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Continuous Treatment of Low Levels of TNT and RDX in Range Soils Using Surface Liming

Philip G. Thorne, Thomas F. Jenkins, and Michael K. Brown

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Prepared for U.S. ARMY ENVIRONMENTAL CENTER, AT DIVISION

ABSTRACT

Significant quantities of residual energetics are deposited on surface soils at live-fire ranges. Most of these residues come from bulk composition left over following low-order detonations. Of particular concern is RDX, which is environmentally persistent and mobile, and can therefore lead to groundwater pollution. Base hydrolysis can be used to rapidly decompose TNT and RDX in aqueous solutions. Hydrolysis of TNT produces soluble and insoluble polymers, while hydrolysis of RDX releases simple inorganic ions. It is reasonable to expect that similar chemical reactions could be used to decontaminate explosives residues in situ on contaminated range soils. This project investigated surface application of agricultural lime to hydrolyze residual energetic materials (including TNT, RDX, HMX, and 2,4-DNT) that had been deposited on shallow soils at a hand grenade training range. Laboratory experiments conducted using soil samples from the range indicated that lime could be used to destroy all of the TNT and most of the RDX. Results of the laboratory experiments were used to guide field trials at the range. Unfortunately, the heterogeneous distributions of residual TNT and RDX were so great that statistically significant results could not be demonstrated using samples collected from shallow surface soil. Lime applications are continuing at this site. Samples from below the depth of active soil deposition and mixing (cratering) should be collected in the future using remote-controlled equipment. Such samples should reveal whether the lime treatment reduces the downward migration of energetics residuals from the surface.

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PREFACE

This report was prepared by Philip G. Thorne, Senior Scientist, Applied Research Associates, South Royalton, Vermont; Dr. Thomas F. Jenkins, Research Chemist, U.S. Army Engineering Research and Development Center (ERDC), Cold Regions Research and Engineering Laboratory (CRREL), Hanover, New Hampshire; and Michael K. Brown, Environmental Engineer, U.S. Army Center for Health Promotion and Preventive Medicine–West (CHPPM–West), Fort Lewis, Washington.

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The Commander of the Engineer Research and Development Center is Colonel James R. Rowan, EN. The Director is Dr. James R. Houston.

Continuous Treatment of Low Levels of TNT and RDX in Range Soils Using Surface Liming

PHILIP G. THORNE, THOMAS F. JENKINS, AND MICHAEL K. BROWN

1 INTRODUCTION

Studies by U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) researchers have revealed that significant quantities of residual energetics can be deposited on surface soils at impact areas at live-fire ranges (Jenkins et al. 1997, Jenkins et al. 2000). The largest mass of these residues appears to come from bulk composition left over from low-order (partial) detonations and munitions that rupture, but do not detonate. Routine clearance of low-order detonation debris and ruptured rounds could remove a large portion of these point sources of energetic contamination, but the small particles of these compositions that are also dispersed onto surface soils would remain. Of particular concern is RDX, which is environmentally persistent and mobile, and can, under some conditions, lead to groundwater pollution.

Recent publications (Heilmann et al. 1996, Saupe et al. 1998) have reported that base hydrolysis using substantial quantities of sodium hydroxide at elevated temperatures could be used to rapidly decompose bulk TNT and RDX in aqueous solutions. Hydrolysis of TNT produced polymers of molecular weight (MW) 1,000–30,000 daltons. Hydrolysis of RDX released the nitro groups and ruptured the triazine ring. Further rearrangements produced acetate, formate, and ammonium ions, and nitrogen and nitrogen oxide gases. It is reasonable to expect that similar chemical reactions could occur in situ in soils with a milder base (albeit at a slower rate). Mild base hydrolysis of TNT produced very large, complex polymers that eventually become insoluble. These polymers were analyzed by NMR and resembled the products of TNT-humification during composting (Thorn et al. in press). Therefore, in-situ base hydrolysis using lime should represent a remedial strategy that can be used to prevent past and future live-fire activities from contaminating groundwater with energetic materials.

The use of agricultural lime as an inexpensive, in-situ remediation technique is an appealing solution to this problem. In the case of active ranges the challenge

is not only to remediate the accumulated residues, but also to prevent future contamination. To address this need, periodic applications of lime could be added to routine clearance activities, particularly for areas where low-order detonations have taken place. This type of treatment appears to be particularly appealing for hand grenade ranges. This approach would also allow the range to be used while the treatment proceeds.

This project investigated surface application of lime to hydrolyze residual energetic materials (including TNT, RDX, HMX, and 2,4-DNT) that had been deposited on shallow soils at a hand grenade training range. Recent research has shown that hand grenade ranges are contaminated with significant levels of TNT and RDX from low-order detonations of grenades containing Composition B (60% RDX/39% TNT), or blow-in-place operations to destroy duds (Jenkins et al. 2001, Hewitt et al. in press). Laboratory experiments were conducted using soil samples from a hand grenade range that were contaminated with TNT and its environmental degradation products, RDX, HMX, and 2,4-DNT. Results of the laboratory experiments were used to guide field trials at a currently active range. The potential to remediate existing contamination at grenade ranges and to prevent future contamination was assessed.

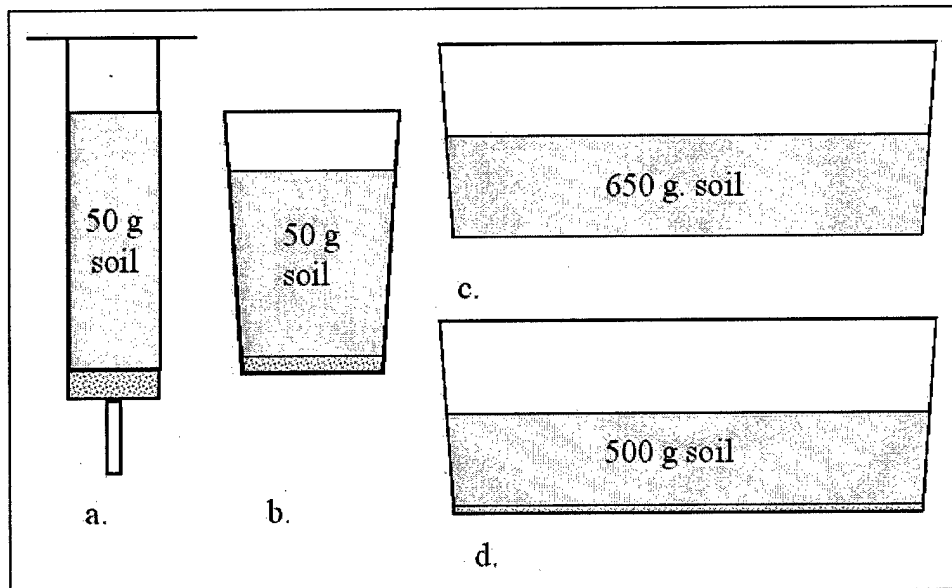
2 INITIAL EXPERIMENTS PERFORMED AT CRREL PRIOR TO THIS PROJECT

Soil samples and leachates were analyzed using EPA Method 8330. Acetate, formate, and nitrite were analyzed as protonated acids using an LC-C18 column with an eluent composed of 2% acetonitrile in pH 2 water.

Preliminary experiments with room temperature aqueous solutions that contained low amounts of agricultural lime (calcium oxide) produced results similar to those produced by German researchers, but at a slower rate (Heilmann et al. 1996, Saupe et al. 1998). A second series of experiments was conducted using lime to produce conditions of high pH in soil columns and slurries using soil from an explosives load, assemble, and pack facility (Iowa Army Ammunition Plant [IAAAP]) that was contaminated with explosives: HMX = 3.8 mg/kg, RDX = 6.3 mg/kg, TNT = 43.4 mg/kg. The results were as follows:

(1) A mixture of 50 g of IAAAP soil + 10%-volume lime + 50 mL of reagent-grade water was placed in 250-mL flasks on a shaker table for 21 days. The control contained the same soil and volume of water but no lime. At the end of the experiment, the slurries were air-dried, homogenized, subsampled, and extracted with water for the ionic compounds or acetonitrile for the residual explosives. In the lime slurries, TNT and RDX concentrations were reduced to below detection limits, while HMX was reduced to 2.6 mg/kg. Formate, acetate, and nitrite were recovered in the leachates. There was no degradation of explosives observed for the control sample.

(2) A mixture of 50 g of IAAAP soil + 10%-volume lime was placed in 60 mL (9.5-cm × 2.5-cm) syringes and brought to field capacity (Fig. 1a). The control contained no lime. A simulated rain event of about 1 cm (15 mL water) was applied on Days 1, 2, 5, 10, and 21. Leachates were collected and analyzed. There were substantial quantities of formate (5.1 mg), acetate (6.3 mg), and nitrite (1.1 mg) recovered in the leachates from the syringes containing lime. At the end of the experiment, samples were treated as above for the slurries. RDX concentration was reduced to 0.67 mg/kg, HMX was unaffected, and TNT concentration was reduced only to 36.2 mg/kg. No degradation of explosives in the control was observed. We postulated that the mass of acids and nitrite came from the hydrolysis of a few RDX crystals that happened to be in proximity to wetted lime particles. The greater reductions in explosives concentrations that occurred in the slurries most likely resulted from the hydrolysis of explosives as they dissolved in water that had dissolved the lime.



a. 60-mL syringe with glass wool plug.

b. Plastic cup with filter paper drain.

c. Shallow dish without drain.

d. Shallow dish with porous foam drain.

Figure 1. Soil columns.

The results achieved from our preliminary experiments suggest that the use of agricultural lime on ranges may be a feasible and highly cost-effective remediation strategy warranting further study.

3 FORT LEWIS TREATABILITY STUDY AT ARA

Soils and leachates were analyzed using Method 8330.

Assessing the treatability of hand grenade range soils proved to be quite a bit more challenging than anticipated. The soils from Fort Lewis were extremely fine sand that tended to form a compact soil column through which water percolated very slowly. The sieving that was performed to remove large gravel and metallic debris > 1 mm and to promote homogeneity of subsamples for soil columns exacerbated this characteristic.

The first set of columns was filled to 1.5 cm with 50 g each in plastic cups, perforated for drainage beneath disks of filter paper (Fig. 1b). Treatments and wetting regimes were set up in triplicate as follows:

Moisture Regimes

- WD** = Wet/dry-wetted to saturation, then left uncovered to dry (four cycles).
- S** = Saturated and covered to prevent drying.
- R** = Saturated + 1 cm "rain"—Leachate collected, then covered to prevent drying (four events).

Treatments

- C** = No treatment other than the applied moisture.
- LS** = Lime sprinkled on top of soil 1 g/50 g (equivalent to 2 tons/acre).
- LM** = Lime mixed through soil 1 g/50 g.

The **LM** treatment was added to investigate a "best case" where lime was mixed into the soil to some depth. In actual practice, the hand grenade range at Fort Lewis was so heavily used that the lime applied to the surface was mixed down a few inches by the continual redistribution of soil in and out of craters. The four events were spread over two weeks. Leachate was collected and analyzed by Method 8330 for explosives. At the end of two weeks the entire contents of the columns were dried and extracted with acetonitrile, then analyzed. The first set of columns proved to be too small to overcome the heterogeneity of these soils (Table 1a).

The second set of soil columns was two 15-cm-square shallow plastic trays filled to 2.5 cm with 650 g of soil that was rained on five times over two weeks, decanted to drain, and then allowed to dry out over several days (Fig. 1c). The

treatments were control and lime mixed into the soil. Leachate was collected and analyzed. At the end of two weeks the columns were dried, homogenized, subsampled (3×10 g), and analyzed (Table 1b). The result of the 650-gram trays was apparently that natural biological action promoted by the extended wetted times resulted in anaerobic reducing conditions so that the untreated controls were remediated at the same rate as the lime-treated soils. Furthermore, some nitroso-RDX breakdown products were generated in the decanted supernatant, reinforcing the theory that anaerobic conditions had been produced.

The third and final set of columns consisted of trays constructed as above using 500 g of soil and an efficient porous bottom so that the columns drained within a day and could dry out before anaerobic conditions were produced (Fig. 1d). These columns were rained on five times over two weeks, with the leachate collected as above. At the end, the columns were dried, homogenized, subsampled (8×10 g), and analyzed (Table 1c). There was a 75% reduction in RDX for the lime treatment compared to control soils after five rainfall events over two weeks. No reduction in HMX concentration was observed. Unfortunately, there was still some RDX and traces of nitroso-RDX (never more than 1–2% of the RDX) in the leachate from control and some RDX in the limed column leachate—although less than from the control. Nearly 25% of the RDX leached from both control and treatment columns during these “events” that simulated soaking rains that exceed field capacity, alternating with dry conditions when the lime wouldn’t be working. HMX was not detected in the leachate because of interferences present in the C18 primary LC column and non-detectable concentrations in the CN confirmatory column. TNT was completely removed from the limed soil and appeared only in the initial leachate in equal concentration to the initial control leachate. RDX occurred in every subsample at concentrations that were not correlated with the TNT, supporting the hypothesis that low-order detonations can produce soil contamination that does not reflect the %-composition of the starting fill material. The uncorrelated occurrence of RDX and TNT is due to the structure of Composition B, which is manufactured by suspending particles of RDX in melted TNT. In low-order detonations, ejected Composition B residuals weather unequally—the TNT is washed away first, leaving intact grains of RDX that are gradually shed onto the surface soil.

Although the third set of experiments was completed with less anaerobic reduction, there was still some nitroso-RDX in the leachate. A brief set of cup columns with 50 g was constructed with adequate drainage and watered with *aerated* reagent-grade water. The use of aerated water appeared to eliminate the formation of the nitroso transformation products of RDX.

Table 1. Residual energetic material remaining in soils after treatment (mg/kg).			
a. 50-g columns	HMX	RDX	TNT
Soil-Initial	2.6	10.1	0.3
Control-Wet/Dry	3	14.3	8.5
Control-Saturated	3.2	14.8	0.4
Control-Rain	0.9	2.2	0.8
Surface Lime-Wet/Dry	1.1	0.8	0.1
Surface Lime-Saturated	0.3	0.4	0.1
Surface Lime-Rain	0.6	1.7	0.1
Mixed Lime-Wet/Dry	0.7	1.2	1.8
Mixed Lime-Saturated	1.3	6.6	0.8
Mixed Lime-Rain	0.6	2.9	0.2
b. 650-g columns	HMX	RDX	TNT
Soil-Initial	1.4	6.6	0.7
Control-Wet/Dry	0.3	0.4	0.1
Mixed Lime-Wet/Dry	0.4	0.5	1.1
c. 500-g columns	HMX	RDX	TNT
Control Rep 1	0.97	5.47	0.76
Control Rep 2	0.98	6.25	<0.1
Control Rep 3	0.89	11.1	0.36
Control Rep 4	1	7.64	2.73
Control Rep 5	0.93	19.6	<0.1
Control Rep 6	0.94	3.85	<0.1
Control Rep 7	0.99	7.12	<0.1
Control Rep 8	1.04	15.6	29.7
Mean mg/kg	0.97	9.58	8.39
SD	0.05	5.47	14.25
Total mass (mg)	0.484	4.789	4.194
mg in leachates	Interference	1.355	0.018*
3% Lime Rep 1	1.03	2.44	
3% Lime Rep 2	0.95	4.42	<0.1
3% Lime Rep 3	1.08	2.42	<0.1
3% Lime Rep 4	0.89	1.92	<0.1
3% Lime Rep 5	1.09	2.31	<0.1
3% Lime Rep 6	1.03	2.25	<0.1
Mean mg/kg	1.01	2.63	<0.1
SD	0.08	0.9	
Total mass (mg)	0.506	1.313	
mg in leachates	Interference	1.096	0.015*
* TNT in first leachate only			

Description of the grenade range

The hand grenade range at Fort Lewis, Washington, is divided into four launching and impact bays separated by concrete and wooden walls (Fig. 2). The soil in the grenade impact area is a coarse gravelly sand with cobbles as large as 15 cm. Grasses sparsely cover areas not recently affected by range use. The four impact areas within the grenade range are consecutively numbered, and based on the numbers of craters in each, appear to have been used to a similar extent. There are no records available to differentiate usage rates in the discrete bays. Records obtained from Fort Lewis Range Operations indicate that approximately 12,000 to 15,000 grenades are thrown on the range each year, or about 3,000 to 3,750 grenades per launching area per year.



Figure 2. Bay 3 of the hand grenade range on Fort Lewis, Washington.

Currently, about 95% of the hand grenades detonated on this range are M67 fragmentation grenades, which are the type of hand grenade currently used by the U.S. Army (Fig. 3). The other 5% of the grenades used at this range are of Canadian and British manufacture and used by Canadian and British troops who train regularly at Fort Lewis. The Canadian hand grenade, model C7, is manufactured to the same specification as the M67. The current British hand grenade, Model L2, is based on the older U.S. M26 hand grenade.

The M67 and C7 grenades contain 186 g of Composition B as the main charge. Military-grade RDX generally contains HMX as the major impurity, with concentrations ranging from 8 to 12% (U.S. Army 1984). Military-grade TNT is about 99% 2,4,6-trinitrotoluene with the remainder made up of other isomers of

TNT, the various isomers of dinitrotoluene (2,4-DNT being the most abundant), 1,3-dinitrobenzene, and 1,3,5-trinitrobenzene (TNB) (Jenkins et al. 2001). Therefore, each grenade contains about 101 g of RDX, 11 g of HMX, and 72 g of TNT, with less than a gram of 2,4-DNT, TNB, and other impurities in the main charge. The M26 and L2 grenades contain about 84 g of RDX, 9 g of HMX, 60 g of TNT, and 0.6 g of 2,4-DNT and other impurities.

Over the last four years unexploded ordnance cleanup practices (detonation of duds and low-order detonations) involved the use of C-4 explosive (91% RDX). In years prior to the use of C-4, TNT was used for this activity.

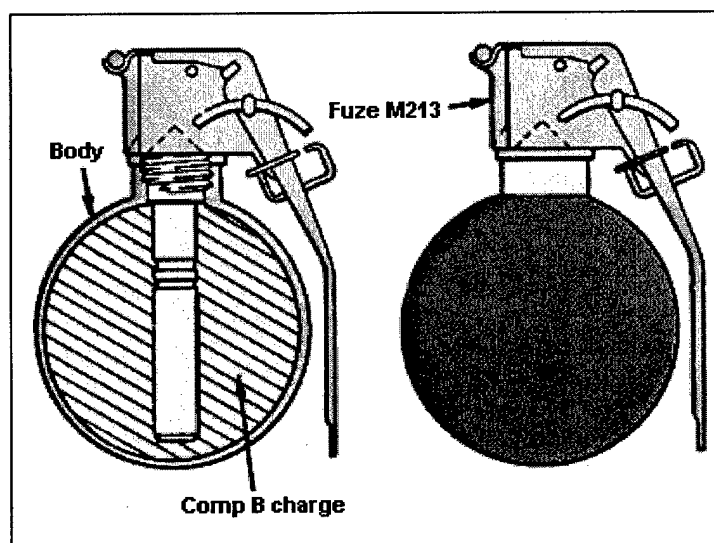


Figure 3. M67 fragmentation grenade.

Sampling procedures

The nature of energetic materials as contaminants must be taken into consideration for all aspects of environmental sampling, preservation, and analysis (Thiboutot et al. 2002). Energetic materials are solids at room temperature, and contamination often occurs as particles. These compounds migrate only as they slowly dissolve in precipitation. Therefore, the highest levels of energetic materials residue are present at or near the surface of the soil, even at locations that have remained dormant for many years after contamination occurred (Thiboutot et al. 2002). The crystalline nature of energetic materials and their likely association with munition casing fragments often result in a heterogeneous distribution of contaminant particles in the source region (Jenkins et al.

2001, Thiboutot et al. 2002). To address the spatial variability of the study area, composite sampling was employed during this investigation.

Figure 4 displays the generalized sampling scheme for this investigation. Bay 2 served as the control area while Bay 3 was the treatment area. A 100-square-meter sampling area in each bay was delineated and marked to ensure replication both before and after treatment.

Each sampling area ($10\text{ m} \times 10\text{ m}$) was sampled before and after treatment. Samples consisted of five composite samples of 50 random scoops per sampling container; thus, a total of 10 soil samples was collected during each sampling event. Soil samples were collected using stainless-steel hand shovels that were carefully wiped with a clean paper towel, washed with acetone, and air-dried between samples.

As samples were collected they were placed in pre-cleaned plastic bags and overnight-shipped to the laboratory in ice-filled coolers. Upon arrival at the U.S. Army Cold Regions Research and Engineering Laboratory, the samples were frozen at -30°C until extraction and analysis, which were performed within two weeks.

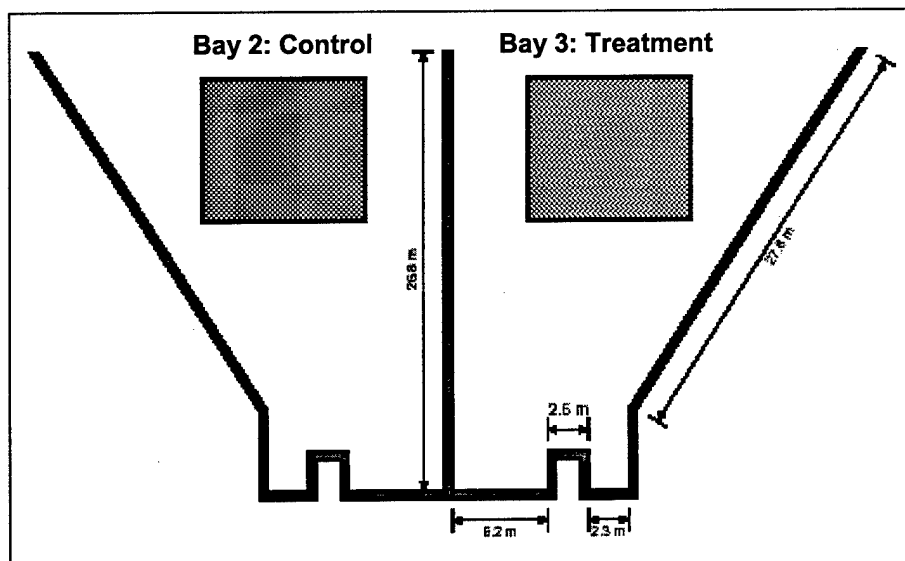


Figure 4. Hand grenade range, Bays 2 and 3. Lime was applied only to Bay 3. Each sampling area ($10\text{ m} \times 10\text{ m}$) was sampled before and after treatment. Five composite samples of 50 random samples per event were taken.

Application procedures

Initially, calcium carbonate was applied to a 10-m × 10-m square located in the middle of the target area (Fig. 4). This was due to supplier limitations. Two applications of 500 pounds each were applied in November 2001 and February 2002 using two different methods. For the first application, the lime was mixed with 700 gallons of water and sprayed from behind the throwing wall (Fig. 5). This resulted in saturated soil conditions and subsequent puddling of lime solution in the craters. The second application was done by mixing the 500 pounds in 500 gallons of water and delivering the slurry through a hose carried into the target area. This resulted in a much more uniform deposition of lime that did not run into the low spots.

In August 2002, calcium hydroxide was applied through a hose as a slurry to the treatment area by mixing 500 pounds in 400 gallons of water. This quantity was equivalent to a typical agricultural application rate of 4.2 tons/acre and likely produced a soil pH of over 12.



Figure 5. Lime application using a hydro-seed spreading cannon.

Sample analysis procedure

Numerous studies have addressed the optimization of sampling and analysis for explosives in soil and water (Thiboutot et al. 2002). For determination of energetic analytes, U.S. EPA Method 8330 (HPLC) is preferred; however, when analyzing samples suspected of being contaminated with trace levels (low $\mu\text{g}/\text{kg}$) of energetic materials, gas chromatography coupled to an electron capture detector (GC-ECD, U.S. EPA Method 8095) is preferred.

Soil samples were collected on 19 December 2001, 1 March 2002, 18 August 2002, and 31 October 2002 and sent to the U.S. Army Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire, for processing and analysis by methods 8330 and 8095.

Field trial results

Results are listed in Appendix A and summarized in Table 2. After each application the differences between the treated and untreated bays were slight. The concentrations of the energetic materials residue in the treated bay were higher than those observed in the untreated bay. The relative standard deviation of sample concentrations was very high, and in some cases larger than the mean.

The variability of analyte concentrations for the samples taken one month after the second, more uniform application was lower and did indicate a reduction in TNB, RDX, and TNT. The apparent reduction in HMX was within the standard deviation of mean values.

During the final treatment, the concentrations of each energetic compound were elevated in the treated bay when compared to the previous sampling events. During this trial calcium hydroxide was applied to the grenade range after significant training had occurred during the summer months.

Table 2. Summary of treatment effectiveness. Mean values reported in mg/kg.					
		HMX	TNB	RDX	TNT
19 December 2001					
Control	Bay 2	0.206 ± 0.106	0.071 ± 0.027	0.682 ± 0.930	2.755 ± 2.430
Limed	Bay 3	0.269 ± 0.176	0.041 ± 0.013	1.062 ± 1.181	1.217 ± 1.691
% Reduction		-30.7	41.7	-55.8	55.8
1 March 2002					
Control	Bay 2	0.135 ± 0.082	0.033 ± 0.027	0.457 ± 0.642	0.837 ± 1.871
Limed	Bay 3	0.111 ± 0.141	0.018 ± 0.016	0.135 ± 0.910	0.140 ± 1.250
% Reduction		17.4	46.7	70.5	83.2
31 October 2002					
Control	Bay 2	0.205 ± 0.079	0.022 ± 0.026	0.444 ± 0.552	0.227 ± 1.731
Limed	Bay 3	0.271 ± 0.128	0.035 ± 0.146	1.960 ± 0.830	2.999 ± 3.835
% Reduction		-32.5	-60.6	-341.5	-1221.1

4 FIELD TRIAL DISCUSSION

This treatment technology has been shown to effectively degrade energetic materials in a number of situations including energetic materials in water and energetic materials in soils (Emmrich 1999, Felt et al. 2001). The results reported here suggest that the combination of an uneven distribution of the lime solution, and continual deposition of energetic material from use of the range, made it difficult to demonstrate that the lime application was having an effect on reduction of these compounds.

Rainfall during the winter in the Northwest is fairly continuous. The ground rarely dries out. This has both positive and negative impacts on this treatment approach. Both the energetic material and the lime must be in solution in order to react. Since the kinetics of energetic material dissolution is slow, a constantly wet environment favors the hydrolysis of the energetic material (Felt et al. 2001). Alternatively, if rainfall causes too many days of saturated soil conditions, the dissolved lime will be washed into the subsurface, away from the energetic materials. This condition is common from November to March. By March, soil samples had fairly similar pH: 8.0 for the untreated and 8.4 for the treated bays. It is possible that this rainfall effect reduced the treatment effectiveness.

To compensate, the third treatment was applied to the hand grenade range during August 2002. Unfortunately, very little moisture was present in the soil during the summer months in the Northwest. A result of this lack of moisture was that the lime completely dried out, thereby causing a crusting effect. Successive hand grenade detonations resulted in relocating a significant portion of the lime away from the treatment area, further reducing the treatment effectiveness.

Hand grenade training continued throughout the application periods, as it would if the method were to be executed on any active firing range. Although the analytical and sampling procedures employed during this investigation were rigorous, overcoming the large spatial variability in the distribution of energetic materials on the range remained daunting. An addition of energetic material could mask the effectiveness of the method. For example, one low-order detonation of an M67 fragmentation grenade could add 93 g of Composition B to the treatment area, if only fifty percent of the main charge was consumed during the blast. It is likely that the continued addition of energetic materials to the range during this investigation confounded the treatment effect.

Finally, chemical weathering, energetic blast deposition, and the chemical properties of the material affect the occurrence of energetic materials contamination on the range. In low-order detonations, ejected Composition B residuals

weather unequally depending on the size, shape, and location of the material. The uncertainty associated with the distribution of post-blast energetic material residues resulting from low-order detonations significantly limits the ability to quantify impacts to the treatment area and the methodology used during this investigation. Although six composite samples were taken each time from both treatment and control bays, the heterogeneity of the surface samples was too great to allow conclusions to be drawn regarding the effectiveness of the treatment. It is believed that samples taken from several feet below the depth of cratering would provide the information needed to observe if the lime treatment does, in fact, reduce the amount of TNT and RDX that is percolating downward beneath this active live-fire range.

Lime treatment might offer several advantages to remediation of energetic materials on active training lands. These advantages include (a) a cost saving due to limited material handling, (b) the equipment needed to implement this technology is commercially available, (c) the lime treatment eliminates the hazards of human exposure to UXO, (d) an elimination of toxicity caused by inhalation and skin contact associated with excavation and material handling (Felt et al. 2001), and (e) the range can continue to be used as the treatment proceeds.

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APPENDIX A: FORT LEWIS HAND GRENADE RANGE DATA

Table A1. Bay 2: Control. All values reported are in mg/kg.						
Sampling Date	Sample	Replication	HMX	TNB	RDX	TNT
19 December 2001	1 February	Rep 1	0.158	0.053	0.115	0.929
		Rep 2	0.166	0.052	0.095	0.865
	2 February	Rep 1	0.394	0.116	2.44	7.37
		Rep 2	0.411	0.123	2.43	7.08
	3 February	Rep 1	0.204	0.052	0.382	1.18
		Rep 2	0.177	0.052	0.43	1.27
	4 February	Rep 1	0.144	0.06	0.213	1.9
		Rep 2	0.13	0.061	0.175	1.91
	5 February	Rep 1	0.145	0.072	0.282	2.58
		Rep 2	0.13	0.066	0.256	2.47
		Mean	0.206	0.071	0.682	2.755
		SD	0.106	0.027	0.930	2.430
1 March 2002	1 February	Rep 1	0.088	0.026	0.252	0.614
		Rep 2	0.108	0.028	0.266	0.58
	2 February	Rep 1	0.142	0.032	0.874	0.788
		Rep 2	0.164	0.034	0.846	0.876
	3 February	Rep 1	0.128	0.034	0.492	1.54
		Rep 2	0.15	0.034	0.552	1.07
	4 February	Rep 1	0.098	0.05	0.276	0.596
		Rep 2	0.106	0.028	0.292	0.788
	5 February	Rep 1	0.18	0.032	0.374	0.72
		Rep 2	0.184	0.032	0.344	0.798
		Mean	0.135	0.033	0.457	0.837
		SD	0.082	0.027	0.642	1.871
31 October 2002	1 February	Bay 2-1	0.204	0.02	0.288	0.364
		Bay 2-2	0.212	< 0.02	0.306	0.08
	3 February	Bay 2-3	0.2	0.024	0.572	0.302
	4 February	Bay 2-4	0.202	< 0.02	0.48	0.342
	5 February	Bay 2-5A	0.192	0.024	0.5	0.128
		Bay 2-5B	0.218	0.02	0.518	0.146
		Mean	0.172	0.046	0.559	1.506
		SD	0.074	0.026	0.552	1.731

Table A2. Bay 3: Control. All values reported are in mg/kg.							
Sampling Date	Sample	Replication	HMX	TNB	RDX	TNT	
19 December 2001	1 March	Rep 1	0.16	0.056	0.3	4.25	
		Rep 2	0.151	0.063	0.274	4.45	
	2 March	Rep 1	0.587	0.05	2.85	0.929	
		Rep 2	0.515	0.045	2.751	0.82	
	3 March	Rep 1	0.142	0.029	0.125	0.075	
		Rep 2	0.138	0.032	0.116	0.081	
	4 March	Rep 1	0.358	0.036	1.996	0.734	
		Rep 2	0.379	0.048	1.985	0.764	
	5 March	Rep 1	0.124	0.027	0.117	0.033	
		Rep 2	0.137	0.026	0.108	0.032	
			Mean	0.269	0.041	1.062	1.217
			SD	0.176	0.013	1.181	1.691
	1 March 2002	1 March	Rep 1	0.088	0.014	0.118	0.098
			Rep 2	0.096	0.01	0.114	0.084
2 March		Rep 1	0.106	0.04	0.16	0.104	
		Rep 2	0.138	0.014	0.176	0.1	
3 March		Rep 1	0.142	0.014	0.174	0.118	
		Rep 2	0.166	0.014	0.2	0.082	
4 March		Rep 1	0.11	0.016	0.122	0.092	
		Rep 2	0.1	0.018	0.13	0.076	
5 March		Rep 1	0.076	0.018	0.068	0.274	
		Rep 2	0.092	0.018	0.086	0.376	
			Mean	0.111	0.018	0.135	0.140
			SD	0.141	0.016	0.910	1.250
31 October 2002		1 March	Bay 3-6	0.188	0.394	0.49	10.36
		2 March	Bay 3-7	0.218	0.074	0.574	0.948
	3 March	Bay 3-8	0.378	0.33	1.5	11.16	
	4 March	Bay 3-9	0.292	0.148	0.86	6.98	
	5 March	Bay 3-10A	0.278	0.516	0.528	11.18	
		Bay 3-10B	0.246	0.522	0.48	11.74	
			Mean	0.203	0.089	0.656	2.341
			SD	0.128	0.146	0.800	3.835