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AT TA 16:
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TABLE OF CONTENTS

LIST OF FIGURES iii
LIST OF TABLES iii
ACRONYMS AND ABBREVIATIONS iv

1.0 INTRODUCTION AND PROJECT BACKGROUND 1
1.1 Objectives 1
1.2 Site Contamination 1
1.2 Composting Technology Overview 2
2.0 STUDY DESIGN, METHODS, AND RESULTS 3
2.1. Conventional Composting 3
2.1.1 Study Design and Methods 4
2.1.2 Implementation and Results 5
2.1.2.1 Phase I 5
2.1.2.2 Phase II 8
2.1.2.3 Phase III 10
2.1.2.4 Phase IV 14
2.2 DARAMEND Bioremediation 19
2.2.1 Study Design and Methods 19
2.2.2 Implementation and Results 19
3.0 CONCLUSIONS AND RECOMMENDATIONS 22
4.0 REFERENCES 22

LIST OF FIGURES

Figure 2.1-1: Phase I compost temperatures, 4/6/00-4/19/00. 7
Figure 2.1-2 Phase II compost temperatures, 4/22/00-5/18/00. 9
Figure 2.1-3: Phase III compost temperatures, 8/3/00-9/21/00. 12
Figure 2.1-4: Phase IV compost temperatures, 9/20/00-12/6/00. 13
Figure 2.1-5: Phase IV total HE concentrations. 18
Figure 2.2-1: DARAMEND Study HE concentrations 8/2/00-11/30/00. 23

LIST OF TABLES

Table 2.1-1: Phase I compost formulas, April 6th to April 19th, 2000. 6
Table 2.1-2: Phase II compost formulas, April 22nd to May 18th, 2000. 8
Table 2.1-3: Baseline HE-concentrations in composting test soil -field results 10
Table 2.1-4: Baseline HE-concentrations in composting test soil -laboratory results. 10
Table 2.1-5: Phase III compost recipes, August 8th to September 21st, 2000.. 11
Table 2.1-6: Phase IV compost recipes, Sep. 20tht to Dec. 7th, 2000. 14
Table 2.1-7: Analytical laboratory results for Phase IV. 18

ACRONYMS AND ABBREVIATIONS

DNT	Dinitrotoluene
DOE	Department of Energy
FTL	Field Team Leader
HE	High Explosives
HMX	1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane
HPLC	High-Performance Liquid Chromatography
IM	Interim Measure
LANL, Laboratory	Los Alamos National Laboratory
PRS	Potential Release Site
RCRA	Resource Conservation and Recovery Act
RDX	Cyclonite
RFI	RCRA Facility Investigation
SOP	Standard Operating Procedure
SSHASP	Site-Specific Health and Safety Plan
TA	Technical Area
TNB	1,3,5-trinitrobenzene
TNT	2,4,6-trinitrotoluene
XRF	X-ray Fluorescence Spectrometry

1.0 INTRODUCTION AND PROJECT BACKGROUND

This report discusses the implementation and results of a soil composting pilot study conducted in support of the PRS 16-021(c)-99 Corrective Measure Study (CMS). In this study, the term composting includes the Grace Bioremediation Technologies (Grace) DARAMEND© treatment process as well as more conventional composting techniques. This composting evaluation is a required component of the PRS 16-021(c)-99 CMS and is one of several Bench-and-Pilot studies that have been or will be conducted to address various site contaminant concerns.

A RCRA facility assessment (RFA) and two phases of a RCRA facility investigation (RFI) have been conducted on PRS 16-021(c) (LANL 1990, 43827.254; LANL 1996, 55077; LANL 1998, 59891, respectively). The results of these investigations have demonstrated the need for corrective action at this site. The Building 260 outfall drainage channel is known to have contained a significant volume of highly contaminated material (concentrations in excess of 20 weight percent total HE have been observed) and is thought to be the principal source of contamination impacting the physical system associated with PRS 16-021(C)-99. Through the RFI and CMS process it was recognized that any removal action at the source area would generate large volumes of highly contaminated material and, therefore, identifying and evaluating practical treatment technologies for wastes derived from the source area was incorporated into the CMS.

1.1 Objectives

The principal objective of the study was to assess the effectiveness of composting as a treatment technology for the high-explosives (HE)-contaminated soils present at PRS 16-021(c)-99. The study was designed to identify compost formulas that created conditions with the potential to effectively degrade high explosives and, subsequently to evaluate the effectiveness of those candidate formulas at reducing HE concentrations in 260-outfall drainage channel material.

1.2 Site Contamination

Contaminants known to be present in the 260 drainage area include barium, cyclonite (RDX), 2,4,6-trinitrotoluene (TNT), 1,3,5,7-tetranitro-1,3,5,7-tetrazacyclooctane (HMX), dinitrotoluene (DNT), amino-DNT, 1,3,5-trinitrobenzene (TNB), acetone, chloromethane, dichloroethane, isopropyltoluene, tetrachloroethene, trichloroethene, anthracene, bis(2-ethylhexyl)phthalate, butylbenzylphthalate, copper, cadmium, chromium, cobalt, lead, nickel, silver, vanadium, uranium, and zinc. HE, barium, and low levels of other contaminants have also been observed in waters from TA-16 springs, Cañon de Valle, the R-25 regional aquifer monitoring well, and nearby shallow (approximately 17 to 80 ft deep) boreholes. Detailed contaminant information is presented in the RFI Report for Potential Release Site 16-021(c) (LANL 1998, 59891).

Subsurface sampling in the outfall and drainage indicated that concentrations decrease rapidly below the soil/tuff interface. However, up to 1000 mg/kg of HE was found within the uppermost tuff unit (7 to 14 ft beneath the pond) and up to 1% total HE was reported in a sample from a surge bed encountered at a depth of approximately 16 ft beneath the pond. HE was observed only sporadically and at much lower concentrations (typically less than 5 mg/kg) below the surge bed.

Human health and ecological screening assessments performed as part of the Phase II RFI identified barium, bis(2-ethylhexyl)phthalate, HMX, RDX, and 2,4,6-TNT as the contaminants of potential concern. RDX (due to toxicity) and HMX (due to high concentrations) present the most significant potential risks to human health and the environment.

1.2 Composting Technology Overview

Composting is the decomposition of organic material, typically by naturally occurring bacteria and fungi. In the presence of a sufficient carbon source and easily available nitrogen the microbial population will expand rapidly creating significant heat as a decomposition byproduct. The rise in temperature forces a shift in the microbial population to more thermophilic bacteria; which are more efficient decomposer organisms and are capable of degrading synthetic organic chemicals including HE. A composting environment that will typically foster sufficient microbial activity to generate thermophilic conditions with temperatures exceeding 70° C requires a plentiful short-chained carbon source, soluble nitrogen, high moisture levels (near the specific retention of the medium), sufficient oxygen, and a neutral pH. The process of biostimulation, which is simply the intentional alteration of these parameters to create conditions more favorable for growth of the naturally occurring microbial population, enhances the organic decomposition process and is the fundamental basis of engineered composting systems. Manure and a nitrogen fertilizer are commonly used in composting recipes to provide the short-chain carbon and soluble nitrogen sources. Bulking agents (e.g. yard waste or straw) to provide pore space to the mixture are also a typical component of composting recipes. Pore space is important to permit the supply of oxygen to aerobic microorganisms and to allows gas-phase microbial degradation products to vent from the compost. Periodic turning to re-aerate the compost mixture and to reestablish pore space lost through settling and compaction of the mixture is often required. The addition of water to maintain moisture levels is also necessary.

Composting has previously been shown to lower HE concentrations in soil (Craig et. al. 1995, 58939). The general approach is to mix HE contaminated soil with an active compost mixture. Up to approximately 30% soil can be incorporated into the composting mixture without negatively affecting the organic degradation process. Composting mixtures that include soil are more subject to compaction and typically require frequent turning to maintain pore space and, therefore, to maintain the aerobic microorganism population. Composting technology has shown successful, efficient destruction of HE and has met HE site cleanup goals at other sites (Craig et. al. 1995,

58939). It is also a permitted treatment technology used at several commercial TSDs to treat HE and organic contaminated soils prior to final disposition.

The Grace DARAMEND process is similar to conventional composting in that biostimulation is used to promote the biodegradation of synthetic organic compounds (in this application nitroaromatics) by the naturally-occurring microbial population. DARAMEND amendments, which are a family of proprietary solid phase organic materials selected on a waste/contaminant specific basis, are used to stimulate microbial oxygen consumption. This causes the rapid development of anoxic conditions within the soil. An inorganic amendment (typically zero-valent iron) is used in conjunction with the organic amendments to chemically scavenge oxygen further. Redox potentials as low as –500mV have been attained using this combination of induced aerobic microbe activity and chemical oxidation. Under such conditions nitro-groups on organic explosive compounds are rapidly reduced. It is often necessary to restore aerobic conditions within the soil to eliminate aneorbic microbial waste byproducts and to enhance the degradation of organic contaminants by promoting aerobic mineralization processes. Aerobic conditions are typically reestablished naturally as microbial activity ceases and the soil dries; tilling the soil can improve the rate at which oxygen is reincorporated into the soil and is sometimes necessary. The application of sequential anoxic and oxic conditions to the soil can be repeated multiple times depending on initial contaminant concentrations and treatment goals.

Other key components of the DARAMEND process are the use of amendments with very small particle size and the application of aggressive tillage during the initial preparation of the treatment pile. This thoroughly disrupts soil aggregates and completely disperses the amendment particles throughout the treatment pile resulting in uniform anoxic conditions within the soil matrix. As a result, amendments can be applied at much smaller rates than in conventional composting processes; amendments typically comprise less than 5% of the total amendment/soil mixture.

The Grace DARAMEND process has also been used effectively to remediate HE-contaminated soils at multiple DOD facilities and a modification of the process is used to treat HE-contaminated soils at a commercial TSD facility.

2.0 STUDY DESIGN, METHODS, AND RESULTS

This section of the report addresses the study design, methods, and results for both the conventional composting experiments and the Grace DARAMEND bioremediation experiments.

2.1. Conventional Composting

A study of conventional composting methods was conducted as part of the CMS to evaluate the application of composting to the treatment of the highly contaminated soils in the Building 260 outfall drainage channel.

2.1.1 Study Design and Methods

A total of 25 different compost formulas were prepared during the course of this pilot project. The compost formulas included combinations of one or more of the following: horse stable waste (approximately 70% straw, and 30% urine and manure), cow manure, chicken manure, straw, wood chips, potato, and alfalfa. When soil was included in the compost formula, it was added at a compost-to-soil ratio of approximately 7:3. Ammonium sulfate (NH_4SO_4) was also added to the formulas to serve as both an initial nitrogen source and to chemically stabilize barium for the tests using contaminated soil.

Both HE contaminated soils and uncontaminated soils were used in various phases of the study. Uncontaminated soils were collected from an undisturbed area at TA-16. The contaminated material was produced by mixing soils and sediments from locations in the 260-outfall drainage channel identified as containing more than 5% total HE with material containing less than 5% HE. The resultant mixture was intended to approximate the concentration of contaminants expected in the waste soils that would be produced during the 260 IM. The contaminated soil mixture also needed to be less than 5% total HE so that it would not be categorized as a RCRA waste, which would require special permitting to be treated on-site, and to avoid DOT shipping requirements applicable to materials categorized as explosives.

The pretreatment contaminated soil was sampled prior to mixing with the various compost amendments to establish baseline HE and barium concentrations and to verify that the mixture met the intended contaminant concentration requirements. The sample was analyzed on-site using a field-deployed High-performance Liquid Chromatography (HPLC) analytical instrument and X-ray fluorescence (XRF) machine. Once it was established that the material was below 5% total HE (and therefore could be shipped unrestricted) the material was sent to an off-site EPA-approved laboratory to verify the field analytical results.

A mixture of several composting amendments (straw, alfalfa, horse manure, and cow manure) without soil was also prepared and sampled to determine if the off-site laboratory could achieve efficient HE extraction rates and effectively analyze the compost mixtures. The analytical lab spiked the amendment mixture with varying concentrations of the EPA method 8330 suite of HEs and extracted and analyzed the spiked material. The results were compared to the known spiked concentrations. The data indicated that the analytical laboratory could effectively determine the concentration of HE in the compost mixtures within an acceptable level of accuracy and precision. A complete discussion and results of the evaluation prepared by the analytical laboratory are provided in Appendix I.

Water was added to the test batches until the soil-compost treatments were at the specific retention of the mixture. The piles were mechanically compiled and homogenized using hand tools. After the soil-compost treatments were sufficiently mixed, the treatments were placed in closed, insulated coolers or 30-gallon trashcans; the containers were labeled with the treatment number and corresponding formula. The treatment period was

approximately 30 days. The temperature of each compost recipe was monitored continuously using a thermistor placed near the center of mass in each container and recorded using a Campbell Scientific CR10X data logger. Temperatures were logged hourly and were reviewed by the project team daily: a decision to mix the treatments was made when readings indicated a decreasing trend in temperature. During mixing, the water content was evaluated qualitatively and sufficient water was added to ensure that the moisture content of the soil-compost treatment mixtures remained near specific retention.

For the composting experiments using contaminated material, samples of each soil-compost mixture were collected at regular intervals throughout the course of a treatment cycle to evaluate HE degradation. The samples were analyzed on-site for the primary HE constituents TNT, RDX, and HMX. Barium concentration was not evaluated during treatment cycles since the XRF can only analyze total barium and is not appropriate for determining leachable barium concentrations. Furthermore, the process of barium stabilization is not time-dependent in the same way that HE composting is and the concentration of leachable barium was not expected to evolve significantly through the course of the treatment cycle. At the completion of the experiment, samples of the compost mixtures were again analyzed off-site by an EPA approved laboratory to confirm field results and to further substantiate the effectiveness of each compost recipe for HE degradation and barium stabilization.

2.1.2 Implementation and Results

The composting pilot project was implemented in four phases. The goal of the first two phases was to experiment with different compost formulas to identify recipes most capable of producing the elevated temperatures favorable to thermophillic bacteria, which in turn would be good candidate recipes for HE degradation. The goal of the last two phases was to use the successful formulas with the addition of HE-contaminated soil to directly evaluate composting as a treatment technology for the site-specific soil-type and suite of contaminants.

2.1.2.1 Phase I

Phase I was conducted from April 6th- April 19th 2000. Table 2.1-1 presents the 9 different compost formulas evaluated in the first phase. Uncontaminated soil was used for formulas requiring soil. Compost mixtures were stored in insulated 4-gallon coolers within a transportainer located at TA-16. Figure 2.1-1 shows the temperature data for the Phase I trials. The results indicate that the compost mixtures were significantly impacted by the large diurnal fluctuations in ambient air temperature. This was almost certainly due to the low total mass of the individual compost batches and the relatively poor insulation of the coolers. Several of the formulas did produce temperatures slightly elevated above ambient air temperatures indicating that composting was occurring; however, none of the formulas achieved expected temperatures. Compost formula #8 containing horse manure, straw, and alfalfa, produced the highest peak temperatures at slightly more than 35 degrees Celsius.

Table 2.1-1: Phase I compost formulas, April 6th to April 19th, 2000.

Amendments	# 1	# 2	# 3	# 4	# 5	# 6	# 7	# 8	# 9
Wood Chips						x			
Old Soil						x			
Soil	30%	30%	30%	30%	30%				
Cow Manure			30%			x			
Horse Manure	30%	30%		30%	50%		100%	40%	30%
Straw	40%	20%						30%	70%
Alfalfa		20%	10%	10%	5%			30%	
Yard Waste			10%	10%	15%				
Potato			20%	20%					
NH4SO4	100g	100g	250g	250g	250g	0g	0g	100g	100g

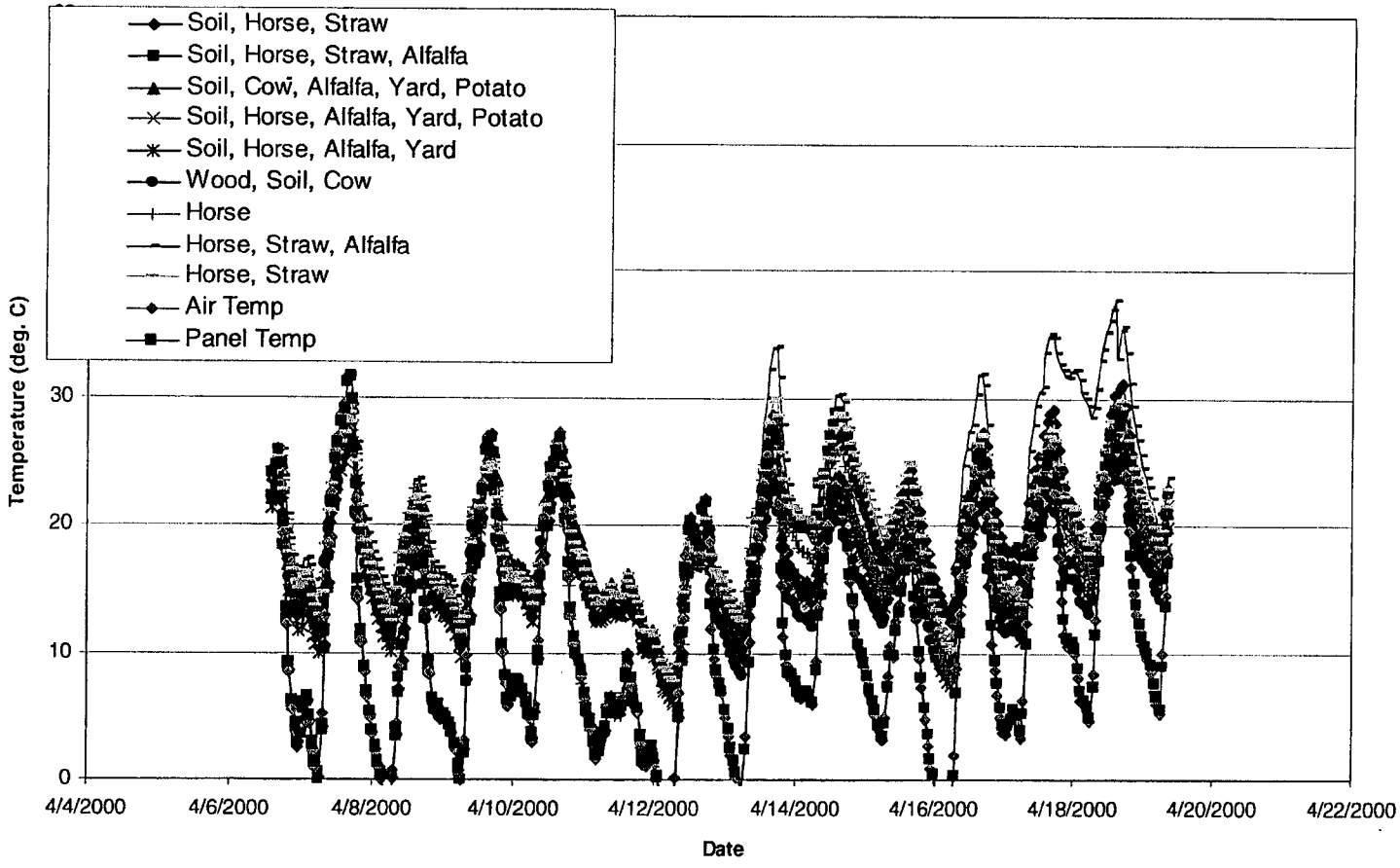

Figure 2.1-1: Phase I compost temperatures, 4/6/00-4/19/00.

2.1.2.2 Phase II

A second trial phase was initiated due to the generally poor performance of the Phase I trials. Phase II ran from April 22nd to May 18th 2000. The Phase II trials were conducted in a partially heated facility in an effort to minimize diurnal fluctuations in ambient temperature. Additional insulating material was placed around the coolers to further mitigate the effect of air temperature variation. Most of the compost formulas were also adjusted in an effort to attain better heat production and to establish optimum ingredient ratios; only two Phase I-compost recipes were repeated in Phase II. In addition, ammonium sulfate was not added to four of the Phase II recipes to determine if the ammonium sulfate was impeding microbial activity. Table 2.1-2 presents the compost recipes tested in Phase II.

Figure 2.1-2 shows the temperature data from the monitoring period. The temperature fluctuations observed in Phase I were reduced significantly in Phase II. The Phase I fluctuations were approximately 15° C whereas in Phase II the fluctuations were down to approximately 5° C. Several formulas produced temperatures well above the ambient air temperature. Formulas based on horse manure and cow manure showed similar performance; the addition of ammonium sulfate did not appear to impact microbial activity and the associated production of heat. Formula #1, containing cow manure, straw, potato, and ammonium sulfate, produced the highest temperatures (nearly 50° C); formulas #4 and # 8, both horse manure-based formulas, produced temperatures similar to formula #1. The Phase II trials in general were successful; however, peak temperatures were still not as high as expected. This is again most likely attributable to the low mass of individual test batches.

Table 2.1-2: Phase II compost formulas, April 22nd to May 18th, 2000.

Amendments	# 1	# 2	# 3	# 4	# 5	# 6	# 7	# 8	# 9
Soil		30%		30%		30%	30%		
Cow Manure	30%	20%							
Horse Manure			40%	30%	30%	30%	20%	40%	30%
Straw	60%	40%	60%	40%	70%	40%	30%	60%	40%
Alfalfa							20%		30%
Potato	10%	10%							
NH4SO4	100g	100g	250g	100g	100g				

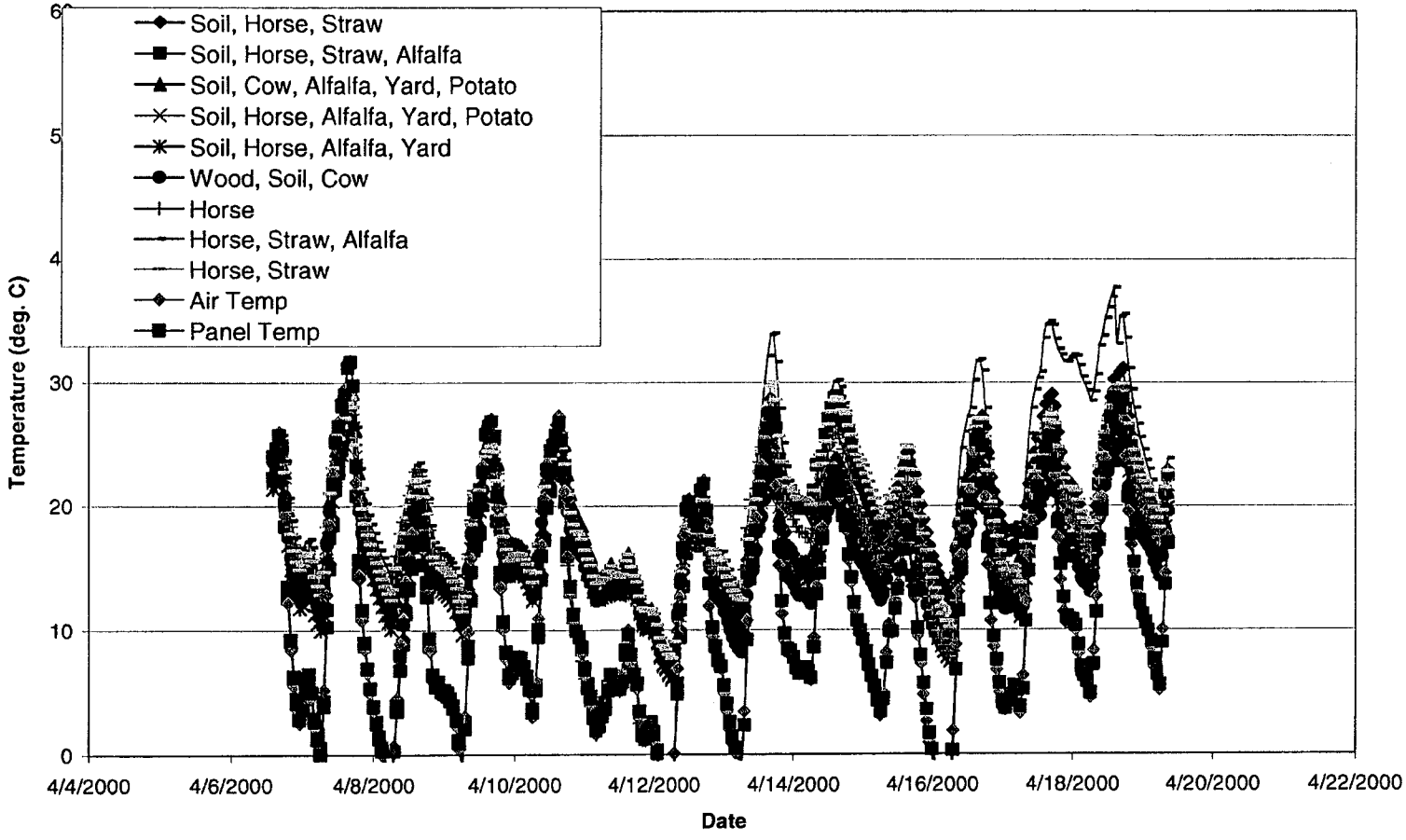

Figure 2.1-2 Phase II compost temperatures, 4/22/00-5/18/00.

2.1.2.3 Phase III

Phase III was the first phase designed to directly evaluate the effectiveness of composting for HE degradation. The three most successful compost recipes from Phase I and Phase II were tested using the blended HE-contaminated soil derived from the 260 drainage-channel in place of the uncontaminated TA-16 soil. Phase III was conducted from August 3rd to September 21st 2000.

The contaminated soil was sampled (sample number RE16-00-1098) and field-analyzed on 4/15/00. The soil was sampled (sample number RE16-00-4000) and submitted to the off-site laboratory on 06/15/00. The field analytical results are presented in Table 2.1-3; the analytical laboratory results are presented in Table 2.1-4.

Table 2.1-3: Baseline HE-concentrations in composting test soil -field results.

Analyte	Concentration (mg/kg)
HMX	14622.8
RDX	8185.0
TNT	
Total HE	22807.8 (≈2%)
Ba	6502.0

Table 2.1-4: Baseline HE-concentrations in composting test soil -laboratory results.

Analyte	Concentration (mg/kg)
HMX (ppm)	27000
RDX (ppm)	16000
TNT (ppm)	1900
Total HE (ppm)	44900
Ba	

The results indicate that field and fixed laboratory results are directly comparable. The observed variability is more likely due to sample heterogeneity rather than a result of variability in the analytical method.

For Phase III, several changes in procedure were made in an effort to improve microbial heat production. Most significantly, the quantity of material used for the test batches was increased from 4-gallons to 32-gallons. Increasing the volume of composted material was intended to reduce the influence of external air temperature on the composting process. As in Phase II, the compost containers were stored beneath an insulated foam board box; however, a small space heater equipped with a thermostat was placed in the storage area to further dampen diurnal temperature fluctuations. The thermostat on the heater was set to prevent the temperature from dropping below 20 degrees C. Finally, small pumps were used to circulate air through each test batch to improve oxygen supply and reduce the need for frequent turning of the mixtures.

Identical 32-gallon compost mixtures using uncontaminated soil were prepared as references for the contaminated soil batches. Duplicate batches of formulas containing contaminated soil were also prepared. In addition, 4-gallon test batches using two of the three recipes and uncontaminated soil were prepared to determine if diurnal fluctuations impacted the higher mass mixtures less than the 4-gallon mixtures.

Table 2.1-5 lists the three formulas tested. Figure 4.2-3 shows the compost temperatures during the monitoring period. The data show continued impacts of diurnal fluctuations; however, all formulas, including those contained in 4-gallon coolers achieved temperatures several degrees above ambient at some point during the study. Formula #1, containing uncontaminated soil, cow manure, straw, potato, and ammonium sulfate achieved the highest peak temperature at more than 55 degrees C. Formula #2 in both 4-gallon and 32-gallon batch sizes, comprised of uncontaminated soil, horse manure, straw, and alfalfa, achieved maximum temperatures nearly equivalent to formula # 1 at approximately 53 degrees C. All three formulas containing contaminated soil performed essentially identically throughout the study; the three contaminated mixtures achieved maximum peak temperatures of 50 degrees C.

Table 2.1-5: Phase III compost recipes, August 8th to September 21st, 2000.

Amendments	Formula #1	Formula #2	Formula #3
Soil	30%	30%	30%
Cow Manure	18%		
Horse Manure		40%	35%
Straw	50%	30%	20%
Alfalfa			15%
Potato	2%		
NH4SO4	570g	570g	570g

The three primary contaminated mixtures and the three duplicate contaminated mixtures were sampled six times through the course of the study. HE concentrations as a function of time for all six mixtures are shown in Figure 4.2-4. Formula # 2, comprised of horse manure and straw achieved the greatest reductions in HE, from an initial concentration of approximately 35,000 mg/kg total HE to less than 500 mg/kg total HE. These results are moderately supported by the data from the duplicate of formula #2, which shows a reduction in total HE concentration from approximately 18,000 mg/kg to 7,500 mg/kg. With the exception of formula #2, all of the test batches, including the duplicate of formula #2, are subject to a high degree of variability in the HE concentration data, most likely due to sample heterogeneity. This makes a definitive interpretation of the data and an evaluation of HE degradation equivocal.

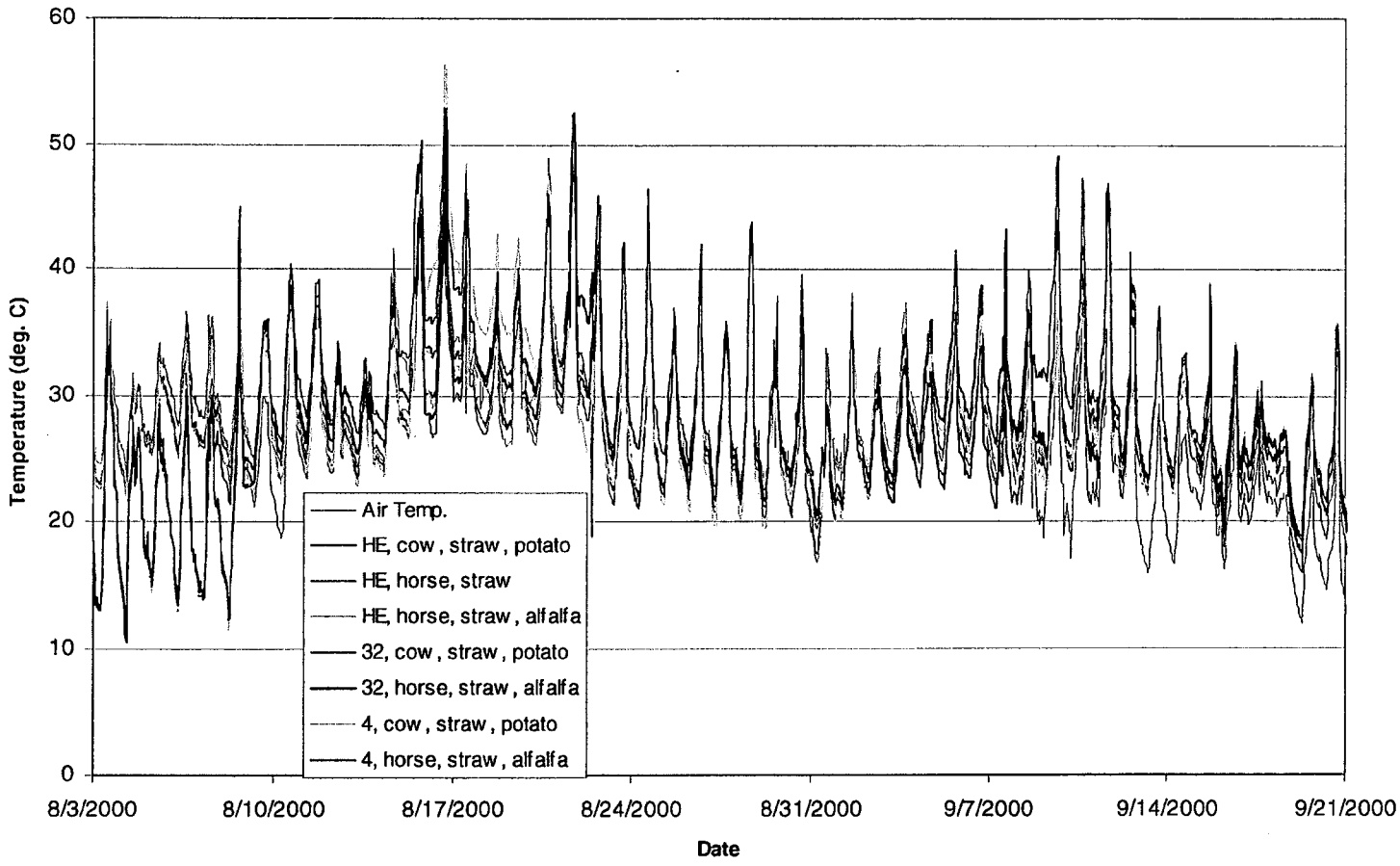

Figure 2.1-3: Phase III compost temperatures, 8/3/00-9/21/00.

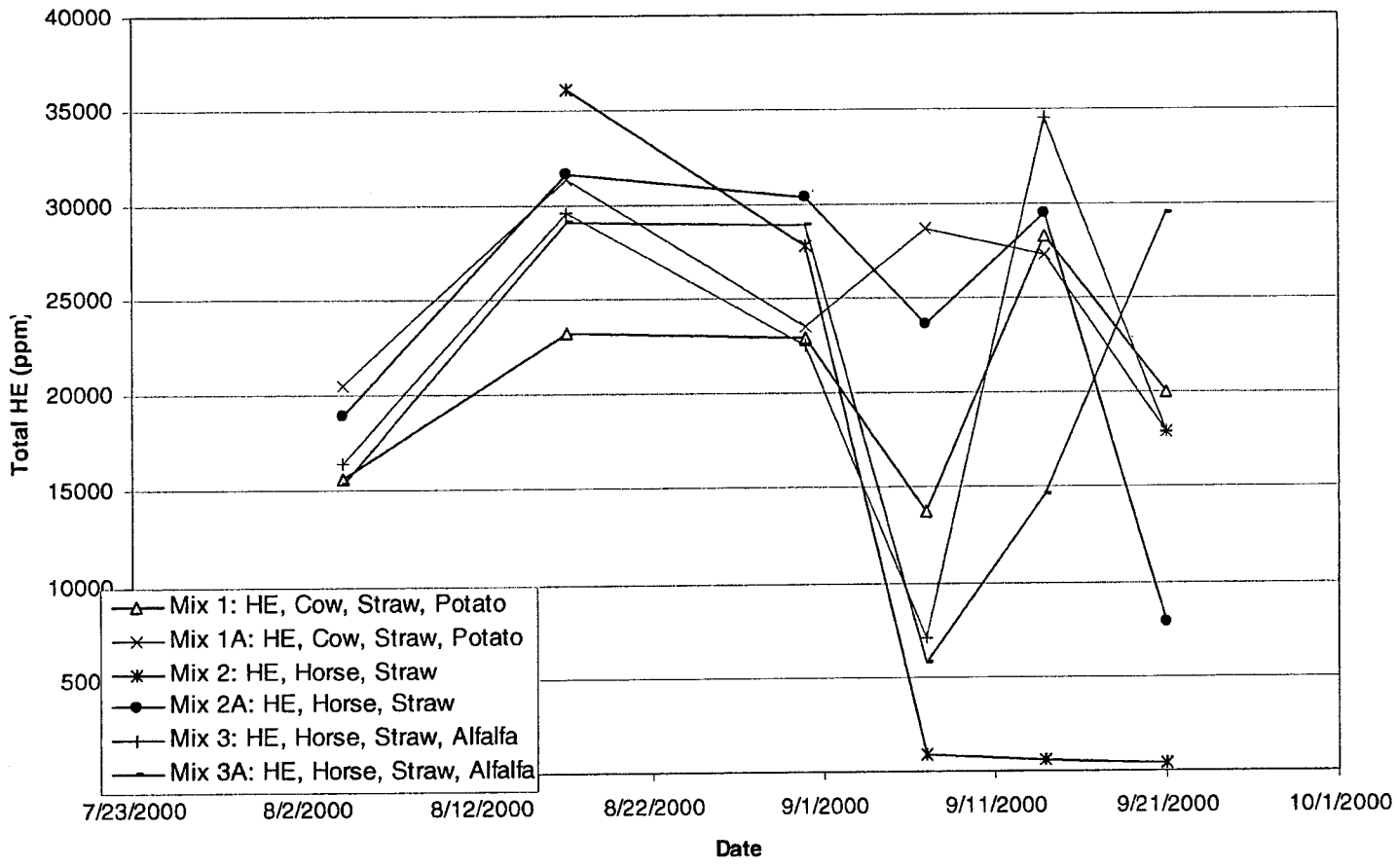

FIGURE 2.1-4: **PHASE III TOTAL HE CONCENTRATIONS.**

2.1.2.4 Phase IV

A fourth phase of the study was conducted in a controlled indoor environment in a final effort to minimize the impacts of ambient, diurnal temperature fluctuations that persisted through Phase III. The compost containers were also stored beneath the insulated foam board box and the temperature-controlled space heater was placed inside the box along with the compost containers. Air pumps were not used. The Phase IV indoor test used four compost recipes. All three recipes evaluated in Phase III were reevaluated in Phase IV; an additional formula based on chicken manure was also tested. Again, 32-gallons of compost were prepared using HE contaminated soil. Two temperature probes were placed in each 32-gallon compost container. Phase IV was conducted between September 20th and Dec 7th 2000.

Table 2.1-6 presents the formulas used in the Phase IV indoor test.

Table 2.1-6: Phase IV compost formulas, Sep. 20^{tht} to Dec. 7th, 2000.

Amendments	Formula 1	Formula 2	Formula 3	Formula 4
Soil	30%	30%	30%	30%
Cow Manure	18%			
Horse Manure		40%	35%	20%
Chicken Manure				15%
Straw	50%	30%	20%	20%
Alfalfa			15%	15%
Potato	2%			
NH4SO4	570g	570g	570g	570g

Figure 4.2-4 shows the temperatures for the indoor test. The data show that the diurnal fluctuations in ambient air temperature were effectively eliminated. Peak temperatures were similar to those achieved during Phase III and ranged from approximately 45 degrees C to nearly 50 degrees C for all formulas. However, in contrast to Phase III, the temperatures remained steady and elevated above the ambient air temperature inside the insulated box (and outside the box) throughout the experiment for all formulas. Formula #4, composed of horse and chicken manure, straw, alfalfa, and ammonium sulfate, achieved the highest peak temperatures and maintained the highest average temperatures. The other two horse manure based formulas (formula #2 and formula #3) produced only slightly lower peak and average temperatures.

Samples from each of the four compost mixtures were collected for field HE analysis seven times during the course of the experiment. HE concentrations as a function of time are shown in Figure 4.2-5. The data show that all formulas successfully degraded HE. The two horse manure-based formulas were the most successful, reducing total HE concentrations from approximately 10,000 mg/kg to 120 mg/kg and 12 mg/kg respectively. All formulas successfully reduced total HE concentrations to below 400 mg/kg; however, formula # 4 (horse and chicken manure based) may not have contained HE at concentrations as high as the other three mixtures.

A sample from each of the four compost mixtures was submitted for offsite analytical laboratory analysis on 12/7/00. Table 4.2-7 lists the analytical laboratory results. The pre-compost total HE concentrations are included for comparison. The analytical results also suggest that all formulas successfully degraded HE; however, formulas #1 and #2 may not have performed as well as was indicated by the field data. In contrast, formula # 4 may have performed better than was indicated by the field data but, as stated previously, this formula may have contained lower total HE at the initiation of the experiment.

Table 2.1-7: Analytical laboratory results for Phase IV.

Recipe	HMX (mg/kg)	RDX (mg/kg)	TNT (mg/kg)	Total HE (mg/kg)	Percent HE Reduction (%)	XRF Ba (mg/kg)	TCLP Ba (mg/L)
pre-compost	27000	16000	1900	44900		6502	
pre-compost (30%)	8100	4800	570	13470		1951	
cow, straw, potato RE16-00-0373	3600	200 (u)	50 (u)	3850	71		1.9
horse, straw RE16-00-0374	4200	200 (u)	50 (u)	4450	66		3
horse, straw, alfalfa RE16-00-0375	40	18	1.3	59.3	>99		2.6
horse, chicken, straw, alfalfa RE16-00-0376	130	20	5	155	99		1.9

(u) indicates the constituent was not detected.

Table 4.2-7 also presents the concentration of leachable barium as determined using the toxicity characteristic leaching procedure (TCLP) for each of the four formulas. Included for comparison are the concentration of total barium in the contaminated soil used for the tests (determined in the field using XRF) and the estimated concentration of total barium in the compost mixtures (based on the 70:30 mixing ratio). The data show that the ammonium sulfate effectively stabilizes the leachable barium.

In summary, the HE contaminated soil used for composting had an initial HE concentration of 44900 mg/kg. Contaminated soil comprised 30% of the compost mixture. Thus the initial or pre-treatment HE concentration was approximately 13000 mg/kg. Final HE concentrations ranged from 60- 4500 mg/kg. This is a 66% to almost 99% reduction in HE concentration. This suggests that proper conditions for the HE degrading bacteria were achieved. The data also suggests that the process of HE degradation is not highly sensitive to the specific composting formula as long as composting in general is occurring. In addition, ammonium sulfate is an effective barium stabilizing agent and soluble nitrogen source that does not adversely impact the composting process.

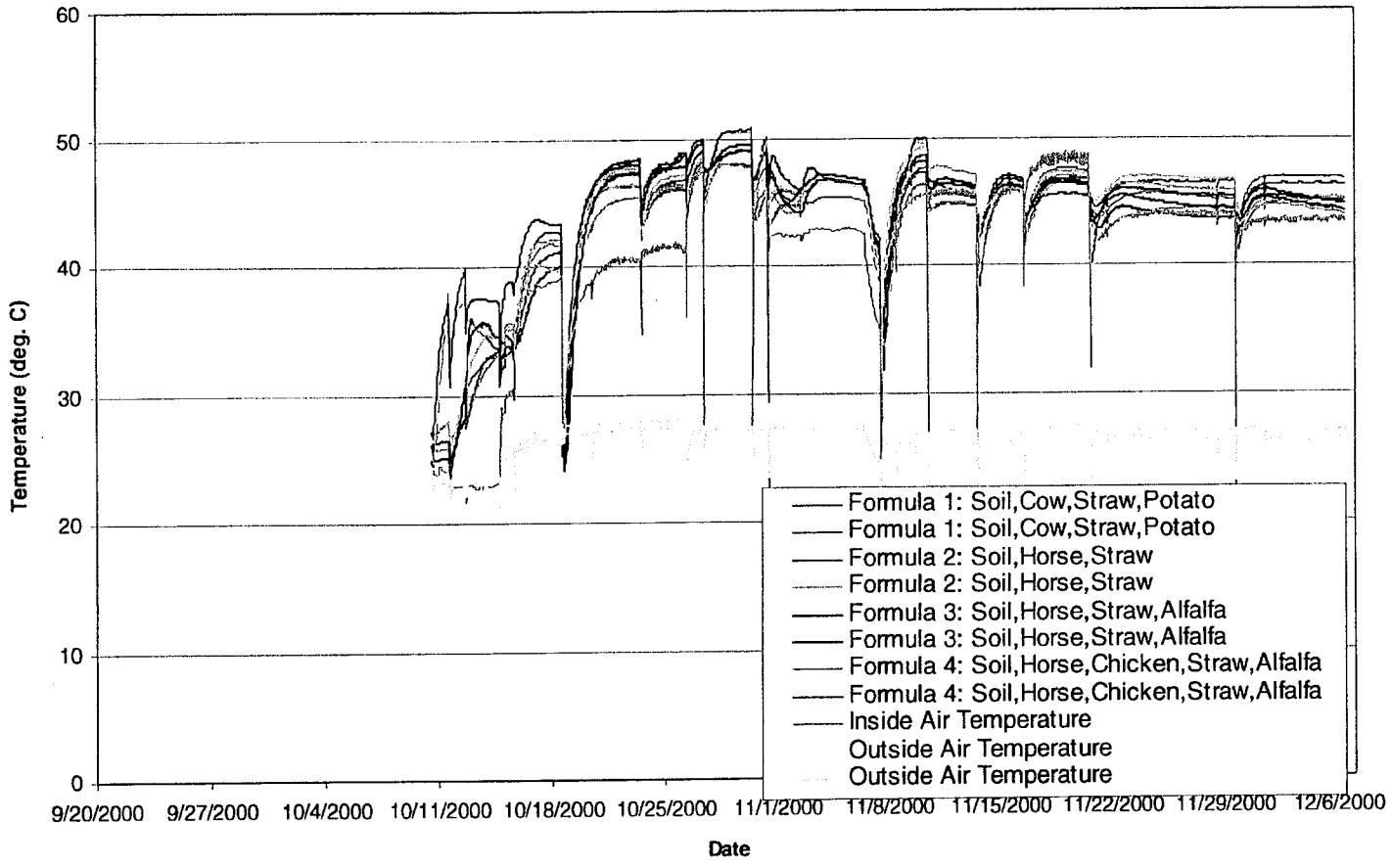

Figure 2.1-5: Phase IV compost temperatures, 9/20/00-12/6/00.

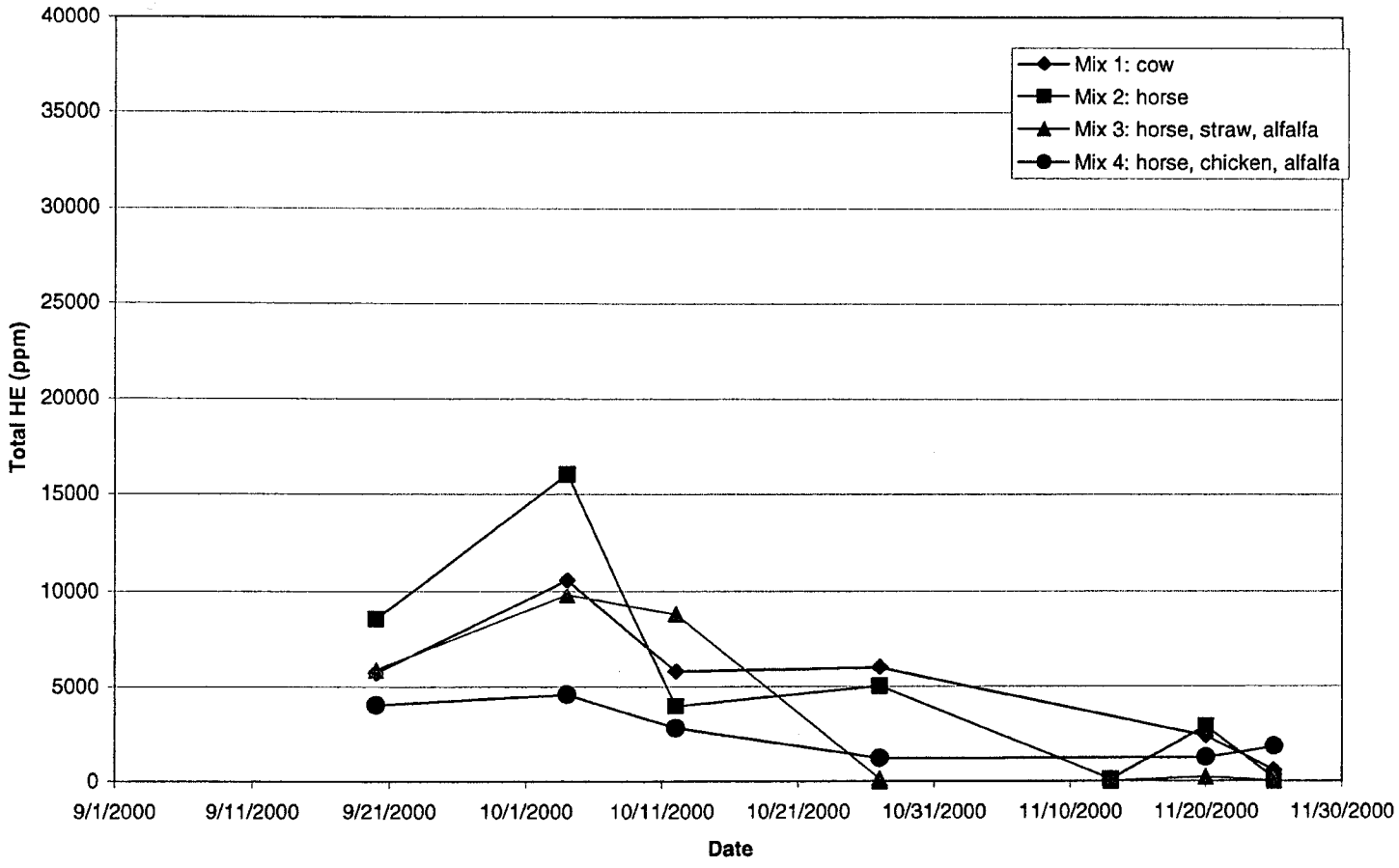

Figure 2.1-6: Phase IV total HE concentrations.

2.2 DARAMEND Bioremediation

A study of the DARAMEND bioremediation treatment process was conducted for the CMS as an alternative treatment method to conventional composting for the highly contaminated soils in the Building 260 outfall drainage channel. The DARAMEND experiment was conducted between August 2nd, 2000 and November 25th, 2000.

2.2.1 Study Design and Methods

The DARAMEND process requires active manipulation and control of redox conditions within the soil treatment pile. This is achieved through the addition of the proprietary organic amendments and zero valent iron to the soil and then measuring and adjusting moisture content. In order to accurately control moisture content the soil water holding capacity of the soil to be treated must first be determined. Water is then added to the soil to achieve and maintain a moisture content greater than 90% of the holding capacity for the duration of the anoxic phase of a treatment cycle. Moisture content is periodically evaluated through direct sampling but the judgement of field personnel is paramount in determining the amount of water to add in order to maintain proper moisture levels. For the oxic phase of the treatment cycle the soil is tilled and simply aloud to dry. Cycles of anoxic and oxic phases are repeated until treatment is achieved. The treatment process also requires periodic additions of amendments.

Strict adherence to the operational protocols is critical to maintain the proper redox conditions for each phase of the treatment cycle. A thorough discussion of the experimental procedures developed for this study and additional background information on the DARAMEND bioremediation treatment process is provided in the document "Experimental Protocol for DARAMEND Bioremediation Treatability Investigation: Los Alamos National Laboratory" prepared by Grace Bioremediation Technologies for this experiment. This document is included in its entirety as Appendix II.

2.2.2 Implementation and Results

For the PRS 16-021(c)-99 experiments, two HE-concentration levels of soil sourced from the 260 outfall drainage channel were used. One soil was specified to have an initial total HE concentration of slightly less than 5%; the other soil was specified to have an initial total HE concentration of less than 1%. After mixing and preparing the soils the more highly contaminated material had an actual initial total HE concentration of 3.5%; the less contaminated material had an initial concentration of 0.5%.

30 kilograms of each soil type was mixed with 620 grams of DARAMEND and 62 grams of powdered zero-valent iron, irrigated with water to achieve a moisture content greater than 90% of saturation, and stored in sealed five-gallon buckets. The soil, DARAMEND, and iron were mixed thoroughly prior to irrigation to ensure an even distribution of amendments throughout the soil. The same quantities of amendments were incorporated into the soil at the beginning of each anoxic phase. The experimental procedure prepared

by Grace Bioremediation Technologies for this study (presented in Appendix II) provides additional detail.

A six-day anoxic phase and a one-day oxic phase was prescribed for this experiment. The experiment was conducted for 15 treatment cycles over a period of 120 days. Samples were collected at the end of each treatment cycle, prior to the addition of any amendments, and analyzed by field HPLC to evaluate HE degradation. Samples for moisture content analysis were also collected and analyzed at the end of each treatment cycle to establish irrigation requirements.

Figure 2.2-1 shows the HE concentrations as a function of time. The DARAMEND treatment effectively reduced the total HE concentration in the highly contaminated soil from 3.5 % to approximately 1.5%. This is a substantial reduction; however, the total HE concentration remains very high and would probably not meet performance criteria for the treatment of 260 drainage channel soils. The DARAMEND treatment was even less effective on the 0.5% total-HE material; the final concentration for this soil type was approximately 4500 mg/kg, only a very slight reduction in the concentration of HE. This data suggests that the DARAMEND process may be effective at reducing initial high concentrations of HE but is ineffective at reducing HE-concentrations below a critical (relatively high) concentration threshold.

It is important to note that it proved difficult to achieve an even distribution of moisture throughout a treatment batch during irrigation cycles; similarly, during drying cycles sections of the material retained higher moisture levels. This may have resulted in less than optimum redox conditions throughout a treatment pile for a specific phase of a treatment cycle. These problems could be reduced significantly by using larger treatment piles and employing a mechanical tillage method.

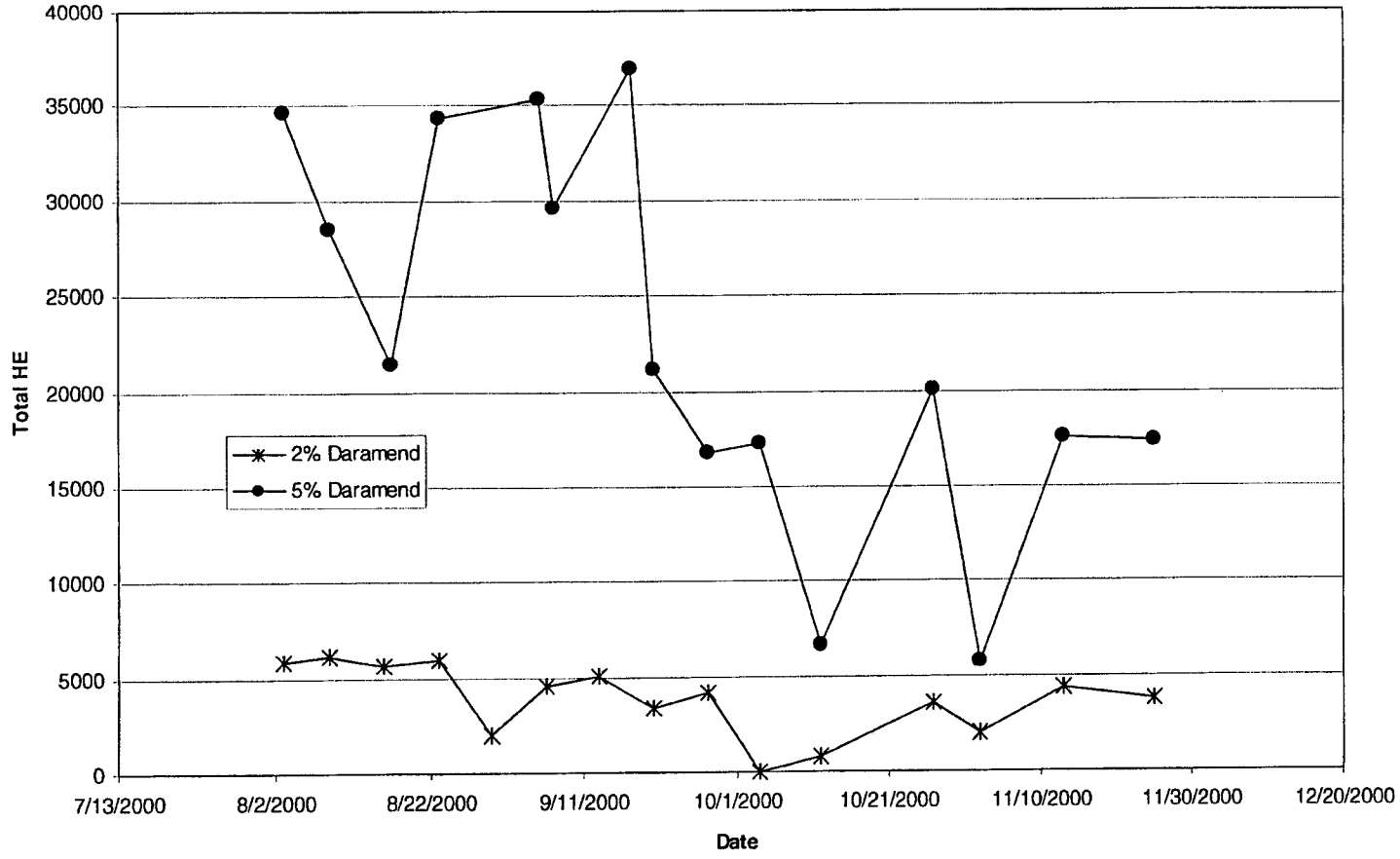

Figure 2.2-1: DARAMEND Study HE concentrations 8/2/00-11/30/00.

3.0 CONCLUSIONS AND RECOMMENDATIONS

The CMS soil treatment Bench and Pilot studies successfully identified technologies that could, to varying degrees, effectively treat the highly contaminated HE and barium soils derived from the TA-16-260 drainage channel.

Both the conventional composting experiments and the DARAMEND experiments were hindered by the relatively small scales of the treatment batches. The composting experiments were severely impacted by large diurnal fluctuations in ambient air temperature due to the low thermal mass of the treatment piles. The DARAMEND experiments were subject to moisture content control problems due to uneven drying rates within the small treatment piles and the non-uniform distribution of added water due to the limitations of hand mixing methods. Field scale applications of both conventional composting and the DARAMEND process are not expected to be as severely impacted by these problems.

Conventional composting achieved substantial reductions in total HE concentrations with final HE levels likely meeting or exceeding potential, appropriate treatment goals for 260 drainage channel derived wastes. Barium was effectively stabilized by the ammonium sulfate, which was also a soluble-nitrogen source for the compost. The most significant limitation of conventional composting is the large increase in waste volume; added amendments comprise approximately 70% of the waste. DARAMEND did not perform as well as conventional composting and potential HE treatment goals were not reached; however, in other studies DARAMEND successfully reduced HE concentrations to levels comparable to those achieved through conventional composting and the process remains advantageous due to the minimal increase in waste volume.

4.0 REFERENCES

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