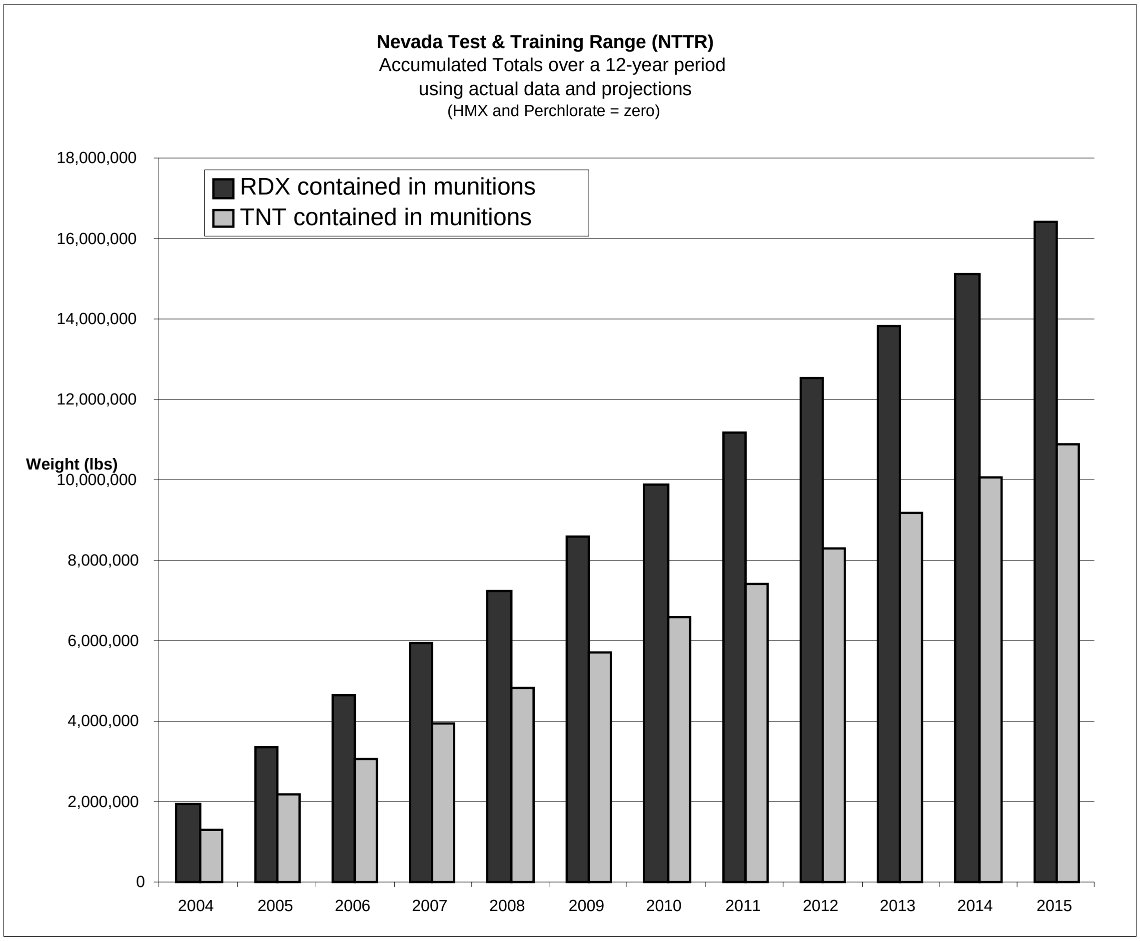

Figure 3. RDX and TNT usage and projected use in ordnance fired at the Nevada Test and Training Range.

Munition usage containing HMX occurs less frequently for the Air Force than by the Army. The quantity of HMX used at Air Force ranges was two orders of magnitude less than used by the Army (Table 8). At Army impact areas, HMX is expected and present in surface soils; therefore its presence at Air Force installations where large quantities of munitions containing RDX have been used is expected as well. Recall, HMX is an impurity in

RDX, present up to 10 percent by weight. Because the quantity of HMX compared to RDX is much lower, the probability of HMX being present in surface water or groundwater is much lower than for RDX. The probability of HMX in surface water or groundwater will be higher for the OB/OD and EOD training areas versus the bombing ranges. In general, the quantity of HMX and perchlorate contained in the munitions ranges between zero and several hundred pounds per year.

The amount of perchlorate used in Air Force munitions is lower than that used by the Army (Table 8). However, perchlorate has been observed in groundwater at the Army artillery and mortar impact area of Camp Edwards (AMEC 2004, Clausen et al. 2004) The presumed source of the perchlorate is from spotting charges, which in general contain very little perchlorate, e.g., the spotting charge for the 105-mm artillery round contains 0.2 pounds of perchlorate. The installation reporting the greatest amount of munition usage having perchlorate was Eglin AFB (Appendix A). The greatest single source of perchlorate at Eglin AFB comes from the multiple launch rocket system (MLRS) rocket (POD 298 mm), which contains 896 pounds of perchlorate. Consequently, any Air Force installation using MLRS rockets in training has a high potential for perchlorate surface water or groundwater impacts.

Navy/Marines

Specific munition Navy/Marine range usage records were unavailable when this report was written. However, of the ranges identified as potentially affected by energetic residues resulting from training (Table 4), all are undergoing a range condition assessment (RCA) and are at various stages of review under the Navy's RSEPA program. One range, the Jacksonville Range Complex (Rodman and Pinecastle), has completed the final RCA review and is now under a comprehensive range evaluation (CRE) to further analyze munitions constituents risks.

Several commands use bombs containing RDX and TNT: Marine Forces Atlantic, Marine Forces Pacific, Marine Forces Reserves, Naval Reserves, Naval Air Systems Command, Fleet Force Command, and Marine Aviation Weapons and Tactics Squadron. It is clear from Tables 10 and 11 that a significant quantity of munitions containing RDX and TNT are projected to be used by the Navy. However, the per-year quantities for the entire Navy represent only what have been used at a single Air Force range, such as NTTR. The most likely sources of energetic residues are demolition charges used at OB/OD and EOD training sites, medium caliber ammunition, and bomblets, where the risk and incidence of low-order reactions is high. Studies on low-order rates and residues produced by low-order detonations of Army munitions (Dauphin and Doyle 2001) suggest low-order detonations could be a potential source for energetic residues on Navy and Marine ranges.

In contrast, the projected usage of energetic materials on a per-year basis by the Marines is slightly greater than that at any single Air Force range. Although records were not obtained quantifying current or past munition usage, it seems reasonable that the projected numbers are similar. Consequently, there is potential for sizeable quantities of munition usage containing RDX and TNT at individual Marine training ranges. Given the fewer number of Marine training installations (three) as compared to the Army (more than 25), there is a high potential for RDX, HMX, TNT, and perchlorate to have been introduced to the environment at Marine installations. The potential for surface water and groundwater impacts is highest for Camp Lejeune, a location with a significant amount of precipitation. Camp Pendleton and Twentynine Palms have a low probability of surface and groundwater impacts because of limited precipitation.

Perchlorate use was prominent in Smokey Sams. Units allocated a large number of these for training have the potential to contribute the greatest quantity of perchlorate to the environment. The users of the greatest number of Smokey Sams are Fleet Force Command and the Marine Aviation Weapons Tactics Squadron.

JATO (Jet-Assisted Take-Off) rockets, another potential large source of perchlorate, are used to help overloaded planes by providing additional lift or for launching aircraft targets and drones. There is a potential for a large quantity of perchlorate residue at installations where the JATO devices are used in large quantities. Although usage of these devices and the associated perchlorate does not occur at training ranges, usage of the JATO devices occurs in training exercises, and residues are expected near the runways used by aircraft and drones.

8 Conclusions

The relationship of munitions used in training to the presence of explosives residues on ranges as a predictor for potential releases has been demonstrated for Army sites (Jenkins et al. 2005). The current study provides a leading indicator by merging training allocations and range records with MIDAS. This approach provides an indication of the types of munitions used, as well as the location and quantity of energetic materials used, at live-fire training sites. There is no reason why this technique could not be applied to other emerging contaminants, as well.

This approach of merging past, current, or future training allocations with net explosive mass drawn from MIDAS is a useful qualitative tool for potentially identifying sites impacted by energetic residues; however, there are a number of limitations to this approach. Obviously, to determine the net explosive weight of the munition, the item must be included in MIDAS. Although the original design of MIDAS was as an inventory tool to assist demilitarization, it is increasingly used to address potential environmental issues. Its use and application have grown to include most conventional weapons, not only those in the demilitarization stockpile. MIDAS continues to be improved and grows every year; however, not all ordnance items are currently represented in MIDAS.

Also, introduction of some uncertainty occurs by trying to match DODIC, NSN, and NALC numbers from different sources of data. To be able to match different spreadsheets using Excel functions, there must be a common denominator, and the identification numbers must be in alignment. There are some entries where a munition item may have more than one DODIC, or vice versa. The user must be aware of these subtle variations in record keeping because one model of a munition may contain a HE filler, another white phosphorus, or another be inert and yet each have a unique DODEC number. Also, the formulations for some munitions have changed over time. For example, up until 2001, the Army's 155-mm artillery round was produced with TNT only and Comp B (a mixture of RDX and TNT) in addition to a WP and illumination model. TNT alone is no longer a HE formulation used in the 155-mm artillery round, although TNT-only rounds remain in the ordnance stockpile.

Furthermore, range managers must maximize the use efficiency of their ranges, and many different customers may use the same ranges. The analysis described here does not capture past usage (e.g., a bombing range converted to a training site) or the use of ordnance items by foreign customers, such as the North Atlantic Treaty Organization (NATO), for its training exercises.

One concern with using training allocations as a data source for the Navy and Marine estimates is that future training requirements may change, resulting in different ordnance used for training than what had been projected in the past. It also is difficult to know how closely the projected munition usage numbers compare with actual munition use in the recent past. These numbers are, of course, estimates based on current national objectives, but still can be used to provide insight into what activities can contribute to energetic residues at certain training sites.

Our results suggest a significant quantity of ordnance has been used (Air Force) and is projected to be used (Navy and Marines). The munitions identified contain primarily RDX and TNT. Combining the amount of RDX and TNT in individual items with the historical and projected quantity used indicates a large mass of RDX and TNT associated with the various ordnance items. In general, if munitions containing RDX and TNT such as Comp B or C4 have been used, then there is a high probability RDX, HMX, and TNT will be present in the surface soil. Measurable levels of RDX, HMX, and TNT have been detected in surface soils of the Impact Area, OB/OD, and EOD training areas at numerous Army ranges. Because of perchlorate’s fate-and-transport properties, i.e., rapid flushing from soil, it is not expected to be detectable in soil.

Although studies of groundwater and surface water at Army installations have been limited, evidence exists for the movement of RDX and HMX from surface soils to groundwater and surface water. If RDX and HMX are observed in soil at impact, OB/OD, or EOD training areas of the Air Force, Navy, or Marines, then there is a possibility for surface water and/or groundwater impacts due to RDX’s and HMX’s recalcitrant nature. The highest likelihood would be for those installations where fixed targets have been used for a long period of time, shallow depth to groundwater, and locations with high precipitation, such as the east and west coasts of CONUS. If RDX or HMX reach the water table, then it is possible a groundwater plume is present to some degree. The length of the plume and associated RDX and HMX concentrations will be dependent on the history of munition usage and geological, geochemical, and hydrogeological conditions of the site.

Perchlorate salts are highly soluble and can be persistent and very mobile in surface water and groundwater. This could lead to a problem with perchlorate residues in areas with a high water table or extensive rainfall. Perchlorate can be found in explosives and rocket propellants widely used in military munitions items, yet the quantities of perchlorate indicated in this report are generally low, with Eglin AFB being the only exception. This could be due to the fact that many of the DODIC/NSN numbers provided are for the warhead only and may not include a rocket motor containing perchlorate. Based on our study, the highest potential for perchlorate environmental impacts are for Air Force sites where MLRS rockets have been used; Air Force, Navy, Marine sites where JATO rockets have been used; OB/OD locations; and Marine sites where pyrotechnics and smokes, in particular Smokey Sams, have been used.

TNT, on the other hand, undergoes rapid photodegradation as well as transformation process in the unsaturated zone soil as well as in groundwater. Therefore, the potential for TNT associated with range training activities to be present in groundwater or surface water would appear to be very low.

9 Recommendations

Air Force

It has been demonstrated that on many of the Air Force training ranges large quantities of energetic compounds contained in the munitions expended. It is probable some of this material may be found on the ranges. The extent to which these munitions pose an environmental and/or health and safety risk related to range activities can be determined only by conducting on-site testing. Therefore, it is recommended follow-up field work be conducted, based on a prioritized list, in order to determine the quantity and location of any energetic materials that may be present on Air Force training ranges, as well as what threat, if any, may be posed to health, safety, and the environment. An assessment program similar to the SERDP-funded CP-1155 effort for Army ranges seems warranted for the Air Force ranges.

Another recommendation for the Air Force includes maintaining cradle-to-grave munitions records, including DODIC and NSN information on all systems containing munitions data. This could minimize the time and effort required for the identification of potential range residues in the future as well as some of the uncertainty associated with this information.

Navy/Marines

The recommendations for the Navy and Marine ranges is to coordinate these results with the Navy's RSEPA program and its RCA and CRE processes and reports, and to confirm the projections made here with the Chief of Naval Operations N45 engineers. Furthermore, the munitions use information derived from the Navy's NCEA needs to be analyzed further to determine which ranges are specifically used by which command for specific training activities and ordnance use. Several commands are users of bombs containing RDX and TNT: Marine Forces Atlantic, Marine Forces Pacific, Marine Forces Reserves, Naval Reserves, Naval Air Systems Command, Fleet Force Command, and Marine Aviation Weapons and Tactics Squadron. The live-fire bombing ranges used by these commands should be assessed for RDX and TNT residues because of the high volume of explosive material used at these sites. The medium caliber ammunition training sites used by all the commands should be assessed, as well as the demolition charge training sites used by the Naval Reserves and Fleet Force Command and sites of bomblet use by Fleet Force Command and the Marine Aviation Weapons Tactics Squadron. Units using large numbers of Smokey Sams have the potential to release large quantities of perchlorate into the environment. Therefore, any focus on perchlorate residues should include the ranges where the Smokey Sam is heavily used. Also, airfields where there may be perchlorate residue buildup resulting from repeated or long-term use of JATO rocket training exercises should be assessed. A large number of JATO units are allocated to Marine Forces Pacific, Naval Air Systems Command, and Naval Education and Training. Since the Marines use many of the same ordnance items as the Army, it seems prudent to fund range assessment studies similar to the SERDP CP-1155 project to evaluate Marine training ranges.

10 References

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Appendix A: Munitions constituent quantities.

Table A-1. Munitions constituent quantities used by Luke Air Force Base at the Barry M. Goldwater Range.

BMGR AFB*	RDX (lb)	HMX (lb)	TNT (lb)	Perchlorate (lb)	Major weapons used
CY 2004	54,294	0	35,207	0	MK-82, MK-84, illumination signals, flares, air-to-ground missiles (AGM-65 and 114), rockets
CY 2005	5,900	205	3,841	0	
Accumulated 2-year totals	60,194	205	39,048	0	

* Decrease from 2004 to 2005 is attributable to a significant reduction in the use of MK-82s and MK-84s.

Table A-2. List of munitions constituent quantities used by Eglin Air Force Base at the Eglin Range.

Eglin AFB	RDX (lb)	HMX (lb)	TNT (lb)	Perchlorate (lb)	Major weapons used
2003	11,768	166	47,756	11,243	105-mm rockets, 2.75 rockets with warhead, guided missiles, smoke and illumination signals, rocket POD 298 mm
2004	1,233	873	13,000	26,144	
2005	4,436	201	34,053	72,719	
Accumulated 3-year totals	17,437	1,239	94,809	110,106	

Table A-3. List of munition constituent quantities used by Edwards Air Force Base at the Edwards Range.

Edwards AFB*	RDX (lb)	HMX (lb)	TNT (lb)	Perchlorate (lb)	Major weapons used
2005	8,624	0	17,267	0	Guided bomb units, practice bombs, flares
FY projection 2006	10,886	14	42,913	316	
FY projection 2007	12,613	15	78,199	323	
FY projection 2008	12,613	15	78,199	323	
FY projection 2009	12,613	15	78,199	323	
FY projection 2010	12,613	15	78,199	323	
Accumulated 6-year totals	69,961	75	372,976	1,606	

* Although this information was provided by Edwards AFB, the only range actually located there is the Precision Impact Range Area (PIRA), which is used for inert munitions. The energetic compound totals reflect munitions expended at other ranges, including UTTR, Point Magu, White Sands, and China Lake NWS.

Table A-4. List of munitions constituent quantities used by Seymor-Johnson Air Force Base on the Dare County Range.

Dare County	RDX (lb)	HMX (lb)	TNT (lb)	Perchlorate (lb)	Major weapons used
2004	12,209	0	7,905	0	Practice bombs (BDU-33 and BDU-50), guided bomb units, MK-82 inert, MK-84 inert
2005	12,902	0	8,354	0	
10-year projection (totals)	129,888	0	84,096	0	
Accumulated 12-year totals	155,000	0	100,355	0	

Table A-5. List of munitions constituent quantities used by Holloman Air Force Base at the Holloman Range Complex.

Holloman Range Complex	RDX (lb)	HMX (lb)	TNT (lb)	Perchlorate (lb)	Major weapons used
2004	8,705	0	5,636	0	Guided bomb units, MK-82 inert, MK-82 live
2005	6,754	0	4,373	0	
10-year projection (totals)	88,852	0	57,527	0	
Accumulated 12-year totals	104,311	0	67,536	0	

Table A-6. List of munitions constituent quantities used by the Cannon Air Force Base at the Melrose Range.

Melrose	RDX (lb)	HMX (lb)	TNT (lb)	Perchlorate (lb)	Major weapons used
2004	na	na	n/a	n/a	2.75-inch rockets, guided bomb units, practice bombs
2005	3,039	0	1,969	0	
10-year projection (totals)	na	na	na	na	
Accumulated 12-year totals	na	na	na	na	

Table A-7. List of munitions constituent quantities used by the Shaw Air Force Base at Poinsett ECR.

Poinsett ECR*	RDX (lb)	HMX (lb)	TNT (lb)	Perchlorate (lb)	Major weapons used
2004	0	0	0	0	Practice bombs, 2.75-inch rockets
2005	0	0	0	1	
10-year projection (totals)	0	0	0	6	
Accumulated 12-year totals	0	0	0	7	

* Electronic Combat Range (ECR)

Table A-8. List of munition constituent quantities used by Nellis Air Force Base at the Nevada Test and Training Range.

Nevada Test and Training Range (NTTR)	RDX (lb)	HMX (lb)	TNT (lb)	Perchlorate (lb)	Major weapons used
2004	1,966,968	0	1,298,892	0	BDUs, guided bomb units, MK-82, 83, 84, guided missiles (AGM), 2.75-inch rockets
2005	1,400,817	0	907,194	0	
10-year projection (totals)	13,053,656	0	8,712,627	0	
Accumulated 12-year totals	16,421,441	0	10,918,712	0	

Table A-9. List of munition constituent quantities used by Hill Air Force Base at the Utah Test and Training Range.

Utah Test and Training Range (UTTR)	RDX (lb)	HMX (lb)	TNT (lb)	Perchlorate (lb)	Major weapons used
2004	554,174	0	555,167	0	BDUs, guided bomb units, MK-82, MK-83, MK-84, guided missiles (AGM), 2.75-inch rockets, CBUs
2005	541,525	159	460,898	0	
10-year projection (totals)	5,204,145	530	4,846,553	0	
Accumulated 12-year totals	6,299,844	689	5,862,618	0	

Table A-10. List of munitions constituent quantities used by Eielson and Elmendorf Air Force Bases at the Alaska Range Complex.

	RDX (lb)		HMX (lb)		TNT (lb)		Perchlorate (lb)		Major weapons used
Alaska Range	Eielson	Elmendorf	Eielson	Elmendorf	Eielson	Elmendorf	Eielson	Elmendorf	
2004	143,153	15,064	46	0	184,745	14,240	1	0	Air-to-ground missile (AGM-65), practice bombs, MK-82, MK-84, guided bomb units
2005	461,311	12,507	39	0	332,358	12,584	0	0	
Combined 10-year projection (totals)	3,160,180		421		2,719,640		4		
Accumulated 12-year combined totals	3,792,216		506		3,263,568		5		

Appendix B: Navy and Marine Corps Command Usage of Munitions Containing RDX

Navy Munitions Containing RDX (10-year Non-Combat Expenditure Allowance)

Claimant Name	Munition Type	RDX (lb)	Subtotals (lb)	Total RDX (lb)
Coast Guard	med caliber	136,834		**46,463,964**
	grenades	129		
			136,963	
Marine Forces Atlantic	med caliber	5,527		
	bombs	895,768		
	rocket WHs	3,051		
			904,347	
Marine Forces Pacific	med caliber	10,590		
	bomblets	620		
	bombs	9,083,922		
	5"54 projectiles	4,300		
	rocket WHs	52,482		
			9,151,914	
Marine Forces Reserve	med caliber	11,130		
	bomblets	178		
	bombs	1,871,556		
	rocket WHs	48,803		
			1,931,667	
Naval Air Systems Command	med caliber	5,546		
	bomblets	198		
	bombs	3,775,117		
	rocket WHs	297,678		
	demolition charges	19,006		
			4,097,546	
Naval Reserves	med caliber	760		
	bomblets	238		
	bombs	1,634,948		
	demoliton charges	58,729		
	blasting caps	539		
			1,695,213	
Pacific Fleet Command	med caliber	56,398		
			56,398	
Fleet Force Command	med caliber	14,689		
	bomblets	2,460		
	bombs	11,025,193		
	5"54 projectiles	79,675		
	demolition charges	46,425		
	cutters	199,090		
			11,367,533	
Marine Aviation Weapons and Tactics Squadron One	med caliber	10,762		
	bomblets	2,649		
	bombs	15,575,468		
	rocket WHs	166,582		
			15,755,461	
Naval Strike Warfare Center	med caliber	5,156		
	bomblets	202		
	bombs	714,551		
			719,909	
Naval Surface Warfare Center	med caliber	8,831		
	5"54 projectiles	19,241		
	test charges	130,735		
	demolition charges	328,497		
	detonators	149		
			487,452	
Naval Education and Training Command	demolition charges	146,354		
			146,354	
Naval Research Laboratory	demolition chages	13,206		
			13,206	

Appendix C: Navy and Marine Corps Command Usage of Munitions Containing HMX

Navy Munitions Containing HMX (10-year Non-Combat Expenditure Allowance)

Claimant	Munition Type	Total (lb)	Subtotals (lb)	Total HMX (lb)
Marine Forces Atlantic	medium caliber	3,913		**31,564**
	bomblets	3,311		
	impulse cartidges	268		
			7,491	
Marine Forces Pacific	medium caliber	5,015		
	bomblets	5,086		
			10,101	
Marine Forces Reserve	medium caliber	1,643		
	bomblets	297		
			1,940	
Naval Air Systems Command	medium caliber	518		
			518	
Naval Reserves	bomblets	223		
	impulse cartridges	109		
			332	
Fleet Forces Command	medium caliber	1,003		
	bomblets	1,283		
	5"/54 projectiles	184		
	CADs	1,722		
			4,191	
Marine Aviation Weapons and Tactics Squadron One	medium caliber	5,388		
	bomblets	248		
			5,636	
Naval Strike Warfare Center	bomblets	252		
			252	
Naval Surface Warfare Center	CADs	181		
			181	
Naval Education and Training Command	CADs	801		
	Detonators	120	921	

Appendix D: Navy and Marine Corps Command Usage of Munitions Containing TNT

Navy Munitions Containing TNT (10-year Non-Combat Expenditure Allowance)

Claimant	Munition Type	Total (lb)	Subtotals (lb)	Total TNT (lb)
Marine Forces Atlantic	med caliber	562		**14,100,580**
	bomblets	1,722		
	bombs	3,719,070		
	rocket WHs	101,722		
			3,823,075	
Marine Forces Pacific	bomblets	2,645		
	bombs	3,404,218		
	rocket WHs	194,129		
			3,600,992	
Marine Forces Reserve	bomblets	154		
	bombs	691,279		
	rocket WHs	31,822		
			723,256	
Naval Air Systems Command	bombs	687,640		
	rocket WHs	1,965		
	demolition charges	35,366		
	UW charges	22,137		
			747,107	
Naval Reserves	bomblets	116		
	bombs	804,278		
			804,393	
Fleet Forces Command	med caliber	3,121		
	bomblets	667		
	bombs	3,227,863		
	grenades	684		
	demolition charges	36,443		
	UW chages	45,900		
	cutters	665		
			3,315,343	
Marine Aviation Weapons and Tactics Squadron One	bomblets	129		
	bombs	730,237		
	rocket WHs	41,089		
			771,455	
Naval Strike Warfare Center	med caliber	3,121		
	bomblets	131		
	bombs	89,956		
			93,208	
Naval Surface Warfare Center	test charges	124,303		
	grenades	125		
			124,428	
Naval Education and Training Command	demolition charges	88,478		
	cutters	343		
			88,821	
Naval Research Laboratory	UW charges	8,500		
			8,500	

Appendix E: Navy and Marine Corps Command Usage of Munitions Containing Perchlorate

Navy Munitions Containing Perchlorate (10-year Non-Combat Expenditure Allowance)

Claimant	Munition type	Total (lb)	Subtotals (lb)	Total (lb)
Marine Forces Atlantic	med caliber	12,127		**456,475**
	flares	577		
	impulse cartridges	114		
	Smokey Sams	712		
			13,531	
Marine Forces Pacific	med caliber	11,840		
	JATO rockets	14,580		
	flares	402		
	impulse cartridges	114		
	Smokey Sams	292		
			27,228	
Marine Forces Reserve	med caliber	5,784		
	flares	176		
			5,960	
Naval Air Systems Command	med caliber	468		
	JATOs	14,616		
	Smokey Sams	222		
			15,306	
Naval Reserves	med caliber	417		
	flares	257		
			674	
Military Sealift Command	med caliber	349		
			349	
Fleet Forces Command	UW charges	32,160		
	med caliber	563		
	flares	3,617		
	grenade fuzes	118		
	CAD/PAD	728		
	simulants	5,266		
	Smokey Sams	1,686		
			44,138	
Marine Aviation Weapons and Tactics Squadron One	med caliber	9,066		
	Smokey Sams	10,210		
			19,277	
Naval Strike Warfare Center	simulants	123		
	Smokey Sams	3,456		
			3,578	
Naval Surface Warfare Center	med caliber	160		
	flares	151		
			310	
Naval Education and Training Command	JATOs	325,462		
	flares	662		
			326,124	

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14. ABSTRACT

Use of conventional weapons and explosives in live-fire military training can lead to release of munitions constituent residues, which can migrate to groundwater and drinking water sources. The extent to which major energetic constituents (RDX, HMX, TNT, and perchlorate) are present at military installations is being analyzed and assessed. Studies of the presence of energetic materials on US Army live-fire training sites have increased our understanding of the environmental fate and transport of energetic constituent residues. This study is intended to expand existing information concerning Army installations to Navy, Marine Corps, and Air Force facilities by relating munitions constituent database information with training allocations and recorded range munitions usage. Munition usage projections from training allocations and range records help identify probable presence of energetic residues and allow for prioritization of sites for further analysis and investigation. Data from this study suggest Air Force, Navy, and Marine training in the continental United States involves use of munitions containing quantities of RDX, HMX, TNT, and perchlorate comparable to Army usage on an annual basis. Based on field studies of numerous Army ranges, there is a high probability of introduction of RDX, HMX, TNT, and perchlorate residues into the environment at Air Force, Navy, and Marine ranges as well.

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