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Hand Grenade Residuals

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Environmental Laboratory

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Final report

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Abstract: The Department of Defense operates hundreds of hand grenade ranges for training purposes. The majority of hand grenades used at fixed position ranges are fragmentation grenades that are typically composed of a steel shell and composition B explosive material. Measurable explosive levels have been observed in hand grenade range soils at levels in the low parts per billion up to percent levels.

Previous attempts to measure hand grenade residues have used snow, tarps, and trays as collection media, but each method had some disadvantages. In this research, hand grenades were detonated in a large octagon test chamber at the Aberdeen Training Center, allowing for a more complete collection of the debris. Initially, residues from two hand grenades were analyzed for explosives and metals by the U.S. Army Engineer Research and Development Center, Vicksburg. Residues from 30 hand grenades were analyzed for explosives and metals content. On average, the mass of RDX associated with the hand grenade residue was 0.366 mg with a 101-percent recovery of the iron that composes the steel grenade shell. The results from this study will help determine the potential soil loading of residuals on grenade training ranges.

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Preface

The work reported herein was conducted at the U.S. Army Engineer Research and Development Center (ERDC), Vicksburg, MS. Funding was provided by the Environmental Security Technology Certification Program (ESTCP). The project was designated as ESTCP project ER-0216.

The work presented in this report was part of an effort to investigate the effectiveness of lime application to immobilize metals and transform explosives on active hand grenade ranges. Dr. Steven L. Larson, Dr. Jeffery L. Davis, W. Andy Martin, and Deborah R. Felt of the Environmental Laboratory (EL), Vicksburg, MS; Catherine C. Nestler of Applied Research Associates, Inc., Vicksburg, MS; Gene Fabian, Aberdeen Test Center (ATC), Aberdeen Proving Grounds, MD; and Greg O'Connor, U.S. Army RDECOM-ARDEC, Picatinny, NJ; prepared this report. The authors gratefully acknowledge the technical assistance provided by Chris Griggs and Michelle Thompson (Applied Research Associates, Inc.), and LeeAnn Riggs and Deborah Regan (SpecPro).

This study was conducted under the direct supervision of Dr. Patrick N. Deliman, Chief, Environmental Engineering Branch, EL, and Dr. Richard E. Price, Chief, Environmental Processes and Engineering Division, EL, and under the general supervision of Dr. John M. Cullinane, Technical Director, EL, and Dr. Beth Fleming was the Director, EL.

COL Gary E. Johnston was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Acronyms

AEC	U.S. Army Environmental Command (formerly the Army Environmental Center)
ATC	U.S. Army Aberdeen Test Center
EL	Environmental Laboratory
ERDC	Engineer Research and Development Center
LOTC	Large octagonal test chamber
MIDAS	Munitions Items Disposition Action System database

1 Introduction

Background

The majority of hand grenades used at fixed position ranges are fragmentation grenades, which are typically composed of a steel shell and Composition B explosive. Composition B is made from a combination of hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX), 2,4,6-trinitrotoluene (TNT), and a wax binder at a weight ratio of 60:39:1, respectively. The primary high explosive (HE) contaminant on hand grenade training ranges is RDX, which was found at concentrations ranging from <0.01 to 51 mg/kg (Jenkins et al. 2006).

Metals (iron, zinc, copper, nickel, chromium, and trace amounts of lead and manganese) included in hand grenade construction are also deposited on the soil surface due to the detonation. Depending on the background metals concentrations in the soil, the metals contamination of soils may create a problem for training facilities when the metals are transported off-site. Two such potential pathways for off-site migration of metals and explosives components from hand grenade soils are horizontal transport in surface water and vertical leaching.

Hand grenade ranges can vary in use, size, and design depending on the training requirements of a particular installation. Hand grenade ranges have been described as small in size (only a few hectares), poorly vegetated, with HE contamination concentrated in an area 15 to 35 m from the throwing pit, that is, 20-60 m wide and mixed 10-15 cm deep (Pennington et al. 2006, Jenkins et al. 2001). Cook and Spillman (2000) pointed out high-order detonations (completely exploded) from routine training exercises do not add contaminants to the soil in quantities that could cause concerns. The mean concentration of explosives in soils from six hand grenade ranges was less than 0.12 mg/kg, while single point concentrations up to 54 mg/kg have been reported (Jenkins et al. 2006, Pennington et al. 2006). It has been stated that the low-order detonations add the majority of larger chunk explosive residues to the soil (Jenkins et al. 2006, Pennington et al. 2006).

Hewitt et al. (2005) estimated that roughly 0.025 mg RDX and <0.001 mg TNT is deposited on the soil surface when a hand grenade detonates as designed, but this has not been measured directly. Several sampling techniques have been presented in the literature to determine the amount of explosive residue deposited on soils after high order detonations. Pennington et al. (2003) collected residue samples on tarps and Taylor et al. (2006) used trays set at predetermined distances from the charge. Hewitt et al. (2005) used snow as a collection medium to examine explosives residue post-detonation. All of these collection methods have advantages and disadvantages. Collecting residues on tarps offers the most complete method in an open environment, but it does not account for residue loss due to atmospheric conditions (i.e. wind-blown residuals). Closed test chambers offer the most complete method to collect residuals following a detonation, but closed systems can be very costly to operate.

The current study examined the amounts of HE, metals, and air emissions contained within the hand grenade residuals following high order detonation. Grenades used in this study were M67 fragmentation hand grenades. Almost half of the total mass of the grenade is iron (170.3 g), with another 184.3 g as HE (combined mass RDX, TNT, and wax binder). The remaining 42.3 g is a mix of metals and unnamed components, compounds, and elements. Two hand grenades were used to quantify air emission characteristics (AEC 2004), metals, and explosives analysis. Thirty additional hand grenades from three lots were individually detonated within a closed container; the residuals were collected and analyzed to determine the metals and HE present in the residuals. The results from this study provide insight into the residual deposition in the environment after training with hand grenades.

Objectives

The objectives of this study were to:

- Determine the metals associated with hand grenade residuals.
- Determine the explosives associated with hand grenade residuals.

2 Materials and Methods

Experimental design

Two studies were performed (Table 1). The first examined air emissions as well as solid residues. The second study examined only the solid residues. The solid residue from each grenade was collected separately and analyzed by the U.S. Army Engineer Research and Development Center (ERDC) for explosive and metals content in order to determine the residue concentrations present for each grenade following detonation.

Table 1. Residual components analyzed for during studies.

Study	Emissions	RDX	TNT	Metals
Air emission study with 2 HG	X	X	X	X
Solid residue study with 30 HG		X[1]		X[2]

[1] RDX, MNX, DNX, and TNX
[2] Five of the thirty grenades were analyzed for total metals.

M67 grenades

The hand grenade used in this study was the M67 fragmentation hand grenade (Figure 1). The grenade body is a 6.4-cm-diam steel sphere that contains 184.3 g Composition B explosives. Each grenade is fitted with an M213 fuze, which is a pyrotechnic delay-detonating fuze. The fuze is designed to initiate the explosive charge of the grenade 4 to 5 seconds after the release of the safety lever. The body of the fuze contains a primer and a pyrotechnic delay column. A striker, striker spring, safety lever, safety pin and pull ring, safety clip, and a detonator assembly are attached to the body of the grenade. The steel safety pin is shaped to prevent accidental removal and arming during shipping and handling. The pull ring is provided to facilitate removal of the safety pin. The safety clip prevents the safety lever from snapping upward into a triggered position in case the safety pin is accidentally dislodged from the fuze. The hand grenade components are listed in Appendix A, along with information on mass and chemical composition.

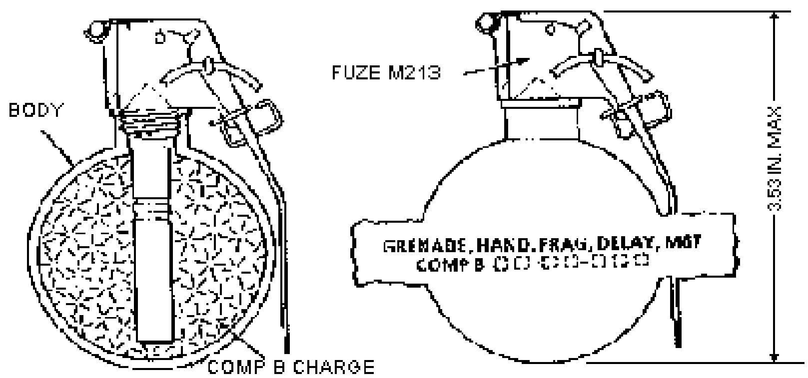

Figure 1. Grenade, hand fragmentation, M67.

Test facility and procedure

Hand grenades were detonated in the U.S. Army Aberdeen Test Center's (ATC) large octagonal test chamber (LOTC) in a controlled environment. The LOTC (Figure 2) is an eight-sided structure with flat ends made from 2.54-cm-(1-in.)-thick steel plates and is designed to withstand the pressures generated by internal detonations. The interior wall-to-wall dimensions of the LOTC are 4.42 m (14.5 ft) and the floor-to-ceiling dimension is 4.27 m (14.0 ft).

The grenade was placed in a cup that was mounted on top of a steel box inside the LOTC (Figure 3). The safety pin was removed and the grenade was pulled from the cup using a cable (Figure 4). The safety handle was actuated and the grenade detonated in approximately 4 to 5 seconds in this tactical scenario.

Figure 2. External view of LOTC.

Figure 3. Grenade in cup inside LOTC.

Figure 4. Cable used to pull grenade from cup.

After the detonation of each grenade, the test chamber interior was completely cleaned. The residue was swept into a dust pan with a broom (Figure 5). The interior of the test chamber was then cleaned with a HEPA filtered vacuum cleaner prior to the next detonation. The collected residue was placed into a separate non-static bag and subsequently placed inside a cooler. All the grenade residues were collected in a similar manner. The non-static bags were sorted by detonation time, i.e., by morning or afternoon detonations, per given day. Following the collection of all 30 grenade residues, the cooler was transported to the U.S. Army Engineer Research and Development Center – Environmental Laboratory (ERDC-EL) located in Vicksburg, MS for analysis. The air emissions for two grenades were collected and analyzed by ATC for the Army Environmental Command (AEC, formerly the Army Environmental Center); the residual metals and explosives analysis for the two hand grenade study was also conducted by ERDC-EL.

Figure 5. Residue from detonated grenade.

A device was designed to detonate the grenade in case the grenade did not function properly when pulled from the cup. The steel box (Figure 4) below the cup was fitted with a sliding lid that could be activated by a cable. If the grenade did not function properly, the lid was removed and the grenade was lowered into the steel box. The steel box contained a demolition charge that could be electrically discharged, detonating the grenade. When the grenade functioned properly, the steel box (Figure 4) protected the demolition charge. No grenades had to be detonated with the demolition charge for this study.

Physical and chemical analysis

The analytical methods and procedures used during this study are summarized below and in Table 2.

Table 2. Chemical and physical analytical procedures used during the study.

Parameter / Procedure	Method	Detection Limit Soil (mg/kg)
Metals	SW-846-Method 3015 SW-846 Method 6010	0.5
Explosives (RDX, TNT)	EPA Method 8330	0.01

Once the samples arrived at ERDC-EL, they were placed into a refrigerator maintained at 4 °C until explosives and metals analysis could be performed. Representative aliquots of residue samples were digested according to SW-846 Method 3015. All digested samples were analyzed for metals concentrations according to EPA SW-846 Method 6010 Inductively Coupled Plasma (ICP) (US Environmental Protection Agency (USEPA) 1999) on a Perkins Elmer Optima 4300 Dual View (DV).

Representative subsamples of each grenade residue were extracted following EPA method 8330 and analyzed for explosives constituents using a Dionex HPLC equipped with a reversed-phase Supelco LC-18 column and a UV detector set at 254 nm. Flow rate was set at 1 mL/min using a mobile phase of 50:50 methanol: water (v:v).

Data were analyzed statistically using SigmaPlot, Version 10 and SigmaStat Version 3.5 software (SyStat Software, Inc.).

Emission data (summary of AEC 2004)

Two M67 hand grenades were detonated in the LOTC and analyzed for the following air emissions data: metals, explosives, total suspended particulates (TSP), PM_{10}, and $PM_{2.5}$. Background levels in the LOTC were accounted for in the particulate calculations. ATC emissions data can be found in the AEC report, Appendix B.

3 Results and Discussion

The controlled detonation of the hand grenades was performed in order to determine the munitions constituents being deposited on the range per hand grenade as a result of training exercises. The masses of the grenade residues were measured and the concentrations of metals and explosives associated with the residue were determined.

The average mass of the 30 hand grenade residues was 0.345 ± 0.040 kg (Appendix C), which is approximately 87 percent of the mass of the grenade collected as residue. Of this, 54 percent is metals and the rest contains the soot and residual explosives. The remaining 15 percent of the grenade was lost as particulate and air emissions in the combustion of the grenade. Some of the residue may have been lost due to transport from the catch box to the non-static bags for storage.

Metals

Air emission study

The metal particulates associated with the two hand grenades that make up this study made up the majority of the residue mass. A fraction of the two-grenade residue was collected and digested for metals concentrations; the predominant metals are summarized in Table 3. The metals associated with the grenade shell and detonation fuze were predominately iron and zinc with trace amounts of nickel, chromium, lead, and cadmium.

Table 3. Metals associated with hand grenade residues.

Metal	Concentration in Fraction of Residue Collected (mg/kg)	
	Grenade 1	Grenade 2
Iron (Fe)	174,300	55,500
Zinc (Zn)	39,700	8,030
Nickel (Ni)	2,835	1,920
Chromium (Cr)	832	872
Lead (Pb)	123	164
Cadmium (Cd)	38	24

Solid residue study

Of the 30 grenades involved in this study, five were selected for metals analysis. Results of this analysis are summarized in Table 4, while the individual results from the same five grenades are listed in Appendix B. The average iron recovered from the five hand grenades was 101 percent. The metals that were less represented in the steel hand grenade shell varied from 13 to 223 percent recovery. The total average metals recovered was 97 percent.

Table 4. Average mass metals and percent recovery for hand grenade residuals (n=5).

Metal	Average (g)	Standard Deviation	Coefficient of Variance (%)	Mass in Hand Grenade	% Recovered
Iron (Fe)	172.310	22.071	13	170.298	101
Zinc (Zn)	29.538	14.303	48	18.399	161
Manganese (Mn)	1.710	0.331	19	0.765	223
Lead (Pb)	0.091	0.035	39	0.709	13
Chromium (Cr)	0.191	0.049	26	0.539	36
Nickel (Ni)	0.313	0.070	22	0.198	158
Vanadium (V)	0.075	0.009	13	0.142	53
Total Metals	205.732	n.a.[1]	n.a.	212.625	97
[1] n.a. = not applicable					

While the variability in the metals data can be reduced with the analysis of a larger sample size, the predominant metals released into the environment from the detonations are iron and zinc with trace amounts of other metals (Table 4). The metals deposited per detonation can be theoretically calculated using the mass balance summary of the hand grenade components data in Appendix A, not taking into account metals that are generated as particulates in the emissions. The mass of residue generated from the detonation, i.e. explosives consumption, cannot be calculated. It must be measured from residue collected.

Explosives

The residue collected for the two grenades was analyzed for both RDX and TNT, while the residue collected from the 30 grenades was analyzed for

RDX, MNX, DNX, and TNX. For comparison purposes, the common explosive analyzed for the collected grenade residues is RDX. Since RDX is typically more mobile than TNT in soils, it was the primary focus of explosives residues studied.

Air emission study

The explosives data for these two grenades is shown in Table 5. The majority of the explosives residue is in the form of TNT, with a small fraction of RDX present. The formulation of Comp B is 60 percent RDX, 39 percent TNT, and 1 percent wax. For these two detonations, it appears that most of the RDX was fully consumed while more of the TNT remained, but with only two grenades to analyze, there is a large degree of variability in the concentrations of both RDX and TNT present in the residual of the two grenades.

Table 5. Explosives results for two hand grenade residues.

Compound	Concentration (mg/kg)	
	Grenade 1	Grenade 2
TNT	5,454	76,990
RDX	52	232

Solid residue study

Variable amounts of explosives were detected from the 30 grenade residue samples collected. The most prominent difference in the explosives content of the residue was associated with the grenades' production lot numbers. The 30 grenades used in the residue production came from three different lots; LOT A consisted of grenades numbered 1 through 12, LOT B from 13 through 19, and LOT C from 20 through 30.

The grenade residue was analyzed for: RDX, MNX, DNX, and TNX (Appendix C). Of the four, RDX (Figure 6) and DNX were the most prominent explosives detected. The grenade residuals associated with LOT A generally had more DNX (Table 6) than the other lots, the mass present ranging from 0.06 to 80.41 mg. Grenades from LOT B and LOT C had higher detected levels of RDX, with the mass present ranging from <0.01 to 13.12 mg.

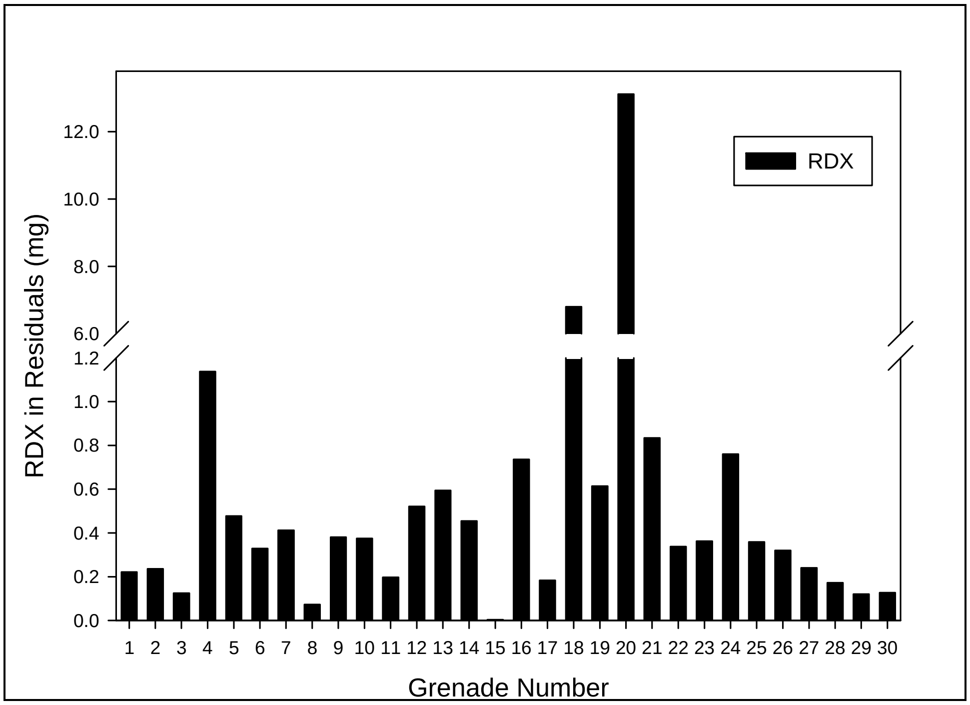

Figure 6. Predominant explosives residue of the 30 hand grenades.

Detonations, manufacture, and storage of hand grenades may determine their detonation efficiency. Detonation and collection of residue were conducted in an identical manner while detonating all 30 grenades. While no low-order detonations were observed during the residue production, the grenades' explosives residue concentrations varied notably according to their production lot number.

The average mass (with outliers removed) of RDX residue per grenade was calculated as 0.366 mg (Table 6) that could be deposited on the range per grenade due to training. This RDX deposition is more than one magnitude greater than the 0.025-mg RDX deposition proposed by Hewitt et al. (2005). On average, based on the results in this study, over 99.67 percent of the RDX in the grenade is consumed when the grenade is used properly, whereas the proposed efficiency by Hewitt et al. (2005) would be greater than 99.98 percent per properly functioning grenade.

Table 6. Average mass explosives associated with grenade residues, by total and by LOT number.

Explosive compound	Mass Explosives Residual (mg)									
	LOT A (1984)		LOT B (1987)		LOT C (1992)		All 30 Grenades		All 30 Grenades	
	Avg	Std	Avg	Std	Avg	Std	Avg	Std	Low	High
RDX	0.304[1]	0.145	0.431[1]	0.282	0.363[1]	0.247	0.366[1]	0.063	<0.01	13.12
MNX	0.187	0.133	0.090	0.071	0.100	0.044	0.126	0.053	0.03	0.34
DNX	11.789[1]	15.226	5.062	0.942	0.316	0.178	5.722[1]	5.765	0.06	80.41
TNX	0.141[1]	0.084	0.087	0.054	0.043*	0.011	0.090[1]	0.049	0.03	0.72

[1] Outlier removed as per Student T-test for outliers.

Statistical analysis

Statistical analysis was conducted for the explosives results from the 30 grenades that were analyzed (Appendix D). Normality failed on all statistical analysis of explosives data. The sample size of this study was too small (n=10) to make meaningful comparisons based on lot numbers. A minimum sample size of 30 from each lot number was determined to be necessary to enable a passing normality for future residue investigative work.

4 Conclusions and Recommendation

Conclusions

This research looked only at hand grenade residues and their potential deposition on the hand grenade range impact area. The conclusions, based on the study objectives, are as follows:

- **Determine the metals associated with hand grenade residuals.** The hand grenade shell is composed of steel and the primary components of the steel shell that are deposited with a grenade explosion are iron and zinc with other metals, such as manganese, chromium, lead, nickel, and vanadium present in trace amounts.
- **Determine the explosives associated with hand grenade residuals.** The primary explosives residual analyzed for this study was RDX and its transformation products (MNX, DNX, and TNX) with a minor emphasis on TNT.
    - The average RDX detected in the grenade residuals ranged from <0.01 to 13.12 mg, with an average of 0.366 mg (with outliers removed); this mass present in the residuals was over an order of magnitude larger than previously reported (Hewitt et al. 2005).
    - DNX, a transformation byproduct of RDX, was detected predominately in the residue of the older hand grenades. This transformation could occur within the round before detonation if moisture was present; for example, the iron in the hand grenade shell could be oxidized when wet, which could in turn reduce RDX to DNX.
    - The mass of TNX and MNX in the residuals was relatively low compared to DNX.
    - TNT was only analyzed for two hand grenades and the results varied for the two grenades.

Recommendation

There is a large variability of explosives and metals in the grenade residue. A minimum sample size of 30 from each lot number was determined to enable a passing normality for future studies.

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Appendix A: M67 Hand Grenade Components Adapted from MIDAS

Table A-1. Approximate mass balance of M67 Hand Grenade Based on MIDAS Data Information.

Component	% by Weight (% per component)	Weight (oz)	Weight (g)
M67 Hand Grenade	100	14	396.9
High Explosives (Composition B)	46.43	6.5	184.275
RDX	(60)	3.9	110.565
TNT	(39)	2.535	71.867
Wax Binder	(1)	0.065	1.843
Metals / Other Components	53.57	7.5	212.625
Fe	(80.09)	6.007	170.298
Zn	(8.65)	0.649	18.399
Mn	(0.36)	0.027	0.765
Al	(0.84)	0.063	1.786
Cr	(0.25)	0.019	0.539
Pb & Pb Compounds	(0.33)	0.025	0.709
Ni	(0.09)	0.007	0.198
V	(0.07)	0.005	0.142
Other Components (Trace metals, string, washers)	(9.31)	0.698	19.788

Appendix B: AEC Emissions Data (Summary of report by U.S. Army Environmental Command (AEC) 2004)

Particulates

The TSP, PM_{10}, and $PM_{2.5}$ emissions data were collected for the total of two M-67 grenade detonations within the LOTC. The TSP averaged 9.65×10^{-2} lb/lb, PM_{10} was 8.03×10^{-2} lb/lb, and $PM_{2.5}$ was 4.55×10^{-2} lb/lb.

Metals

Trace metals were detected in the emissions with the predominant average metal concentration for zinc at 9.87×10^{-6} lb/lb, lead at 1.30×10^{-6} lb/lb, and chromium at 2.95×10^{-8} lb/lb. Iron was not determined and nickel and cadmium were non-detects.

Explosives

The average air emission concentration for the two grenades for RDX was 2.31×10^{-6} lb/lb and for TNT was 1.55×10^{-6} lb/lb. The Army Environmental Command (AEC) reported a 32-percent mass balance recovery for the munitions when the theoretical recovery was calculated to be at 70 to 80 percent.

Appendix C: Grenade Residue Data

Table C-1. Metals (mg) from five hand grenade residuals in triplicate.

M67 Grenade #	Pb	Cr	Cu	Ni	Zn	Fe	Mn	Mo	V	Sb	As
7 rep1	95	175	537	294	27,779	189,991	1,963	n.d.	76	n.d.	n.d.
7 rep2	105	193	986	294	26,239	192,699	1,892	n.d.	77	n.d.	n.d.
7 rep3	91	188	512	308	24,818	190,759	2,007	n.d.	77	n.d.	n.d.
9 rep1	129	243	1,019	378	45,931	188,236	1,893	n.d.	80	n.d.	n.d.
9 rep2	161	301	1,150	456	45,287	205,241	2,312	n.d.	93	n.d.	n.d.
9 rep3	148	261	1,576	405	75,789[1]	200,838	2,069	n.d.	94	n.d.	n.d.
20 rep1	71	167	1,533	294	23,370	155,942	1,569	n.d.	73	n.d.	n.d.
20 rep2	63	151	1,333	244	23,294	138,912	1,475	n.d.	61	n.d.	n.d.
20 rep3	n.d.[2]	136	1,163	215	21,020	145,698	1,219	n.d.	63	n.d.	n.d.
21 rep1	57	156	1,949	267	24,619	156,659	1,406	n.d.	69	n.d.	n.d.
21 rep2	53	151	2,057	252	24,362	153,311	1,305	n.d.	65	n.d.	n.d.
21 rep3	58	170	2,168	316	28,737	164,164	1,819	n.d.	77	n.d.	n.d.
23 rep1	109	250	2,817	420	39,755	184,874	1,917	n.d.	81	n.d.	n.d.
23 rep2	61	162	1,492	260	27,060	171,007	1,451	n.d.	70	n.d.	n.d.
23 rep3	74	166	2,260	297	31,260	146,318	1,348	n.d.	71	n.d.	n.d.

[1] Outlier as defined by Student-T-test for Outliers.
[2]. n.d. = non-detect

Table C-2. Mass of collected grenade residue (kg).

Lot and Grenade #		Weight of Residue without Spoon (kg)	Average (n=30)	Standard Deviation
A	1	0.322	0.345	0.040
	2	0.415		
	3	0.382		
	4	0.377		
	5	0.385		
	6	0.365		
	7	0.366		
	8	0.342		
	9	0.358		
	10	0.360		
	11	0.347		
	12	0.388		
B	13	0.346		
	14	0.391		
	15	0.357		
	16	0.316		
	17	0.345		
	18	0.372		
	19	0.386		
C	20	0.262		
	21	0.279		
	22	0.310		
	23	0.324		
	24	0.260		
	25	0.388		
	26	0.360		
	27	0.289		
	28	0.338		
	29	0.288		
	30	0.319		

Table C-3. Hand grenade explosives residue (mg) for the 30 hand grenade study.

Lot and Grenade #		RDX (mg)	MNX (mg)	DNX (mg)	TNX (mg)
A	1	0.222	n.d.[1]	80.41[2]	0.29
	2	0.236	n.d.	54.67	0.29
	3	0.125	n.d.	10.39	0.13
	4	1.138[1]	0.23	15.72	0.72[1]
	5	0.477	0.03	17.62	0.15
	6	0.329	0.34	0.73	0.04
	7	0.413	n.d.	10.18	0.15
	8	0.073	0.15	2.28	0.05
	9	0.380	n.d.	4.38	0.14
	10	0.375	n.d.	4.01	0.11
	11	0.198	n.d.	5.51	0.12
	12	0.522	n.d.	4.19	0.07
B	13	0.595	n.d.	1.81	0.12
	14	0.454	n.d.	2.53	0.13
	15	0.004	0.14	0.10	0.03
	16	0.736	n.d.	1.77	0.08
	17	0.183	0.04	0.69	0.03
	18	6.802[2]	n.d.	0.49	0.05
	19	0.614	n.d.	5.58	0.17
C	20	13.115[2]	n.d.	0.06	n.d.
	21	0.834	n.d.	0.17	n.d.
	22	0.338	n.d.	0.20	0.04
	23	0.362	n.d.	0.17	0.04
	24	0.760	0.12	0.44	0.06
	25	0.359	n.d.	0.31	0.04
	26	0.321	n.d.	0.52	0.04
	27	0.240	0.05	0.30	0.03
	28	0.172	0.13	0.26	0.03
	29	0.121	n.d.	0.69	0.05
	30	0.127	n.d.	0.35	0.05

[1] n.d. = non-detect
[2] Outlier as defined by Student T-test for Outliers.

Appendix D: Statistical Review of LOTS A, B, and C

Table D-1. Descriptive statistics of explosives data on grenade residue from Lots A, B, & and C

Column	Size	Missing	Mean	Std Dev	Std. Error	C.I. of Mean
Mass - A	12	0	0.368	0.0245	0.00706	0.0155
Mass - B	7	0	0.359	0.0263	0.00993	0.0243
Mass – C	11	0	0.311	0.0404	0.0122	0.0271
RDX – A	12	0	0.394	0.291	0.0841	0.185
RDX – B	7	0	1.413	2.549	0.964	2.358
RDX - C	11	0	1.634	4.142	1.249	2.782
MNX – A	12	0	0.0655	0.121	0.0350	0.0771
MNX – B	7	0	0.0272	0.0556	0.0210	0.0514
MNX – C	11	0	0.0291	0.0541	0.0163	0.0364
DNX – A	12	0	18.577	26.603	7.680	16.903
DNX – B	7	0	2.257	2.653	1.003	2.454
DNX – C	11	0	0.336	0.178	0.0536	0.119
TNX – A	12	0	0.200	0.195	0.0562	0.124
TNX – B	7	0	0.0914	0.0568	0.0215	0.0526
TNX – C	11	0	0.0378	0.0213	0.00644	0.0143

Table D-2. Descriptive statistics of explosives data on grenade residue from Lots A, B, & and C

Column	Range	Max	Min	Median	25%	75%
Mass - A	0.0930	0.415	0.322	0.366	0.353	0.384
Mass - B	0.0750	0.391	0.316	0.357	0.346	0.383
Mass – C	0.128	0.388	0.260	0.310	0.282	0.335
RDX – A	1.120	1.197	0.0770	0.371	0.225	0.468
RDX – B	7.158	7.162	0.00377	0.628	0.265	0.748
RDX - C	13.970	14.098	0.129	0.359	0.201	0.709
MNX – A	0.361	0.361	0.000	0.000	0.000	0.0924
MNX – B	0.148	0.148	0.000	0.000	0.000	0.0316
MNX – C	0.138	0.138	0.000	0.000	0.000	0.0393
DNX – A	87.046	87.814	0.768	7.890	4.259	17.601
DNX – B	7.733	7.851	0.118	1.628	0.581	2.737
DNX – C	0.557	0.604	0.0470	0.336	0.184	0.450
TNX – A	0.713	0.755	0.0415	0.141	0.0954	0.233
TNX – B	0.146	0.174	0.0277	0.0799	0.0388	0.137
TNX – C	0.0663	0.0663	0.000	0.0410	0.0327	0.0540

Table D-3. Descriptive statistics of explosives data on grenade residue from Lots A, B, & and C

Column	Skewness	Kurtosis	K-S Dist.	K-S Prob.	Sum	Sum of Squares
Mass - A	0.0693	0.512	0.115	0.802	4.411	1.628
Mass - B	-0.384	-0.407	0.154	0.726	2.515	0.908
Mass – C	0.571	-0.316	0.158	0.550	3.421	1.080
RDX – A	2.029	5.463	0.215	0.127	4.732	2.799
RDX – B	2.582	6.749	0.455	<0.001	9.892	52.978
RDX - C	3.294	10.891	0.480	<0.001	17.970	200.897
MNX – A	1.808	2.347	0.372	<0.001	0.786	0.214
MNX – B	2.269	5.181	0.402	0.001	0.190	0.0237
MNX – C	1.639	1.161	0.432	<0.001	0.320	0.0386
DNX – A	2.132	4.006	0.332	<0.001	222.925	11925.994
DNX – B	1.958	4.161	0.262	0.155	15.801	77.895
DNX – C	0.0809	-0.782	0.107	0.827	3.691	1.555
TNX – A	2.416	6.563	0.332	<0.001	2.396	0.896
TNX – B	0.289	-1.669	0.179	0.602	0.639	0.0778
TNX – C	-0.888	-.270	0.209	0.192	0.416	0.0203

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14. ABSTRACT
The Department of Defense operates hundreds of hand grenade ranges for training purposes. The majority of hand grenades used at fixed position ranges are fragmentation grenades that are typically composed of a steel shell and composition B explosive material. Measurable explosive levels have been observed in hand grenade range soils at levels in the low parts per billion up to percent levels.

Previous attempts to measure hand grenade residues have used snow, tarps, and trays as collection media, but each method had some disadvantages. In this research, hand grenades were detonated in a large octagon test chamber at the Aberdeen Training Center, allowing for a more complete collection of the debris. Initially, residues from two hand grenades were analyzed for explosives and metals by the U.S. Army Engineer Research and Development Center, Vicksburg. Residues from 30 hand grenades were analyzed for explosives and metals content. On average, the mass of RDX associated with the hand grenade residue was 0.366 mg with a 101-percent recovery of the iron that composes the steel grenade shell. The results from this study will help determine the potential soil loading of residuals on grenade training ranges.

15. SUBJECT TERMS
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