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COMPARISON OF INNOVATIVE TECHNOLOGIES FOR SOIL CLEANUP AT CAMP EDWARDS, MASSACHUSETTS MILITARY RESERVATION

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ABSTRACT

An Innovative Technology Evaluation (ITE) Program was conceived by the Army National Guard in March 2000 to investigate the potential for remediation of explosives-contaminated soil at the Camp Edwards Training Area on the Massachusetts Military Reservation (MMR). In addition, the lessons learned from the technologies studied at this site may have applicability to similar armed services training installations.

Soil remediation technologies participating in the ITE program include: soil washing, low temperature thermal desorption/destruction (LTTD), composting, bioslurry, solid phase bioremediation, chemical oxidation, and chemical reduction. The focus of the study was the destruction of Royal Demolition Explosive (RDX) and High Melting Explosive (HMX), which pose a potential threat to groundwater at the site.

Soil washing was implemented as a field demonstration for remediation of Rapid Response Action soils as part of ongoing characterization and remediation efforts. Innovative technologies may be implemented as a secondary treatment after soil washing. The ITE studies were therefore performed for all technologies using washed soil. The composting, solid phase bioremediation, and LTTD studies were also performed on untreated soils.

Results indicated that all technologies are likely to be effective on washed soils. LTTD was successful on untreated soil, with the exception of an inability to degrade HMX at low temperatures. The composting and solid phase bioremediation studies experienced difficulties in degrading RDX and HMX in the untreated soils, likely due to the presence of particulate explosives.

1. INTRODUCTION

The Massachusetts Military Reservation (MMR) is a 21,000-acre facility located on Cape Cod, Massachusetts. Approximately 14,000-acres of MMR constitute the Camp Edwards Training Ranges and Impact Area. Target practice and other range training operations have historically occurred at Camp Edwards. Such activity resulted in wide dispersion of low concentrations of spent munitions, propellants, explosives, and heavy metals in particulate form at Camp Edwards.

On January 7, 2000, the United States Environmental Protection Agency (USEPA) Region 1 issued an Administrative Order (AO#3) to the National Guard Bureau (NGB) and Massachusetts Army National Guard (MAARNG). AO#3 specifies that a series of Rapid Response Actions (RRAs) be implemented to protect groundwater at Camp Edwards. The overall goal of the RRA is to eliminate current and potential sources of contaminants to the aquifer from soils and sediment in Areas of Concern (AOCs) identified by USEPA.

2. INNOVATIVE TECHNOLOGY EVALUATION PROGRAM

As part of the RRA, the NGB voluntarily instituted an Innovative Technology Evaluation (ITE) program to study technologies that might meet the requirements for remediating soil and groundwater at the site. Successful innovative technologies were defined, for the purpose of the soils studies, as those technologies that can meet the requirements of AO#3 to address the identified AOCs.

In developing recommendations for ITE studies, the NGB assembled an ITE review team, including NGB, the Army Corps of Engineers (ACE), the Army Environmental Center (AEC), and AMEC Earth and Environmental, Inc. (AMEC) as the supervising contractor. The team developed selection criteria by which to assess potential remediation technologies and recommendations of technologies to participate in the treatability studies. The major criteria included:

- Experience with treatment in soils,
- Experience with explosives,
- Level of clean-up achieved, and
- Time frame to complete clean up.

Soil cleanup goals established for the RRA were used as goals for the ITE studies. Some of these goals include:

- RDX 120 μg/kg
- HMX 250 μg/kg
- TNT 250 μg/kg
- Dieldrin 246 μg/kg
- Lead 300 mg/kg

The team incorporated experience with a soil washing technology already demonstrated on the site by Brice Environmental Services Corporation (Brice) as part of the RRA. In soil washing, the fraction of the soil containing the contaminants of concern can be isolated and segregated from the remaining clean soil. Because this process may be implemented at Camp Edwards, it was determined that separate studies would be performed on washed soil and untreated soil from the site. The technologies chosen for the study were:

1) Chemical Oxidation - Brice, subcontracting to University of Nebraska-Lincoln (UNL),
2) Chemical Reduction - Brice / UNL,
3) Thermal Desorption/Destruction (LTTD) - TerraTherm Inc., subcontracting to Kiber Environmental Services (Kiber),
4) Solid Phase Bioremediation - Grace Canada, Inc. (Grace),
5) Composting - BSI Environmental, Inc. (BSI), subcontracting to Woods End Laboratory (WEL), and
6) Bioslurry – Envirogen, Inc.

3. ISSUES FACING THE SOIL TREATABILITY STUDIES

Several difficulties arose during the course of the studies. First, the distribution of explosives residues results in wide variations in contaminant concentrations in Camp Edwards soils. This distribution has the following characteristics: (a) detectable concentrations range from several orders of magnitude for RDX and HMX from 120 μg/kg to 3,700,000 μg/kg; (b) a small number of highly concentrated samples bias the mean value of RDX towards higher concentrations; and (c) duplicate soil samples tend to show high variability. This is consistent with other studies (Jenkins et al., 1996 and 1997). The heterogeneous nature of the contamination was taken into consideration when reviewing the analytical results for the studies. In addition, the ability of a technology to address explosives in particulate form was addressed during evaluation.

Second, explosive contaminants do not adsorb onto the sandy soil grains at Camp Edwards. In addition, after soil washing and perhaps as a result of soil washing, a significant proportion of explosive contaminants tened to be located with the process water and organic matter. Thus, if soil washing is to be considered as a first step in a treatment train, it may be that the particulate nature is mitigated to some extent by the soil washing and explosive contaminants may be successfully isolated into the organic matter and process water.

Third, coagulants used in the soil washing process for more efficient recovery of soil fines strongly imbibe water but are not readily soluble during laboratory extraction of contaminants for analysis. Therefore, any RDX or HMX sorbed by coagulants during soil washing may have been inaccessible for extraction.

4. LABORATORY STUDIES

Brice/UNL tested thee remedial alternatives on washed soils only. Post Treatment was designed to simulate the reductive treatment of soil after the soil washing process, by adding 5% zerovalent iron (ZVI) (mass:mass) in the form of iron filings, acetic acid, and aluminum sulfate solution to washed soils in a mixture maintained at 60% solids (Singh, Comfort and Shea, 1998). Slurry Treatment was designed to simulate reductive treatment within the soil washing process, in a slurry of approximately 7% solids. For the third treatment, Fenton's Reagent (hydrogen peroxide and ferrous sulfate) in concentrations of between 1% and 4% hydrogen peroxide was added to a 7% soil slurry to oxidize contaminants (Li et al., 1997).

BSI tested composting technology on both the washed and unwashed soils. Twelve reactors were maintained for the study. Each reactor contained approximately 30% soil and 70% organic matter, including various forms of manure, cranberry mash, and wood chips. The washed soil reactors were maintained for 12 days and those for the unwashed soils were maintained for 45 days.

Grace performed treatability studies on both washed and unwashed soil. Two separate treatments of the proprietary DARAMEND® treatment were tested on both types of soil. In addition, powdered iron was added to the soil to control the redox potential and calcium oxide was added to adjust the pH. An initial 2% application of DARAMEND® was added soil, as well as 0.2% powdered iron. Weekly amendments of 0.5% DARAMEND® and 0.2% powdered iron were added to the soil.

TerraTherm tested a proprietary LTTD process on both washed and unwashed soil, which involves slowly heating soil to between 200° and 300°C, and holding for a minimum of 24 hours at the elevated temperature.

Envirogen tested a bioslurry process on unwashed soil. Molasses was added to a slurry of 25% soil and 75%

water at a ratio of 0.3% (mass:mass). Results were not complete at the time this report was prepared, and are therefore not included here.

5. RESULTS

Washed soils. In general, the studies on washed soils showed reductions of RDX, there being little or no detectable concentrations of HMX in the initial samples. Of concern in these studies is that the original concentration of RDX in samples sent to subcontractors was fairly low, averaging 590±30 μg/kg, and initial concentrations in soil as received by the subcontractors was approximately 160 μg/kg. Because the laboratory detection limit was 120 μg/kg, it is difficult to conclude that the technologies achieved a reduction in RDX, even though the final results were all below the detection limit.

Figures 1 and 2 show results for the chemical oxidation and reduction studies, both of which were performed using only washed soil.

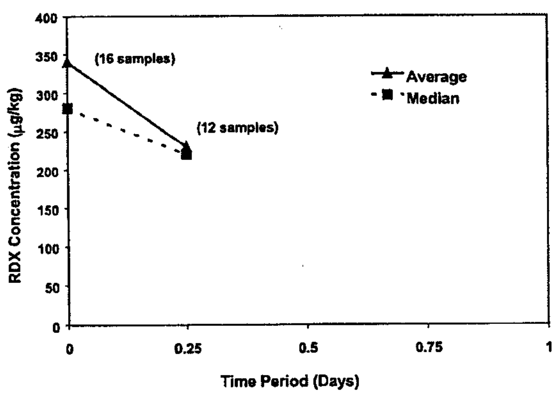

Figure 1. Chemical oxidation results, washed soils - Brice/UNL

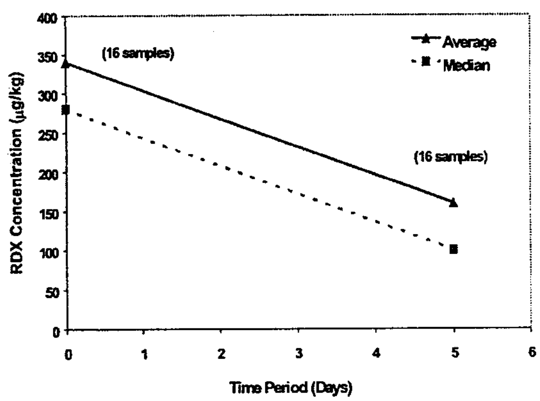

Figure 2. Post treatment chemical reduction results, washed soils - Brice/UNL

Chemical oxidation did not reduce explosives concentrations below RRA soil cleanup goals. Therefore, no further study of this process was made. Chemical reduction was shown to be effective in reducing RDX concentrations to below RRA soil cleanup goals. Results for Slurry Treatment were similar to Post Treatment tests. Results suggest that the iron plus aluminum sulfate treatment was the most effective and yielded results below RRA soil cleanup goals for explosive compounds.

Untreated soils. In general, the studies on unwashed soils showed varying success in reducing RDX concentrations. Figures 3, 4, and 5 display results for LTTD, composting, and solid phase bioremediation.

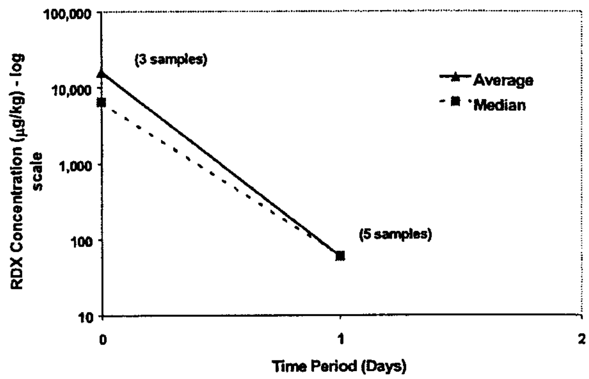

Figure 3. Low temperature thermal destruction results, untreated soils - TerraTherm

LTTD was effective in degrading explosive compounds in soil below RRA soil cleanup goals when temperatures greater than 250°C were applied.

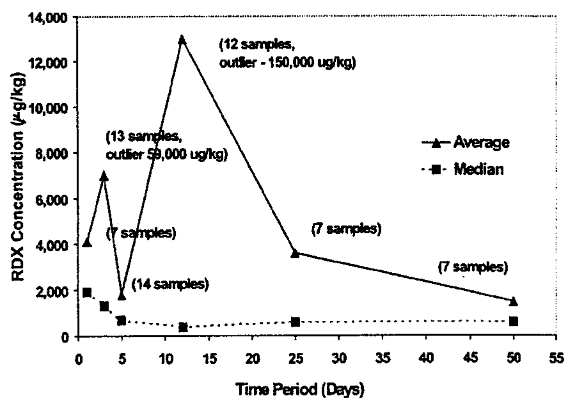

Figure 4. Composting results, untreated soils- BSI

Composting was partially successful in degrading explosive compounds in soil. The most successful compost mixes were those using Hen and Dairy manure, which yielded non-detectable results for HMX at the end of the study period. The final data suggested that HMX concentrations achieve RRA soil cleanup goals; however, RDX was not reduced to levels below RRA soil cleanup goals.

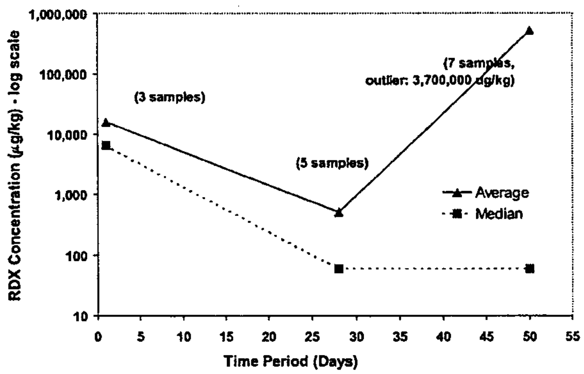

Figure 5. Solid phase bioremediation results, untreated soils - Grace Canada

Solid phase bioremediation using DARAMEND® was effective in degrading explosive compounds below RRA soil cleanup goals in one of two essentially similar unwashed soil tests.

The particulate nature of explosives in soils had implications on data evaluation and comparison of laboratory studies. The variability in sampling between technologies made it difficult to compare the effectiveness of studies. In addition, the average concentration can be greatly influenced by the existence of particulates, especially in smaller data sets, and is not necessarily representative of contamination of the soil. For example, if the average concentration alone is used as a measure of success, composting and solid phase bioremediation do not successfully degrade RDX.

The median concentration is also provided to give a balanced view of the effectiveness of the technology in treating explosives-contaminated soil. The median concentration can be considered to be a measure of the overall success of the technology. However, the technology must be able to treat explosives in all forms, including the particulate form, and therefore it is important to see the impact of the particulates on the outcomes of the studies. For this reason, both average and median degradation curves are shown.

It should be noted that subcontractors were requested to focus on reduction and/or destruction of explosive contaminants. Other contaminants were described but not emphasized, including metals and pesticides. Chemical reduction and LTTD were found to be reasonably likely to achieve the RRA soil cleanup goals for dieldrin. LTTD was also found to achieve these goals for the remaining organic COCs. Metals were not treated by any technology tested.

6. DISCUSSION OF FIELD-SCALE DEMONSTRATION DESIGNS

Chemical Reduction The Brice/UNL report proposed a field-scale demonstration using washed soil placed in windrows, adding water to the soil to obtain a 35% to 40% (mass:mass) soil mass, and adding 5% ZVI, aluminum sulfate, and acetic acid. The soil would be covered with plastic, which would be removed every seven to ten days for sampling and water application. Additional mixing of the soil would not be performed. Brice/UNL recommended that the field-scale implementation be conducted for thirty days rather than the five days used in the laboratory studies to accommodate any impacts from explosives in particulate form.

Composting BSI provided an outline of an ex-situ system using windrows containing 300 cy of soil and 700 cy of amendments. BSI indicated that the required timeframe would be based on the remedial goals set for the site. Periodic samples would be collected to determine the extent to which remediation had occurred.

Two concerns arise regarding field demonstration. First, using 70% amendments to 30% soil may make it difficult to backfill the soil to its original location. Second, high concentrations of explosives were detected in untreated soils, including the final sampling event at Day 45. Therefore, a field-scale demonstration for composting may best be considered as part of a treatment train after soil washing.

Solid Phase Bioremediation The field scale design proposed by Grace involved treating approximately 6,700 cy of soil in-situ to a depth of two feet. Grace's design did not meet some of the requirements of the Request For Proposal, therefore, assumptions were made to be comparable to the other ITE designs. It was assumed that the field-scale design would involve adding similar quantities of additives as in the studies. It was also assumed that the timeframe would be the same as in the laboratory studies.

There were three concerns regarding field demonstration. First, it was not specified whether the field-scale design would include covering the soil or sealing it in some fashion. If the soil is not sealed, it would be inconsistent with the laboratory studies in which the microcosms were maintained in sealed soil jars that were opened once per week. This inconsistency may be significant considering that RDX and HMX remediation are accomplished through anaerobic degradation. Second, the proposed treatment of the soil was made on an in-situ basis, which would require UXO clearance prior to implementation. Third, high concentrations of explosives were detected in untreated soils, including the final sampling event at Day 50. Therefore, a field-scale demonstration for solid phase bioremediation may best be considered as part of a treatment train after soil washing..

LTTD Soil would be staged in a three-sided concrete container. Heating rods would be placed throughout the soil and heated to the extent necessary. Vapors would be extracted through the heating rods so that volatilized contaminants would be captured and submitted to secondary treatment, likely granular activated carbon.

A concern regarding field implementation was that LTTD would likely be implemented as an ex-situ treatment of the soil due to concerns with soil heating. Because large mixing equipment would likely be required to place the soil in windrows, UXO clearance would need to be completed prior to implementing this design. In addition, safety issues would need to be addressed, as historically, the Department of Defense (DOD) has rejected thermal treatments. Although TerraTherm's LTTD uses a different process from other thermal treatments, a safety review by DOD would be required.

The ITE team is currently reviewing preliminary information on implementation costs. Therefore, a discussion of these costs is not included in this report.

7. RECOMMENDATIONS

The following preliminary recommendations were made based on the objectives of the ITE program:

Revise soil sampling methodology. The issue of particulates was a significant factor in assessing the treatability studies. It also has broad implications for soil remediation at Camp Edwards. Variability in the analytical results may be reduced by such modifications in sample preparation for EPA Method 8330 explosives analysis as: (a) prior to analysis, crush the soil to pass a #200-mesh sieve rather than a #30-mesh and then homogenize the soil, and (b) increase the total mass of the sample from 2 grams to 20 grams, as suggested by Jenkins et al. (1997) The total impact would be an approximately eighty-fold increase in the homogeneity of the soil sample. This technique should be used in conjunction with the analysis of discrete samples using Method 8330. Method 8330 will provide information on how well the technology can degrade particulates, while the recommended method will provide an overall concentration of explosives in soil.

Run follow-up studies. Because several issues were not apparent prior to the treatability studies, it may be beneficial to run further studies, such as:

a. A study of the coagulant effect. This may help determine whether explosive contaminants are adsorbed by coagulants, and the impact on achieving cleanup goals.
b. More studies for LTTD at 250° and 300°C on unwashed soils to determine whether LTTD can effectively degrade soil where particulates are present. Prior to repeating these studies, it should be confirmed that dry-sieving the soil would remove metals contamination.

Perform field scale demonstrations. It should be noted that the impact of explosive particulates and the coagulants in soil washing may affect the outcome of the field scale demonstrations. The following recommendations may be affected by analysis of the cost of field-scale demonstrations.

a. Soil washing (stand alone). If soil washing is shown to be effective, it may stand alone as a treatment technology. Effectiveness may be improved by increasing the residence time of the fine soil in the slurry phase to dissolve as much of the explosive contaminants as possible.

b. Soil washing plus chemical reduction or biodegradation. If soil washing is to be used as the first step of a treatment train due to a requirement to remove particulate metals, and increasing the residence time does not result in sufficient dissolution of explosives, chemical reduction may be demonstrated as part of the soil washing treatment train.

   If a biological technology is to be included in the field demonstration, it may be prudent to wait for results of the bioslurry treatability study, as explosives may degrade better in slurries of soils rather than in drier soils, due to the nature of the degradation mechanisms. A second choice for biological demonstration would be solid phase bioremediation.

c. If it is not required that particulate metals be removed, a field demonstration may be performed using thermal desorption/destruction on untreated soil, depending on field demonstration costs. As is true for all technologies, the soil would have to be cleared of UXO prior to implementation.

It is hoped that one or more of these technologies will be implemented at Camp Edwards. In addition, the lessons learned from the technologies studied at this site may have applicability to similar armed services training installations.

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Key words:
Soil remediation: Page 1
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RDX: Pages 1, 2, 3, 4, 5
HMX: Pages 1, 2, 3, 4, 5
Chemical oxidation: Pages 1, 2,3
Chemical reduction: Pages 1, 2, 3, 4, 5
Bioslurry: Pages 1, 2, 5
Solid phase bioremediation: Pages 1, 2, 4, 5
Composting: Pages 1, 2, 3, 4, 5
Soil washing: Pages 1, 2, 5
Innovative treatment
Biodegradation
Contaminated soil