EPA/540/R-05/007
July 2004

Field Evaluation of TerraTherm *In Situ* Thermal Destruction (ISTD) Treatment of Hexachlorocyclopentadiene

Innovative Technology Evaluation Report

National Risk Management Research Laboratory
Office of Research and Development
U. S. Environmental Protection Agency
Cincinnati, Ohio 45268

NOTICE

FOREWORD

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

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Sally Guitterez, Acting Director
National Risk Management Research Laboratory

ABSTRACT

This report summarizes the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program evaluation of the *In Situ* Thermal Destruction (ISTD) technology developed by others and refined by TerraTherm, Inc. The demonstration was designed to evaluate the technology's ability to treat soil-and-waste material contaminated with hexachlorocyclopentadiene (hex) and chlorinated pesticides at a former disposal pit (the Hex Pit) located at the Rocky Mountain Arsenal in Commerce City, Colorado. Operation of the system was terminated soon after initial startup and before the SITE demonstration could be completed, due to the destruction of system components from highly corrosive vapors and liquids.

ISTD is a soil remediation process that applies heat and vacuum simultaneously to contaminated soils, either with surface heater blankets or with an array of vertical heater and vacuum extraction wells. The ISTD system at the Hex Pit used an array of vertical heater and combination heater and vacuum extraction wells. According to the developer, as the soil is heated, volatile contaminants are vaporized or destroyed by a number of mechanisms, including the following: (1) evaporation into the vapor stream, (2) steam distillation into the vapor stream, (3) boiling, (4) oxidation, and (5) pyrolysis (Stegemeier and Vinegar 2001). Most of the contaminants are expected to be destroyed in the soil before the vapor stream is removed by vacuum extraction. Contaminants that have not been destroyed *in situ* and remain in the vapor stream are destroyed by an off-gas treatment system.

Evaluation of the ISTD technology as part of this SITE demonstration included extensive sampling to characterize soil-and-waste material in the Hex Pit before construction and startup of the ISTD system. In general, the Hex Pit contains layers or bands of virtually pure, tar-like waste material interlayered with soil that was used to cover the waste. Due to the early termination of the treatment process, SITE's project objectives and post-treatment sampling were modified from the original plan. For post-treatment sampling, the revised demonstration objective was to evaluate potential contaminant destruction or removal resulting from short-term operation of the system in the near vicinity of combination heater and vacuum extraction wells. Sampling results were inconclusive regarding evidence of contaminant destruction or removal from short-term operation of the system.

ISTD treatment at the Hex Pit was terminated 12 days after initial startup of the system due to the destruction of system components, likely from higher-than-anticipated production of hydrogen chloride (HCl). In addition, vapor-phase HCl condensed to the more corrosive liquid form in the system piping. Corrosion occurred in both aboveground and subsurface piping components constructed of 304 stainless steel. Destruction of the system components appeared to result from a combination of circumstances, including (1) the occurrence of layers of virtually pure, tar-like waste material that were not destroyed *in situ*; (2) the generation of HCl that was not adequately neutralized by *in situ* materials; (3) the choice of 304 stainless steel for system components, which was insufficiently resistant to corrosion; and (4) the inability of the system to maintain extracted vapors in the vapor phase for transport to the off-gas treatment system.

TABLE OF CONTENTS

Section **Page**

CONTENTS (Continued)

Section **Page**

Appendix

FIGURES

TABLES

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

°F	Degrees Fahrenheit
%RSD	Percent relative standard deviation
1,1-DCE	1,1-Dichloroethene
bgs	Below ground surface
CDPHE	Colorado Department of Public Health and Environment
CMS	Colorado Metallurgical Services
COC	Contaminant of concern
cy	Cubic yards
DRA	Dispute Resolution Agreement
DRE	Destruction and removal efficiency
EMTEC	Rocky Mountain Engineering and Materials Technology, Inc.
ENSR	ENSR Corporation
EPA	U.S. Environmental Protection Agency
FTO	Flameless thermal oxidizer
FWENC	Foster Wheeler Environmental Corporation
HCl	Hydrogen chloride (gas) or hydrochloric acid (water)
Hex	Hexachlorocyclopentadiene
HHE	Human health exceedance
HV well	Heater and vacuum extraction well
ISTD	*In Situ* Thermal Destruction
LCS	Laboratory control sample
mg/kg	Milligrams per kilogram
µg/kg	Micrograms per kilogram
MK	Morrison Knudson Environmental Services
MS/MSD	Matrix spike/matrix spike duplicate
NRMRL	National Risk Management Research Laboratory
ORD	Office of Research and Development
PARCC	Precision, accuracy, representativeness, completeness, and comparability
PCB	Polychlorinated biphenyl
PCE	Tetrachloroethene
pg/kg	Picograms per kilograms
ppb	Parts per billion
PRG	Preliminary remediation goal

ACRONYMS, ABBREVIATIONS, AND SYMBOLS (Continued)

QAPP	Quality Assurance Project Plan
QC	Quality control
RMA	Rocky Mountain Arsenal
ROD	Record of Decision
RPD	Relative percent difference
RVO	Remediation Venture Office
SAP	Sampling and analysis plan
SITE	Superfund Innovative Technology Evaluation
South Plants	South Plants Manufacturing Complex
SVOC	Semivolatile organic compound
TCE	Trichloroethene
TEQ	Toxicity equivalent
TerraTherm	TerraTherm, Inc.
Tetra Tech	Tetra Tech EM Inc.
VOC	Volatile organic compound

CONVERSION FACTORS

	To Convert From	*To*	*Multiply By*
Length:	inch	centimeter	2.54
	foot	meter	0.305
	mile	kilometer	1.61
Area:	square foot	square meter	0.0929
	acre	square meter	4,047
Volume:	gallon	liter	3.78
	cubic foot	cubic meter	0.0283
Mass:	pound	kilogram	0.454
Energy:	kilowatt-hour	megajoule	3.60
Power:	kilowatt	horsepower	1.34
Temperature:	(°Fahrenheit -32)	°Celsius	0.556

ACKNOWLEDGMENTS

This report was prepared for the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program by Tetra Tech EM Inc. (Tetra Tech) under the direction and coordination of Marta Richards at the National Risk Management Research Laboratory (NRMRL) in Cincinnati, Ohio.

The *In Situ* Thermal Destruction (ISTD) technology evaluation was a cooperative effort that involved the following personnel from EPA, the Rocky Mountain Arsenal (RMA), and TerraTherm, Inc. (TerraTherm):

Marta Richards	EPA SITE Technical Project Manager
Lorri Harper	RVO Project Manager
Kerry Guy	EPA Region 8
Ralph Baker	TerraTherm Project Manager

SECTION 1
INTRODUCTION

This section provides background information about the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) Program, and discusses the purpose and organization of this Final Report. The technology evaluated in this report is the *In Situ* Thermal Destruction (ISTD) system developed by TerraTherm, Inc. (TerraTherm). The evaluation site is a former hexachlorocyclopentadiene disposal pit (the Hex Pit), located at the Rocky Mountain Arsenal (RMA) in Commerce City, Colorado. This technology evaluation has been conducted by the EPA SITE Program in cooperation with EPA Region 8, the Colorado Department of Public Health and Environment, and RMA's Remediation Venture Office (RVO) (U.S. Army, Shell Oil Company, and U.S. Fish and Wildlife Service). Key contacts for additional information about the SITE Program, this technology, and the demonstration site are listed at the end of this section.

1.1 DESCRIPTION OF THE SITE PROGRAM AND REPORTS

The Superfund Amendments and Reauthorization Act of 1986 mandates that EPA select, to the maximum extent practicable, remedial actions at Superfund sites that create permanent solutions (as opposed to land-based disposal) for contamination that affects human health and the environment. In response to this mandate, the SITE Program was established by EPA's Office of Solid Waste and Emergency Response and Office of Research and Development (ORD). The SITE Program promotes the development, demonstration, and use of new or innovative technologies to clean up Superfund and other contaminated sites across the country.

The SITE Program's primary purpose is to maximize the use of alternatives in cleaning up hazardous waste sites by encouraging the development and demonstration of innovative treatment and monitoring technologies. It consists of the Demonstration Program, the Emerging Technology Program, the Monitoring and Measurement Technologies Program, and the Technology Transfer Program. This evaluation of TerraTherm's ISTD technology was completed under SITE's Demonstration Program.

The objective of the SITE Demonstration Program is to develop reliable performance and cost data on innovative treatment technologies so that potential users may assess specific technologies. Technologies evaluated either are currently, or will soon be, available for remediation of Superfund sites. SITE demonstrations are conducted at hazardous waste sites under conditions that closely simulate full-scale remediation, thus assuring the usefulness and reliability of information collected. Data collected are used to assess the performance of the technology, the potential need for pre- and post-treatment processing of wastes, potential operating problems, and approximate costs. The demonstrations also allow evaluation of long-term risks and operating and maintenance costs. For this evaluation of the ISTD technology, however, no cost information was developed, because the ISTD system did not complete the demonstration.

Technologies are selected for the SITE Demonstration Program through annual requests for proposals. ORD staff review the proposals, including any unsolicited proposals that may be submitted throughout the year, to determine which technologies show the most promise for use at Superfund sites. Technologies chosen must be at the pilot- or full-scale stages of development, must be innovative, and must have some advantage over existing technologies. Once EPA has accepted a proposal, cooperative agreements between EPA and the technology developer establish responsibilities for conducting the demonstration and evaluating the technology. The technology developer is responsible for demonstrating the technology at the selected site and is expected to pay any costs for transportation, operation, and removal of equipment. EPA is responsible for project planning, site preparation, sampling and analysis, quality assurance and quality control, and preparing reports and disseminating information.

1.2 PURPOSE AND ORGANIZATION OF THE FINAL REPORT

The Final Report (Report) provides information on TerraTherm's ISTD technology and includes a description of the demonstration and its results. EPA provides information regarding the applicability of each technology to specific sites and wastes; therefore, the Report includes information on site-specific characteristics. Each SITE demonstration evaluates the performance of a technology in treating a specific waste. The waste characteristics at other sites may differ from the characteristics of the treated waste; therefore, successful field demonstration of a technology at one site does not necessarily ensure that it will be applicable at other sites. Data from the field demonstration may require extrapolation for estimating the operating ranges in which the technology will perform satisfactorily. Only limited conclusions can be drawn from a single field demonstration.

TerraTherm's ISTD system did not complete the demonstration at the Hex Pit at RMA. Operation of the ISTD system was terminated soon after initial startup due to the destruction of system components from highly corrosive vapors and liquids. Consequently, this Report focuses primarily on site characteristics unique to the Hex Pit and the ISTD system design (Section 2.0); a description of the demonstration methodology and results, including a chronology of activities and events that occurred during operation of the ISTD system (Section 3.0); and a description of the component destruction and conditions that may have lead to the system's destruction (Section 4.0). Section 5.0 lists the references used in preparing this Report. This report does not include cost information for the ISTD technology, because the demonstration was stopped during initial operation of the system.

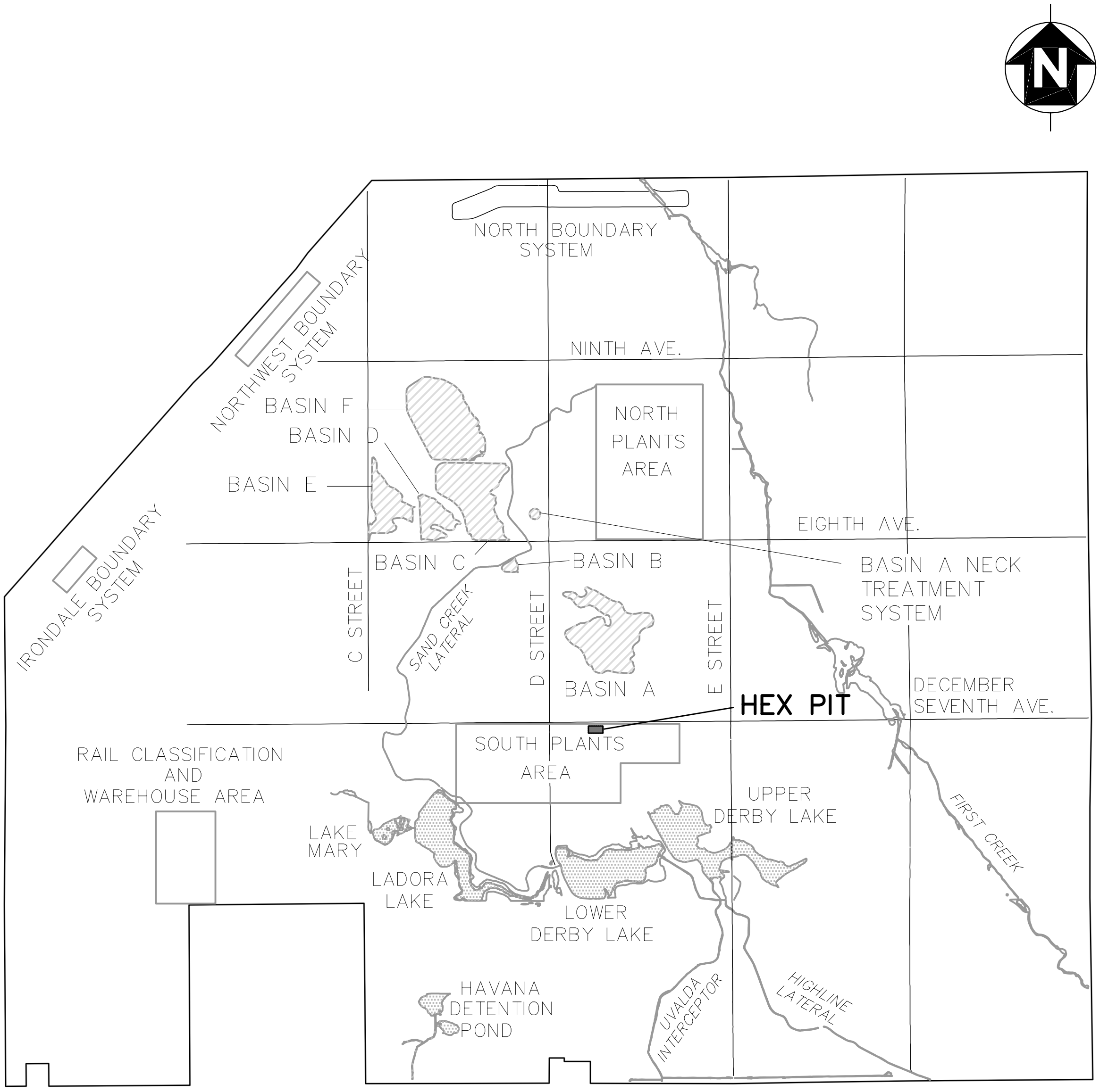
1.3 DEMONSTRATION BACKGROUND

This section describes the history of the Hex Pit at RMA and the selection of the ISTD technology for remediating contamination at the Hex Pit and for evaluation under the SITE Program.

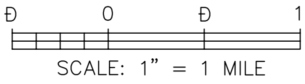
1.3.1 Site History

RMA is located in Commerce City, Colorado, 10 miles northeast of downtown Denver. The U.S. Army originally developed the 27-square-mile facility in 1942, primarily for manufacturing chemical weapons. After World War II, parts of the facility were leased to private industry for pesticide manufacturing.

The Hex Pit is an unlined, earthen-disposal pit located near the northern edge of the South Plants Manufacturing Complex (South Plants) at RMA (Figure 1-1). The pit was used to dispose of distillation bottoms and other residues from the production of hexachlorocyclopentadiene (referred to as "hex" throughout this report), a manufacturing intermediary used in the production of pesticides. Hex was produced in South Plants by Julius Hyman and Company from 1947 to 1951, and by Shell Chemical Company from 1951 to 1955. The black, tar-like distillation bottoms and residues, in drums and in bulk, were buried in the pit from mid-1951 to mid-1952. The waste material was periodically covered with soil backfill. Although the exact quantity of waste material disposed of in the Hex Pit was not recorded, it has been estimated that 833 cubic yards (cy) of waste was disposed of and that the pit contains a total of 2,005 cy of waste materials interlayered with soil backfill (TerraTherm 2001). By the end of 1952, the Hex Pit was completely covered with a soil cap. By 1954, it appeared as an unvegetated rectangular ground scar on aerial photographs. In 1976, waste materials from the Hex Pit were uncovered during construction of the foundation for Building 571B. Building 571B was constructed over the southern end of the pit. Building 571B was later demolished, and most of the foundation was removed (Tetra Tech EM Inc. [Tetra Tech] 2001).



NOTE: BASE MAP PROVIDED BY DP ASSOCIATES, INC.



SCALE: 1" = 1 MILE

ISTD DEMONSTRATION
ROCKY MT. ARSENAL

FIGURE 1–1

LOCATION OF THE HEX PIT AT ROCKY MOUNTAIN ARSENAL

Tetra Tech EM Inc.

R:\EPA\RMA\G1093\46140\ LOCATIONMAP.dwg 05/07/2003 karmen.griffith DN

1.3.2 Technology Selection

Innovative thermal treatment was specified for remediation of the Hex Pit in the Record of Decision (ROD) (Foster Wheeler Environmental Corporation [FWENC] 1996). Through the process identified in the ROD Dispute Resolution Agreement (DRA) (Program Manager Rocky Mountain Arsenal 1996) for this area at RMA., regulatory agencies overseeing environmental activities at RMA selected ISTD as the specific innovative thermal treatment to be used at the Hex Pit. RMA Remediation Goal 1 outlined in the ROD and DRA involves the destruction of contaminants to levels that met human health exceedance (HHE) criteria for the six site contaminants of concern (COCs). The six site COCs consisted of hex and the pesticides aldrin, dieldrin, endrin, isodrin, and chlordane. RMA Remediation Goal 2 involved the destruction of the six COCs to levels that met preliminary remediation goals (PRG). Table 1-1 summarizes the HHE criteria and PRGs for the six COCs.

TABLE 1-1

SUMMARY OF HEX PIT CLEAN-UP CRITERIA

COC	HHE Clean-up Criteria (in parts per million [ppm])	PRGs (in ppm)
Hex	1,100	1,100
Aldrin	71	0.72
Dieldrin	41	0.41
Endrin	230	230
Isodrin	52	52
Chlordane	55	3.7

Source: Foster Wheeler Environmental Corporation (FWENC) 1996

The standard that ISTD was to achieve, as expected by RMA, was 90 percent destruction and removal efficiency (DRE) for hex, dieldrin, and chlordane. Endrin, isodrin, and aldrin were reportedly below detection limits in pre-characterization sampling results, and therefore, RMA did not include them in the post-treatment DRE standard (TerraTherm 2001).

The primary objective of the SITE demonstration of TerraTherm's ISTD technology was to determine the ability of the technology to meet the HHE criteria for the six COCs. Additional discussion of the SITE Program's originally-planned primary and secondary objectives for this evaluation is included in Section 3.1.1

1.4 GENERAL TECHNOLOGY DESCRIPTION

ISTD is a soil remediation process that applies heat and vacuum simultaneously to contaminated soils, either with surface heater blankets or with an array of vertical heater and vacuum extraction wells. Surface heater blankets are used for the removal of surficial contamination down to about 2 feet, while vertical well arrays are used to treat deeper contamination in subsurface soils. Heaters are operated at 1,450 to 1,650 degrees Fahrenheit (°F). According to the developer, as the soil is heated, volatile contaminants are vaporized or destroyed by a number of mechanisms, including the following: (1) evaporation into the vapor stream, (2) steam distillation into the vapor stream, (3) boiling, (4) oxidation, and (5) pyrolysis (Stegemeier and Vinegar 2001). The vaporized water, contaminants, and natural organic compounds are drawn in a direction counter-current to the heat flow to the vacuum source in the blankets or wells.

Because the soil in the proximity of the heater-vacuum wells is heated to high temperatures (above 900 °F) for many days, the technology developer claimed that contaminants in the heated soil can be almost completely removed (Stegemeier and Vinegar 2001). Most of the contaminants are expected to be destroyed in the soil before the vapor stream is removed by vacuum extraction. For the Hex Pit site, the technology developer claims that this expectation was borne out in the results of the Hex Pit Treatability Study, in which the DREs for the site COCs within the treatability study samples exceeded 99 percent (ENSR Corporation [ENSR] 2000, see also Section 3.2.1). Contaminants that have not been destroyed *in situ* that remain in the vapor stream are destroyed by the off-gas treatment system. The technology developer claims that both thermal blankets and thermal wells have been highly effective in removing a variety of contaminants, including polychlorinated biphenyls (PCB), pesticides, chlorinated solvents, and heavy and light hydrocarbons (Stegemeier and Vinegar 2001).

1.5 KEY CONTACTS

Additional information on the SITE Program, TerraTherm's ISTD technology, and the demonstration site can be obtained from the following sources:

The SITE Program

Marta K. Richards and Scott Jacobs
U.S. Environmental Protection Agency
Office of Research and Development
26 West Martin Luther King Drive
Cincinnati, Ohio 45268
Telephone: (513) 569-7692 and (513) 569-7635
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TerraTherm's ISTD Technology

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RMA's Hex Pit Site

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SECTION 2
TECHNOLOGY APPLICATION ANALYSIS

This section describes the general applicability of TerraTherm's ISTD technology to contaminated waste sites. Previous ISTD applications are described; and, since the technology treatment was not completed at this site, this section focuses primarily on descriptions of the Hex Pit site characteristics and the ISTD system specifically designed for the site.

2.1 PREVIOUS APPLICATIONS OF *IN SITU* THERMAL DESTRUCTION

The technology developer currently describes case studies of six completed thermal treatment projects using the ISTD technology on its internet website (www.terratherm.com). These case studies include four sites contaminated with PCBs, one chlorinated solvent site, and one petroleum hydrocarbon site. Of the four PCB sites, three included vertical wells installed to depths of 12 to 15 feet below ground surface (bgs), similar to the thermal treatment approach at the Hex Pit. Two of the sites used thermal blankets, in addition to the thermal wells, to treat near-surface contamination or stockpiled soil, one used only thermal wells, and one site used thermal blankets in a batch-treatment process on stockpiled soil. PCB concentrations ranged up to highs of 20,000 milligrams per kilogram (mg/kg) in soil treated *in situ* using vertical wells and were greater than 10,000 mg/kg in stockpiled soil treated using thermal blankets. One site was also contaminated with dioxins and furans up to a toxicity equivalent (TEQ) concentration of 3.2 parts per billion (ppb). TerraTherm reports that treatment at all four PCB sites achieved cleanup goals ranging from less than 1 mg/kg to 10 mg/kg PCBs. Dioxin and furan contamination at the one site was reduced to the TEQ cleanup goal of less than 1 ppb.

The technology developer claims that soil contaminated with chlorinated solvents, including trichloroethene (TCE), tetrachloroethene (PCE), and 1,1-dichloroethene, were reportedly successfully remediated at one site using the ISTD technology. The site included two vertical well fields; one consisting of 15 wells installed to a depth of 12 feet bgs and the other consisting of 130 wells installed to depths of up to 19 feet bgs. For PCE, the pre-treatment concentrations were as high as 3,500 mg/kg, while those for TCE were as high as 79 mg/kg. For PCE, the post-treatment concentrations in all samples were less than 0.5 mg/kg, while concentrations of TCE were less than 0.02 mg/kg. ISTD technology was applied at one site contaminated with petroleum hydrocarbons, including gasoline, diesel-range organics, and benzene. Reportedly, approximately 200,000 pounds of hydrocarbons, including immiscible product, were successfully removed and treated during the 120-day heating cycle.

The TerraTherm web site also includes the description of a thermal treatment project at a former wood treatment site that is apparently ongoing. Soil at the site is described as contaminated with polyaromatic hydrocarbons, pentachlorophenol, and dioxins and furans. Thermal treatment will be conducted using vertical wells.

2.2 HEX PIT SITE CHARACTERISTICS

This section describes the geologic and hydrogeologic setting and previous investigations completed at the Hex Pit site. Information describing the characteristics of the pit's contents is then summarized. Previous investigations at the site include those completed by Morrison Knudson (MK) (MK 1989), ENSR (ENSR 1999), and EPA (Tetra Tech 2001). Descriptions of the characteristics of the waste material contained in the pit are summarized from these previous investigations, a bench-scale treatability study of the ISTD technology (ENSR 2000), and from the pre-treatment sampling and analysis completed as part of this technology demonstration.

2.2.1 Geologic and Hydrogeologic Settings

The Hex Pit was excavated in alluvial material, predominantly silty sand. This alluvial material is approximately 25 feet thick in the immediately vicinity of the Hex Pit and appears to thicken to the north. The alluvium is underlain by Denver Formation bedrock. The Denver Formation consists of weathered clayey sandstone and sandy shale. The top of the Denver Formation in the area forms an apparent shallow paleochannel that generally trends northward. The local bedrock topography controls the northward thickening of the alluvium and influences the pattern of groundwater flow (MK 1989).

Recently, the water-table surface has been about 13 to 14 feet bgs in the immediate vicinity of the Hex Pit (Tetra Tech 2001, measured during pre-treatment sampling). The depth to the water-table surface reportedly varies seasonally by about 3 feet and is at its lowest during the winter and highest in late spring (TerraTherm 2001). Regional groundwater flow is to

the north-northeast at a gradient of about 0.008 feet per foot, or about 42 feet per mile (MK 1989).

2.2.2 Previous Investigations

Previous field investigations have been completed at the location of the Hex Pit. In 1989, MK completed an investigation to evaluate whether the Hex Pit was an active primary source of groundwater contamination in the South Plants area (MK 1989). In 1998, MK completed a preliminary investigation to evaluate the boundaries of the Hex Pit and to characterize its contents (MK 1998). In 1999, ENSR completed a more extensive evaluation of the boundaries of the Hex Pit and the characteristics of the contained waste material (ENSR 1999). The 1999 ENSR investigation also involved collection of samples of material disposed of in the Hex Pit that were used for a bench-scale treatability study of the ISTD technology (ENSR 2000). On behalf of EPA, Tetra Tech completed a screening investigation in 2000 to further evaluate the boundaries of the Hex Pit, focusing primarily on the south end of the pit that was previously covered by the concrete foundation slab of Building 571B (Tetra Tech 2001). The screening investigation also involved collection of soil samples from just outside the boundaries of the Hex Pit to evaluate the potential migration of contaminants from the Hex Pit to native soils, and installation of piezometers to measure the water table elevation in the immediate vicinity of the Hex Pit. Finally, samples were collected and analyzed as part of this technology demonstration in 2001, further characterizing the contents of the Hex Pit and contaminant concentrations in soil covering, adjacent to, and immediately below the pit before the ISTD system was constructed and operated (pre-treatment sampling and analysis). This section describes the objectives of, and activities completed as part of, these previous investigations and the pre-treatment sampling and analysis. Section 2.2.3 summarizes the characteristics of the Hex Pit based on the results of these previous investigations.

Groundwater Impact Study (MK 1989)

MK completed the following activities to evaluate whether the Hex Pit was an active primary source of groundwater contamination in the South Plants area (MK 1989):

- Aerial photographs from 1948 to 1978 and a blueline sketch dated November 19, 1967 were examined to delineate the approximate boundaries of the site.
- Five new groundwater monitoring wells were installed, one hydraulically upgradient and four downgradient of the Hex Pit. The nearest downgradient monitoring well was located approximately 60 feet from the Hex Pit.
- Groundwater samples were collected and analyzed from the five new monitoring wells and three existing monitoring wells located in the general area. Water-level elevation measurements were also obtained.

The MK study concluded that two compounds associated with waste material in the Hex Pit, hexachlorobenzene and hexachlorobutadiene, may be migrating at relatively low concentrations from the Hex Pit into the alluvial groundwater. However, the study also concluded that the risk to human and non-human biotic receptors from groundwater emanating from the Hex Pit area was insignificant and that no long-term benefit would be gained by conducting an interim response action at the site. The study also established the direction of groundwater flow in the area of the Hex Pit (north-northeast).

Preliminary Investigation (MK 1998)

The preliminary investigation of the boundaries of the Hex Pit and characteristics of its contents included the following activities (MK 1998):

- Geophysical surveys of the area, including an electromagnetic-conductivity survey to evaluate the dimensions of the pit, a metal-detector survey to evaluate the presence of metal objects, and direct-current measurements to evaluate the character of the waste material.
- Drilling three paired soil borings (six total borings) to evaluate the boundaries of the pit.
- Drilling three soil borings to collect waste samples from the pit for chemical, odor, and physical analyses.

The results of the geophysical surveys and observations from drilling the three paired borings provided a preliminary indication of the dimensions of the Hex Pit. Metal objects, presumably buried drums, were detected within the boundary of the pit. The waste samples were found to contain 33 to 38 percent volatile material, 5 to 27 percent carbon, and 14 to 23 percent chlorine. Concentrations of hex ranged from 1.3 to 16 percent. Although the odor from the Hex Pit was judged offensive, it was determined to be unlikely to present any off-post odor problems.

Characterization Study (ENSR 1999)

The objectives of the ENSR Hex Pit characterization study were as follows (ENSR 1999):

- Delineate the vertical and lateral extent of the planned ISTD treatment zone.
- Characterize the chemical and physical nature of the material in the pit.
- Collect samples of the material in the pit for use in a bench-scale treatability study.
- Collect samples outside and beneath the pit to establish background levels of contaminants and physical properties of soil.
- Locate and examine buried utilities in the vicinity of the pit.
- Confirm the depth to groundwater at the pit.

In addition, several former site workers were interviewed as part of the ENSR investigation regarding their recollection of activities at the Hex Pit.

As part of the ENSR investigation, 51 soil borings were drilled within and around the perimeter of the Hex Pit to visually identify its lateral and vertical boundaries. Samples collected to characterize the contents of the Hex Pit included three composite samples obtained from the north, middle, and south portions of the pit, and one sample collected from beneath the concrete foundation that remained from Building 571B. Two composite samples were also collected for a bench-scale treatability study. The SITE Program witnessed the process of opening the collected soil cores and compositing the sub-samples into the Master and Waste Composite samples that were tested during the bench-scale treatability study. “Background” soil samples were collected from beneath the pit and at four locations just outside the boundaries of the pit.

Treatability Study (ENSR 2000)

A bench-scale treatability study of the ISTD technology was conducted on contaminated samples collected from the Hex Pit as part of the characterization study (ENSR 1999). Two composite samples were tested during the treatability study, including the “Master Composite,” which was representative of the entire contents of the pit, and the “Waste Composite, which was representative of only visibly contaminated soil-and-waste material. The purpose of the treatability study was to evaluate whether the ISTD technology could achieve a 90 percent DRE for each of the site COCs. Additional objectives of the study included comparing post-treatment concentrations of the site COCs to the site-specific clean-up goals established in the site ROD, and evaluating the off-gas stream produced for use in designing an emission control system. Results from analyses of the Master-and Waste-Composite samples before treatment are included in the summary of Hex Pit characteristics (Section 2.2.3). The results of the treatability study are summarized in Section 3.2.1

Screening Investigation (Tetra Tech 2001)

EPA’s screening investigation included drilling 57 soil borings to evaluate the boundaries of the Hex Pit and to collect samples of native soil surrounding the pit to evaluate the potential lateral migration of contaminants. In addition, four piezometers were installed near the sides of the pit to measure the local water-table elevation. The screening investigation was completed between September and October 2000, immediately after most of the foundation of Building 571B was demolished and removed. During demolition of the concrete foundation slab of Building 571B, it was discovered that foundation structures under the slab were more extensive than had been previously estimated. These foundation structures included concrete footers and columns that extended to depths exceeding 16 feet bgs near the northwestern corner of the slab. In addition, deteriorating drums and other waste material were discovered beneath the northern half of the slab and extending an unknown distance to the west. Because of these observations, the screening investigation was modified from the outset to focus primarily on evaluating the lateral boundaries and vertical depth of waste material beneath the foundation of Building 571B.

Technology Demonstration Pre-treatment Sampling and Analysis

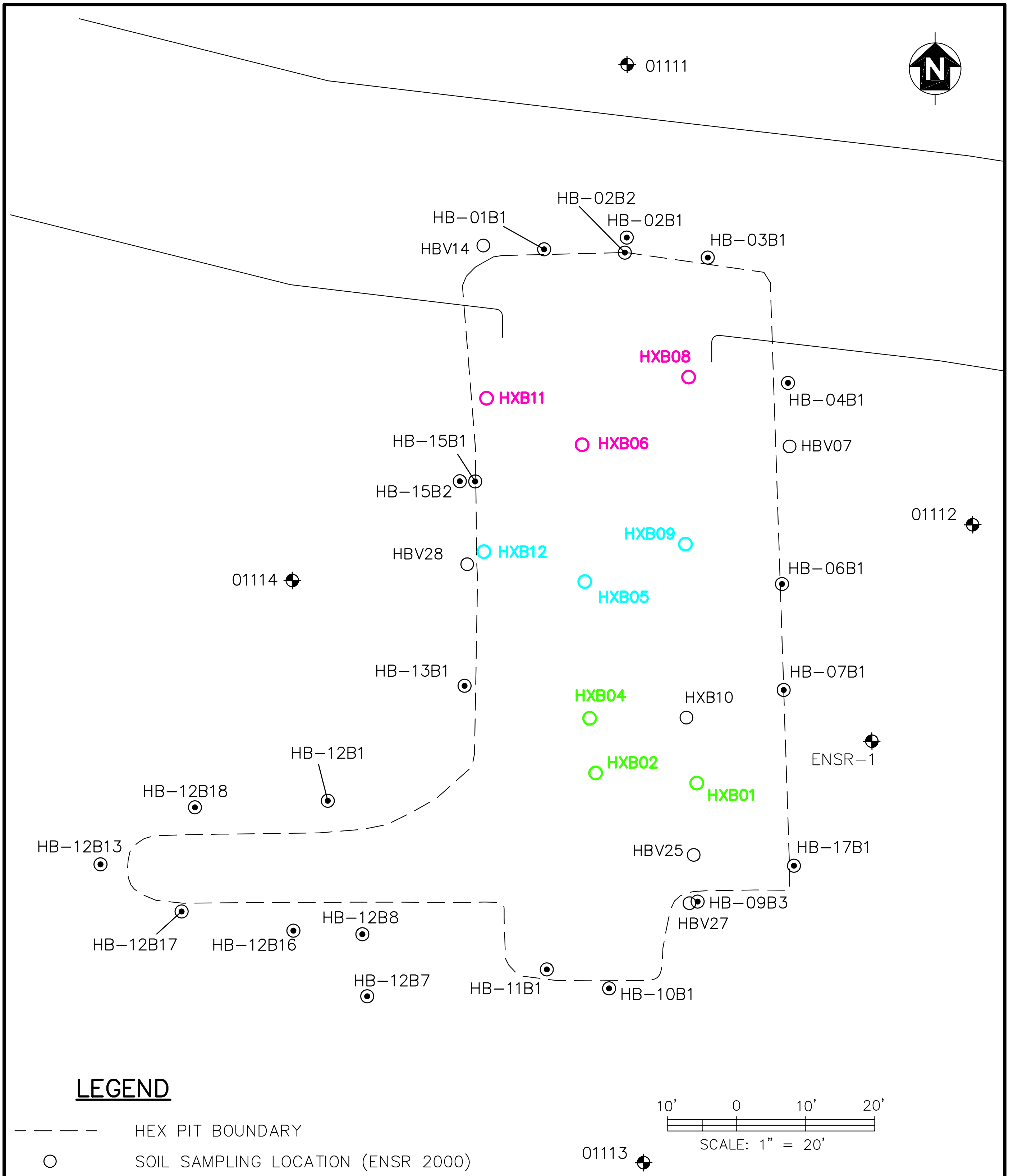
Samples were collected as part of this SITE demonstration to establish conditions existing at the Hex Pit before construction and operation of the ISTD treatment system. The “pre-treatment” samples were collected and analyzed as described in the SITE project quality assurance project plan (QAPP) (EPA 2001) in July 2001. Pre-treatment samples included composites of the materials disposed of in the Hex Pit (Hex Pit soil-and-waste material); soil above, below, and laterally contiguous to the disposal pit (contiguous soil); and groundwater from the four piezometers previously installed as part of the screening investigation. The pre-treatment sampling is further described in Section 3.1.2, and all pre-treatment sampling results are included in Section 3.2.3

2.2.3 Summary of Hex Pit Characteristics

The characteristics of the Hex Pit can be summarized based on the results of previous investigations and the pre-treatment sampling and analysis completed as part of this technology demonstration. Figure 2-1 shows the lateral boundaries of the Hex Pit. The main part of the Hex Pit measures approximately 94 feet long, 45 feet wide, and varies from 8 to 10 feet deep. A narrow trench extends west near the south end of the pit. A ramp is also evident at the south end of the Hex Pit where, presumably, a bulldozer or other heavy equipment entered the pit when it was originally excavated. The north end of the Hex Pit is also sloping, while the east and west sides and the sides of the trench extending west are nearly vertical. The total volume of material in the Hex Pit is estimated to be 2,005 cubic yards (TerraTherm 2001)

Figure 2-2 shows a generalized stratigraphic column through the Hex Pit. As shown in Figure 2-2, materials logged in borings completed as part of the previous investigations can be divided into the following general categories:

- Cover material
- Soil-and-waste material
- Mixed fill-and-waste material from removal of the foundation of Building 571B
- Native soil



LEGEND

- – – – HEX PIT BOUNDARY
- ○ SOIL SAMPLING LOCATION (ENSR 2000)
  - ○ NORTH COMPOSITE
  - ○ MIDDLE COMPOSITE
  - ○ SOUTH COMPOSITE
- ⊙ SOIL SAMPLING LOCATION (TETRA TECH 2001)
- ⊕ PIEZOMETER AND MONITORING WELL LOCATION
- /\/ DIRT ROAD

NOTE: BASE MAP PROVIDED BY DP ASSOCIATES, INC.

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FIGURE 2–1
HEX PIT BOUNDARY AND
HISTORICAL SAMPLING LOCATIONS

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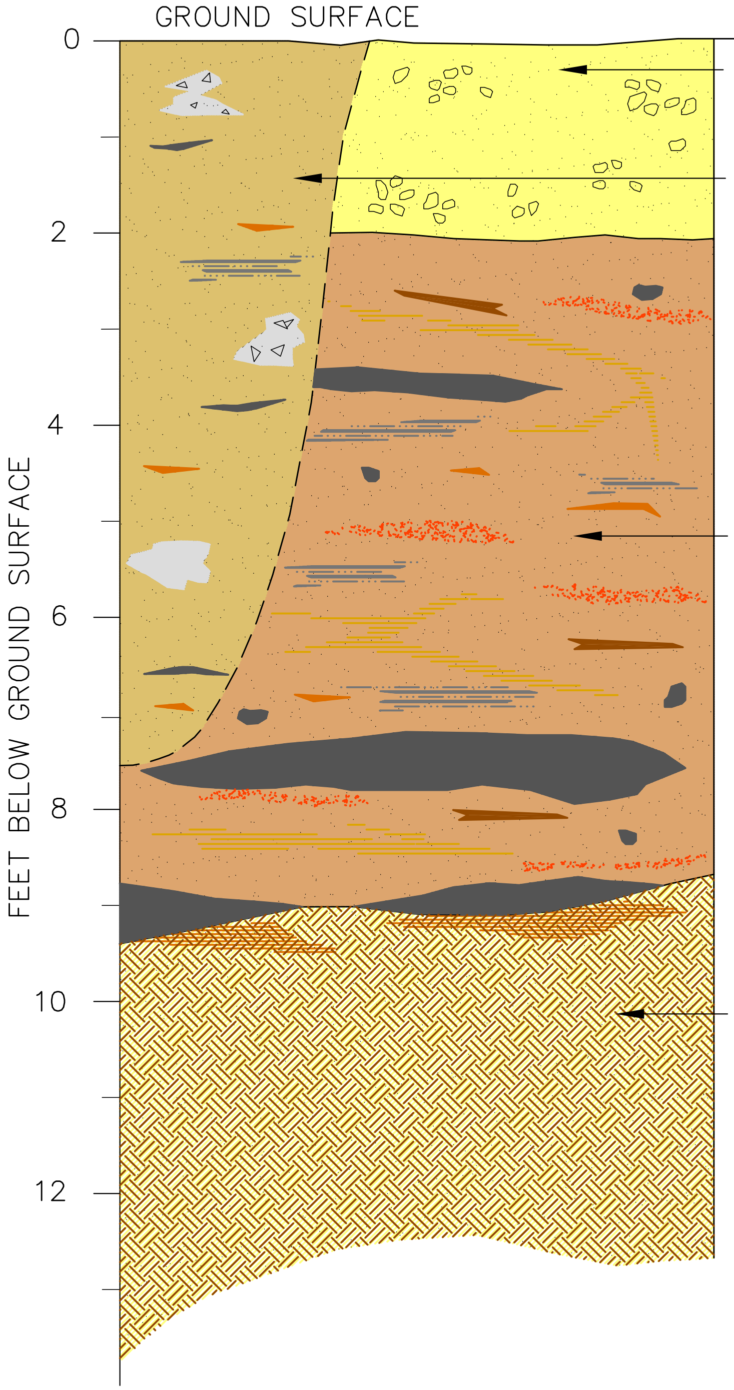

Cover Material. Primarily mixed sand, gravel, and silt that covers the area of the Hex Pit, usually to a depth of several feet.

Mixed Fill and Waste Material. Mixed clean imported fill material and soil and waste material originally disposed of in the Hex Pit. Formed during the removal of the foundation of Building 571B in September 2000 and restricted to the south end of the Hex Pit. Generally consists of silty sand with occasional gravel or concrete rubble fragments; streaks or granules of black, tar–like hex; and rusted metal fragments.

Soil and Waste Material. Material orginally disposed of in the Hex Pit. Mostly silty sand, often stained dark brown, rust orange, or black, and mixed with granules or globules of hex. Includes bands or layers of relatively pure, black, tar–like hex, usually less than 1 foot thick, often water–saturated, and frequently occurring near the base of the unit. Other substances include rusted metal fragments (probably drum remains); black, orange, or white crystalline substances; cloth rags; and wood fragments. Extends to depths of about 8 to 10 feet.

Native Soil. Primarily sand, silty sand, and silt, usually yellow–brown in color. Often stained rust orange with occasional streaks of black hex staining to depths of several feet below the soil and waste material unit.

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FIGURE 2–2
HEX PIT GENERALIZED STRATIGRAPHIC COLUMN

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The Hex Pit cover material is primarily composed of mixed sand, gravel, and silt that were placed as a cap over the entire area. The soil-and-waste material is composed of the material that was originally disposed of in the pit. It consists of soil (primarily silty sand) that is often stained dark brown, rust orange, or black, and may be mixed with granules or globules of hex. Black, tar-like relatively pure hex residue occurs in layers or bands usually less than 1 foot thick. Other substances include rusted metal fragments (probably drum remains), black to orange and occasionally white crystalline substances, layers of light bluish-gray paste-like material that is probably lime, and wood fragments. The layered nature of the soil-and-waste-material unit reflects the historical disposal practices; that is, hex disposed of in drums (that ruptured when dumped or later corroded) or in bulk that was then covered with soil backfill. It is also apparent that lime was occasionally dumped into the pit.

The mixed fill-and-waste material from the removal of the foundation of Building 571B is from the demolition and removal of the building's concrete foundation in September 2000. Foundation structures, including concrete footers and columns, were found to extend below the concrete slab, and attempts were made to excavate and remove these structures. Clean fill was used to cover the excavation at the end of each day to control odors from the Hex Pit waste material. The next morning, this fill material was dug out of the excavation so demolition and removal of the foundation structures could continue. Moving this material in and out of the excavation each day resulted in a mix of clean fill-and-waste material. The mixed fill and waste generally consists of silty sand with occasional gravel or concrete rubble fragments; streaks of granules of black, tar-like hex waste material; and trace amounts of rusted metal fragments. This material is restricted to the southern end of the Hex Pit beneath the location of the former building foundation

Native soil beneath and adjacent to the pit consists of sand, silty sand, and silt, usually yellow-brown in color. The native soil may be stained rust orange to depths of several feet below the Hex Pit waste material. Occasionally, streaks of black hex staining also occur in native soil immediately beneath the pit.

Samples of Hex Pit soil-and-waste material were analyzed as part of the characterization study (ENSR 1999) and the SITE pre-treatment sampling effort. The characterization study samples included three composite samples obtained from the northern, middle, and southern portions of the pit and one sample collected beneath the concrete foundation slab of Building 571B. Two composite samples were collected for the treatability study (ENSR 2000), including the "Master Composite, which was representative of the entire content of the pit, and the "Waste Composite, which was representative of only visibly contaminated soil-and-waste material. These samples were analyzed for volatile organic compounds (VOCs), total chlorine, and the Hex Pit COCs. The Master Composite sample was also analyzed for dioxins and furans. The SITE pre-treatment sampling effort included the collection of six composite samples analyzed for the site COCs, semivolatile organic compounds (SVOCs), and dioxins and furans. In addition, the SITE pre-treatment sampling included the collection of eight grab samples that were analyzed for VOCs. These samples were collected from depths of approximately 5 feet bgs, without regard to whether the material was primarily waste or soil backfill. Table 2-1 summarizes the concentrations of selected chemical constituents detected in these samples of soil-and-waste material disposed of in the Hex Pit.

Samples of native soil (referred to as "contiguous soil") were collected from beneath and adjacent to the Hex Pit as part of the characterization study (ENSR 1999), the screening investigation (Tetra Tech 2001), and the pre-treatment sampling effort. Many of the native soil samples collected beneath or very near the sides of the Hex Pit were visibly stained rust-orange or with streaks of black hex. Visibly contaminated contiguous soil samples often contained concentrations of the site's COCs similar to the soil-and-waste material composite samples. Contamination did not appear to migrate more than a few feet laterally into contiguous soil as evidenced by the lack of hex detected in contiguous soil samples collected approximately 8.5 feet from the sides of the Hex Pit as part of the pre-treatment sampling effort (see also Section 3.2.3).

Groundwater samples were analyzed as part of the screening investigation (Tetra Tech 2001) and pre-treatment sampling effort. Several VOCs, including chloroform, carbon tetrachloride, benzene, TCE, and PCE, were detected in these groundwater samples (Tetra Tech 2001), which are typical of a regional groundwater contaminant plume in the area (MK 1989). However, hex was not detected in these groundwater samples collected as near as approximately 13 feet downgradient of the Hex Pit boundaries.

2.3 *IN SITU* THERMAL DESTRUCTION SYSTEM DESIGN AT THE HEX PIT

TerraTherm's ISTD configuration at the Hex Pit was described in the Hex Pit Remediation Final (100%) Design Package (TerraTherm 2001). At this site, ISTD was designed to heat the soil above the boiling points of the COCs using a network of heater wells. The ISTD remediation design for the Hex Pit assumed that contamination extended 10 feet bgs. To attempt to ensure adequate heating and treatment of the contaminated soils within the delineated boundaries of the Hex Pit, the ISTD remediation design included heating the soil 5 feet laterally and 2 feet vertically beyond the delineated boundaries of the Hex Pit. This area encompassed a target treatment soil volume of 3,198 cy, extending from 0 to 12 feet bgs and 5 feet laterally beyond the boundaries of the Hex Pit. The ISTD heating duration was designed to be 85 days.

Approximately one-quarter of the heater wells were configured as combined heater-and-vacuum extraction wells (HV wells) to allow collection of the volatilized vapors. The well-field layout consisted of a triangular grid of thermal wells spaced on 6-foot centers with a 3.75:1 ratio of heater-only to heater-vacuum wells. The grid resulted in a total of 266 wells, of which 210 were heater-only wells and 56 were HV wells. All well casings (and screens for the HV wells) were constructed of Type 304 stainless steel. Figure 2-3 shows the well-field layout for the ISTD system. According to the developer's design, electrical heating elements placed in the wells were designed to reach temperatures of 1,400 to 1,600 °F, resulting in an extremely hot zone surrounding each heater well. The thermal well field was designed to achieve a minimum temperature of 617 °F between wells within the delineated boundary of the Hex Pit. A thermal heat front was to advance radially outward from the heater wells through thermal conduction.

As contaminants were drawn through the extremely hot zone that surrounds the heater wells, the technology developer expected the majority of the contaminant mass to be destroyed by oxidation or pyrolysis. Thus, the majority of contaminant mass destruction was expected to occur *in situ*. Steam stripping of contaminants was also expected to occur as the soil pore water was boiled off during the initial heating phase.

Soil along the boundaries of the treatment area were maintained under negative pressure to attempt to ensure that steam and volatilized contaminant vapors were captured and directed to the off-gas treatment system. A small vacuum (approximately 20 inches of water column) was expected to provide adequate capture of the vapors released during heating. Vapors extracted from the subsurface were treated aboveground. The aboveground piping network designed to transport vapors to the treatment system was constructed of Type 304 stainless steel, except for high-temperature reinforced flexible hose connecting vapor tees at the HV wellheads to the piping network.

The off-gas treatment system was designed to treat the incoming process vapor stream from the ISTD wellfield to reduce concentrations of organic and inorganic contaminants, including acid gases. The off-gas treatment system consisted of a cyclone separator, flameless thermal oxidizer (FTO), heat exchanger, knock-out pot, two acid gas dry scrubbers, two carbon bed adsorbers, and two main process blowers. The main process blowers were induced draft fans. The fans were designed to supply the motive force (vacuum) needed to draw the vapors from the well field and through the off-gas treatment system. Figure 2-4 is a process flow diagram of the ISTD system.

The cyclone separator was designed to remove particulates from the incoming vapor stream to prevent damage to, or clogging of, downstream off-gas treatment system equipment. The technology developer expected the quantity of particulates to be low at all times, but to increase with time as the soil dried out

The FTO was designed to convert organic constituents in the process stream to carbon dioxide and water vapor. Because a significant quantity of chlorinated organics was expected in the waste stream, hydrogen chloride (HCl) was expected to be produced during the oxidation process. Generation of the acid gas required a separate neutralization step before discharge to the atmosphere. The FTO was expected to operate at temperatures in the range of 1,500 to 1,900 °F.

TABLE 2-1
SELECTED ANALYTICAL RESULTS FOR HEX PIT SOIL-AND-WASTE-MATERIAL SAMPLES

Sample	Hexachlorocyclopentadiene (mg/kg)	Dieldrin (mg/kg)	Carbon Tetrachloride (mg/kg)	Chloroform (mg/kg)	Tetrachloroethene (mg/kg)	Dioxin/furan TEQ (ppb)
Composite Samples from ENSR 2000 Investigation						
North Composite [a,d]	3,350	130 U	17	8.3 U	17	NA
Middle Composite [a]	5,700	2,200	21	8.3 U	22	NA
South Composite [a,d]	7,950	130 U	20	8.3 U	18	NA
Master Composite [a,d]	8,100	5,600	8.3	1.9	13	123
Waste Composite [a]	21,000	1,800	34	31	51	NA
HBV25[b]	6,100	130 U	14	10	25	NA
Composite Samples from SITE Pre-Treatment Sampling						
PRE-W-1[c]	5,500	1,300	NA	NA	NA	581
PRE-W-2[c,d]	9,100	1,367	NA	NA	NA	287
PRE-W-3[c]	7,800	360	NA	NA	NA	596
PRE-W-4[c]	6,000	280	NA	NA	NA	147
PRE-W-5[c]	11,000	1,500	NA	NA	NA	178
PRE-W-6[c]	9,500	23	NA	NA	NA	430
Grab Samples from SITE Pre-Treatment Sampling						
PRE-W-1 (VOC)	NA	NA	8.6	22	4.8	NA
PRE-W-6 (VOC)	NA	NA	0.01	0.17	0.084	NA
PRE-W-14 (VOC)	NA	NA	0.035	0.15	0.2	NA
PRE-W-15 (VOC)	NA	NA	0.49	2.3	1.2	NA
PRE-W-16 (VOC)	NA	NA	3.8	2.4	6.7	NA
PRE-W-23 (VOC)	NA	NA	0.58	1.1	0.48	NA
PRE-W-31 (VOC)	NA	NA	13	4.6	3.7	NA
PRE-W-33 (VOC)	NA	NA	4.6	0.58	0.35	NA
PRE-W-36 (VOC)	NA	NA	5.6	0.47	4.3	NA

Notes:

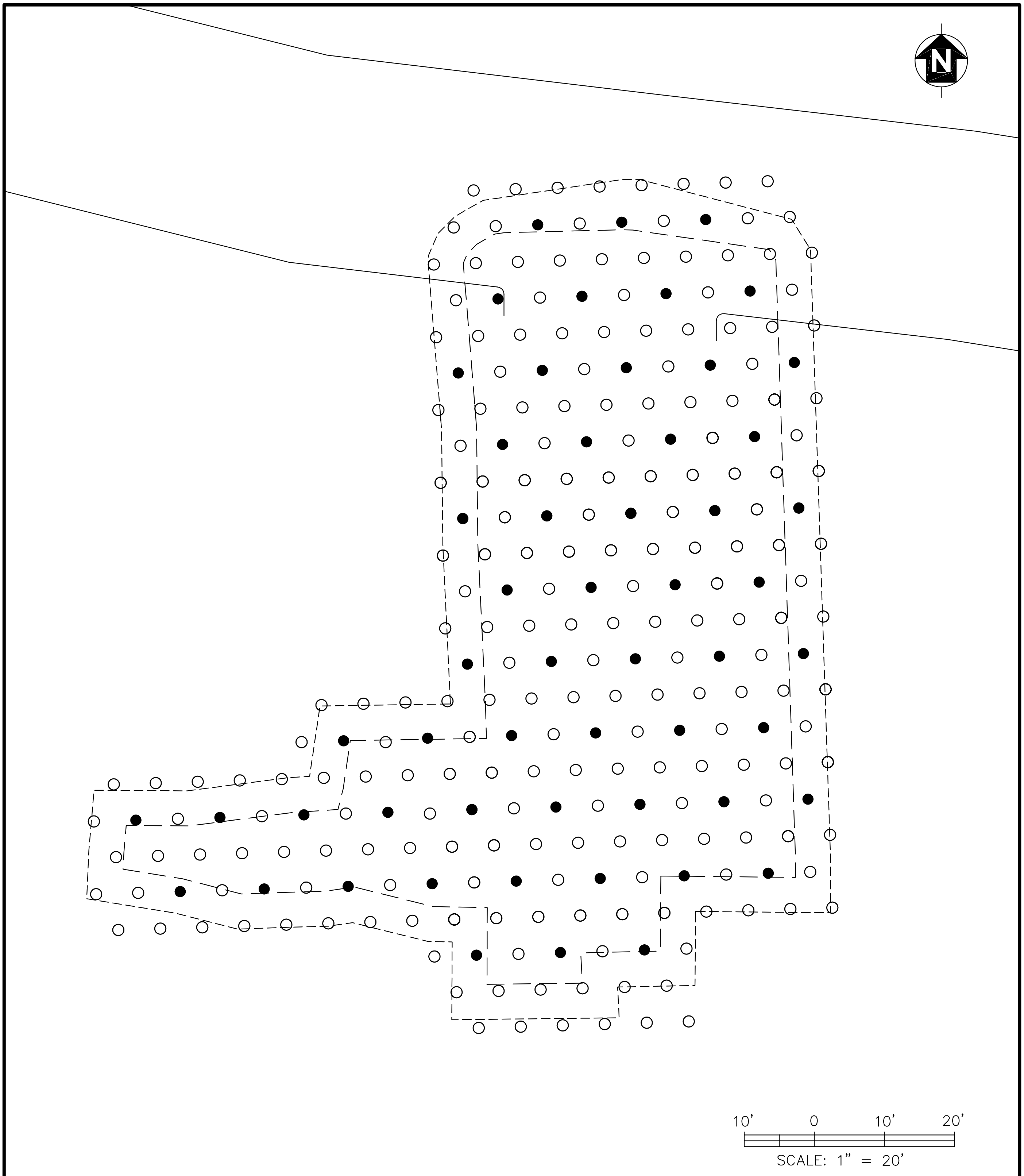
[a] Composite samples from northern, middle, and southern portions of the pit were produced by mixing core samples from three boreholes each (nine borings total). The Master Composite was generated by mixing portions of core from all nine borings. The Waste Composite was generated by mixing visibly contaminated material from all nine borings.

[b] Sample HBV25 was obtained from the 4- to 6-foot depth interval from beneath the concrete slab remaining from Building 571B.

[c] Pre-treatment composite samples were produced by mixing core samples from three borings each (18 borings total).

[d] Average concentration calculated from original and field replicate sample analytical results.

mg/kg	Milligrams per kilogram	T EQ	Toxicity equivalent
NA	Not analyzed	U	Not detected above detection limit shown
pb	Parts per billion	Sample results reported on a dry-weight basis	



NOTE: BASE MAP PROVIDED BY DP ASSOCIATES, INC.

LEGEND

— — — — HEX PIT BOUNDARY

------- TREATMENT AREA BOUNDARY

○ HEATER–ONLY WELLS

● HEATER–VACUUM WELLS

/\/ DIRT ROAD

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FIGURE 2–3

IN SITU THERMAL DESTRUCTION SYSTEM WELLFIELD LAYOUT

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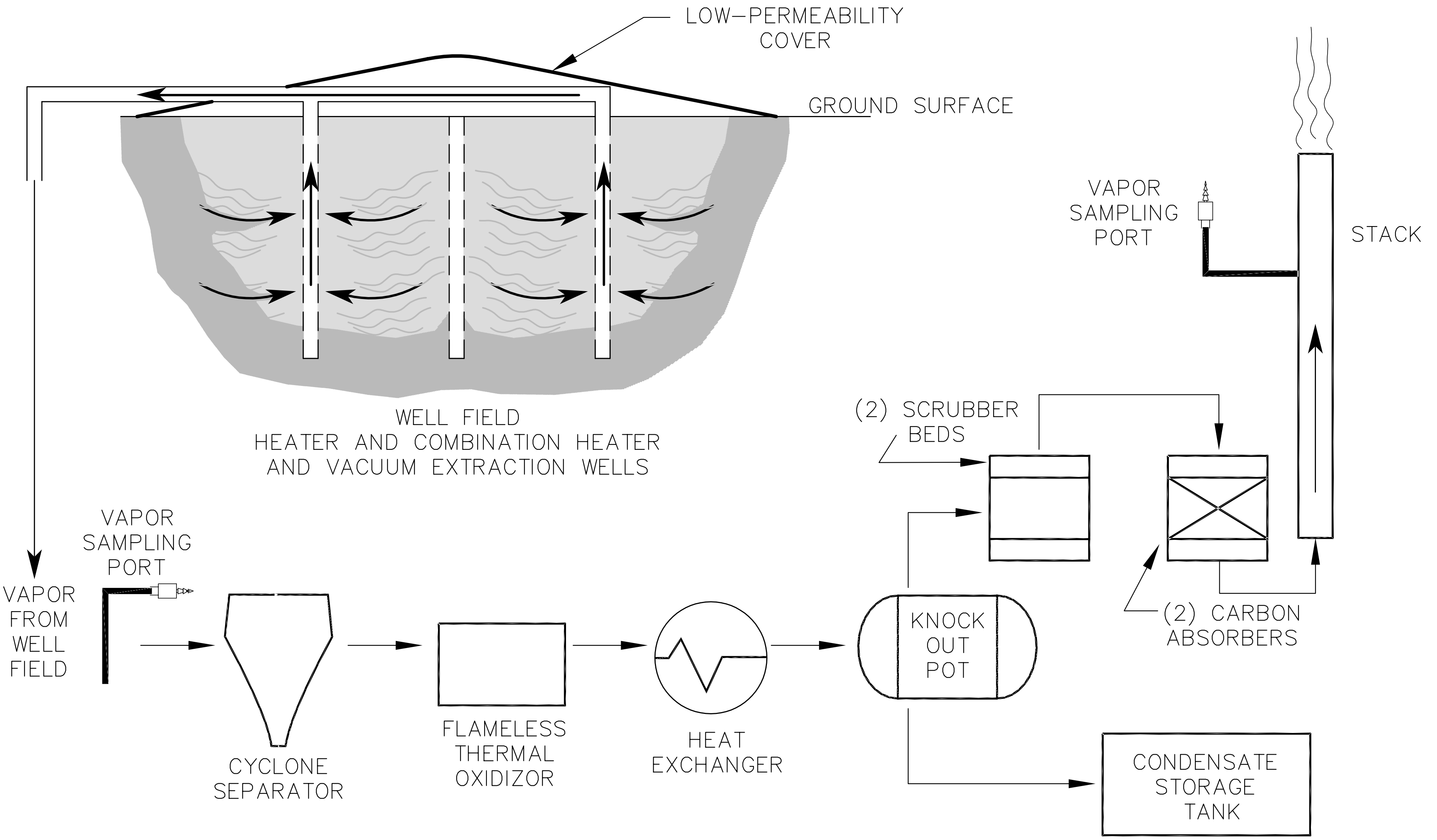

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FIGURE 2-4

PROCESS FLOW DIAGRAM
IN SITU THERMAL DESTRUCTION
TREATMENT SYSTEM

Tetra Tech EM Inc.

A heat exchanger was incorporated to decrease the temperature of the hot process gases that exited the FTO before it entered the scrubber and carbon adsorbers. The high-efficiency air-to-air heat exchanger was designed to cool the hot process stream from 1,600 to 200 °F with a residence time of less than 0.3 second.

Following the heat exchanger, the knock-out pot was used to separate the liquid from the vapor. The vapor passed into a dry scrubber used to neutralize acid gases in the vapor stream. The vapor stream flowed through two packed beds of granular scrubbing media, which were expected to neutralize hydrochloric acid vapor.

Two vapor-phase carbon adsorbers were installed downstream of the scrubber beds as a final polishing step to remove any remaining organic contaminants from the vapor stream. Contaminant mass loading on the adsorber was expected to be low because the technology developer expected that most of the contamination would be destroyed upstream of the carbon adsorbers. As a precaution, an emergency generator was provided and connected so that in the event of a loss of grid power, an automatic transfer switch would cause the generator to start within 30 seconds and continue to power the blowers and air quality control equipment throughout such an outage.

SECTION 3
TREATMENT EFFECTIVENESS

The following sections describe the methods by which the ISTD treatment technology was evaluated and the results of the evaluations.

3.1 DEMONSTRATION METHODOLOGY

The following sections describe the SITE demonstration objectives, including the original demonstration objectives and how the objectives were modified after failure of the ISTD system, the SITE pre- and post-treatment sampling that was completed, and the data quality assessment of the analytical results.

3.1.1 SITE Demonstration Objectives

Similar to other SITE demonstration projects, the ISTD demonstration at the Hex Pit included primary and secondary objectives designed to evaluate the ability of the technology to achieve specific clean-up criteria and to assess the cost and overall effectiveness of the treatment system. The primary objective planned for the demonstration, as described in the SITE project QAPP (EPA 2001), was as follows:

P1 To determine the ability of the TerraTherm ISTD remediation technology to meet RMA HHE cleanup criteria for COCs in soil-and-waste material within the Hex Pit boundaries. The COCs are hexachlorocyclopentadiene (hex), aldrin, dieldrin, endrin, isodrin, and chlordane.

The HHE clean-up criteria are included in Table 1-1 in Section 1.3.2. Secondary objectives planned for the ISTD demonstration were the following:

S1 Determine the cost of treatment for contaminated soil-and-waste material in the RMA Hex Pit.

S2 Evaluate the effluent gas-phase emissions from the TerraTherm treatment process.

S3 Evaluate the DREs of the Hex Pit COCs and dioxins and furans by *in situ* thermal treatment and the off-gas treatment system (FTO, heat exchanger, dry scrubber, and carbon bed).

S4 Compare contaminants remaining in the site soil after treatment to the contaminants present before treatment.

S5 Evaluate changes in concentrations of hex in soil and groundwater outside the boundary of the treatment area.

S6 Determine the ability of TerraTherm's ISTD technology to meet PRG clean-up criteria (shown in Table 1-1 in Section 1.3.2).

These objectives formed the basis for the sampling design described in the SITE project QAPP (EPA 2001) to evaluate the ISTD treatment process. The SITE objectives were to be achieved by collecting and analyzing soil-and-waste samples in the northern portion of the Hex Pit before and after the ISTD demonstration. Pre-treatment sampling was completed as described in the QAPP and is summarized in Section 3.1.2. However, as described in Section 4.0, the ISTD demonstration was terminated prematurely due to unexpected material failures. The average concentration of contaminants in post-treatment samples was considered unlikely to be much different from the average concentration of contaminants found in the pre-treatment samples. Consequently, the sampling strategy to achieve the demonstration objectives was no longer considered viable and was re-evaluated in the SITE post-treatment sampling and analysis plan (SAP) (EPA 2002).

Consistent with TerraTherm's Operations and Maintenance Manual, the heater-only wells were energized in stages. On the fifth day of heating, all heater-only wells in the southern third of the well field were energized; however, the heater-only wells in the northern two-thirds of the well field, which were scheduled to be energized around the time of the failure of the piping, were never turned on. Thus, heating within the northern portion was limited to the HV wells

The SITE post-treatment SAP considered that all HV wells were active for 12 days before system shutdown and may have produced discernable changes in contaminant concentrations in soil-and-waste material immediately adjacent to the wells.

Thus, the objective of the post-treatment sampling was to characterize contaminant concentrations in soil-and-waste material in close proximity to the HV wells (approximately 0.5 feet) for comparison to pre-treatment soil-and-waste material contaminant concentrations. Section 3.1.3 summarizes the post-treatment sampling.

3.1.2 SITE Pre-treatment Sampling

SITE pre-treatment sampling was completed as described in the SITE project QAPP (EPA 2001) to establish baseline conditions at the Hex Pit before construction and operation of the ISTD system. Sampling was confined to the northern half of the Hex Pit and was completed in July 2001. Sampling was confined to the northern half of the Hex Pit because the southern portion of the Hex Pit had been disturbed during the demolition and removal of the foundation of Building 571B, including the mixing of clean fill with material originally disposed of in the Hex Pit. Sampled materials included the soil-and-waste material originally disposed of in the pit; contiguous soil above, below, and laterally adjacent to the pit; and groundwater from piezometers flanking the pit. Table 3-1 summarizes the pre-treatment sampling, and Figures 3-1 and 3-2 show the sampling locations. The pre-treatment sampling results are summarized in Section 3.2.3.

The soil-and-waste material unit was the focus of the ISTD treatment process. Six composite soil-and-waste material samples were collected for analysis. Each composite sample was created by mixing material from three soil cores collected from 2 to 10 feet bgs. Boreholes were drilled using direct-push techniques, and soil cores were obtained with dual-tube sampling equipment. Samples were composited by mixing core material in disposable aluminum pans with disposable plastic scoops. Nine grab samples were also collected for analysis of VOCs. These grab samples were collected from soil cores from 5 feet bgs before the core material was transferred to the aluminum pans for compositing. Figure 3-1 shows the cores that were combined to form the composite samples, and the cores that were used to collect the grab samples for VOC analysis.

Three separate areas of contiguous soil were sampled: cover material above the Hex Pit soil-and-waste material unit (0 to 2 feet bgs); native soil below the soil-and-waste material unit (from two different depth intervals, including 10 to 12 feet bgs and 12 to 13 feet bgs); and native soil outside the perimeter of the Hex Pit. Three composite samples each were collected from the cover material and soil beneath the soil-and-waste material unit (from the two different depth intervals). Each composite sample was created by mixing material from six soil cores collected from the specified depth intervals. Nine grab samples were also collected for analysis of VOCs from a depth of 1 foot bgs in the cover material. Twelve native soil samples were collected outside the perimeter of the Hex Pit, approximately 3.5 feet beyond the boundary of the treatment area (8.5 feet beyond the edge of the Hex Pit). These soil samples were created by homogenizing core material collected from 2 to 10 feet bgs in boreholes drilled outside the Hex Pit. Figure 3-2 shows the cores that were combined to form the composite samples, the cores that were used to collect the grab samples for VOC analyses, and the outside perimeter borehole locations. Compositing and grab-sampling procedures for the contiguous soil samples were the same as procedures described for the soil-and-waste material samples.

Groundwater samples were collected from four piezometers located about 28 feet from the edges of the Hex Pit in each major compass direction (north, south, east, and west). Figures 3-1 and 3-2 show the piezometer locations.

3.1.3 SITE Post-Treatment Sampling

As described in Section 3.1.1, the ISTD demonstration was terminated prematurely due to unforseen material failures. Consequently, the post-treatment sampling strategy to achieve the demonstration objectives originally described in the SITE project QAPP (EPA 2001) was no longer considered viable.

TABLE 3-1

SITE PRE-TREATMENT HEX PIT SAMPLING SUMMARY

Hex Pit Soil-and-Waste Material - Pre-Treatment (Figure 3-1)

Sample Identification	Depth (feet bgs)	Composited Locations	VOC Sampling Locations (5 feet bgs)	Analyses
PRE-W-1	2 -10	1, 5, 16		COCs, SVOCs, D&F
PRE-W-1 (VOC) PRE-W-16 (VOC)	5		1, 16	VOC
PRE-W-2[a]	2 -10	7, 6, 9		COCs, SVOCs, D&F
PRE-W-6 (VOC)	5		6	VOCs
PRE-W-3	2 -10	14, 15, 17		COCs, SVOCs, D&F
PRE-W-14 (VOC) PRE-W-15 (VOC)	5		14, 15	VOCs
PRE-W-4	2 -10	21, 23, 25		COCs, SVOCs, D&F
PRE-W-23 (VOC)	5		23	VOCs
PRE-W-5	2 -10	28, 31, 32		COCs, SVOCs, D&F
PRE-W-31 (VOC)	5		31	VOCs
PRE-W-6	2 -10	26, 33, 36		COCs, SVOCs, D&F
PRE-W-33 (VOC) PRE-W-36 (VOC)	5		33, 36	VOCs

Contiguous Soil, Inside Pit Boundaries - Pre-Treatment (Figure 3-2)

Sample Identification	Depth Range (feet bgs)	Composited Locations	VOC Sampling Locations (1 foot bgs)	Analyses
PRE-S-1 (0-2)	0 - 2	1, 5, 16, 26, 33, 36		COCs, SVOCs D&F
PRE-S-1 (10-12)	10 - 12			
PRE-S-1 (12-13)	12 - 13			Hex
PRE-S-1 (VOC)	1		1, 16, 33, 36	VOCs
PRE-S-16 (VOC)				
PRE-S-33 (VOC)				
PRE-S-36 (VOC)				
PRE-S-2 (0-2)	0 - 2	6, 7, 9, 14, 15, 17		COCs, SVOCs D&F
PRE-S-2 (10-12)	10 - 12			
PRE-S-2 (12-13)	12 - 13			Hex
PRE-S-6 (VOC)	1		6, 14, 15	VOCs
PRE-S-14 (VOC)				
PRE-S-15 (VOC)				
PRE-S-3 (0-2)	0 - 2	21, 23, 25, 28, 31, 32		COCs, SVOCs D&F
PRE-S-3 (10-12)	10 - 12			
PRE-S-3 (12-13)[a]	12 - 13			Hex
PRE-S-23 (VOC)	1		23, 31	VOCs
PRE-S-31 (VOC)				

TABLE 3-1 (Continued)

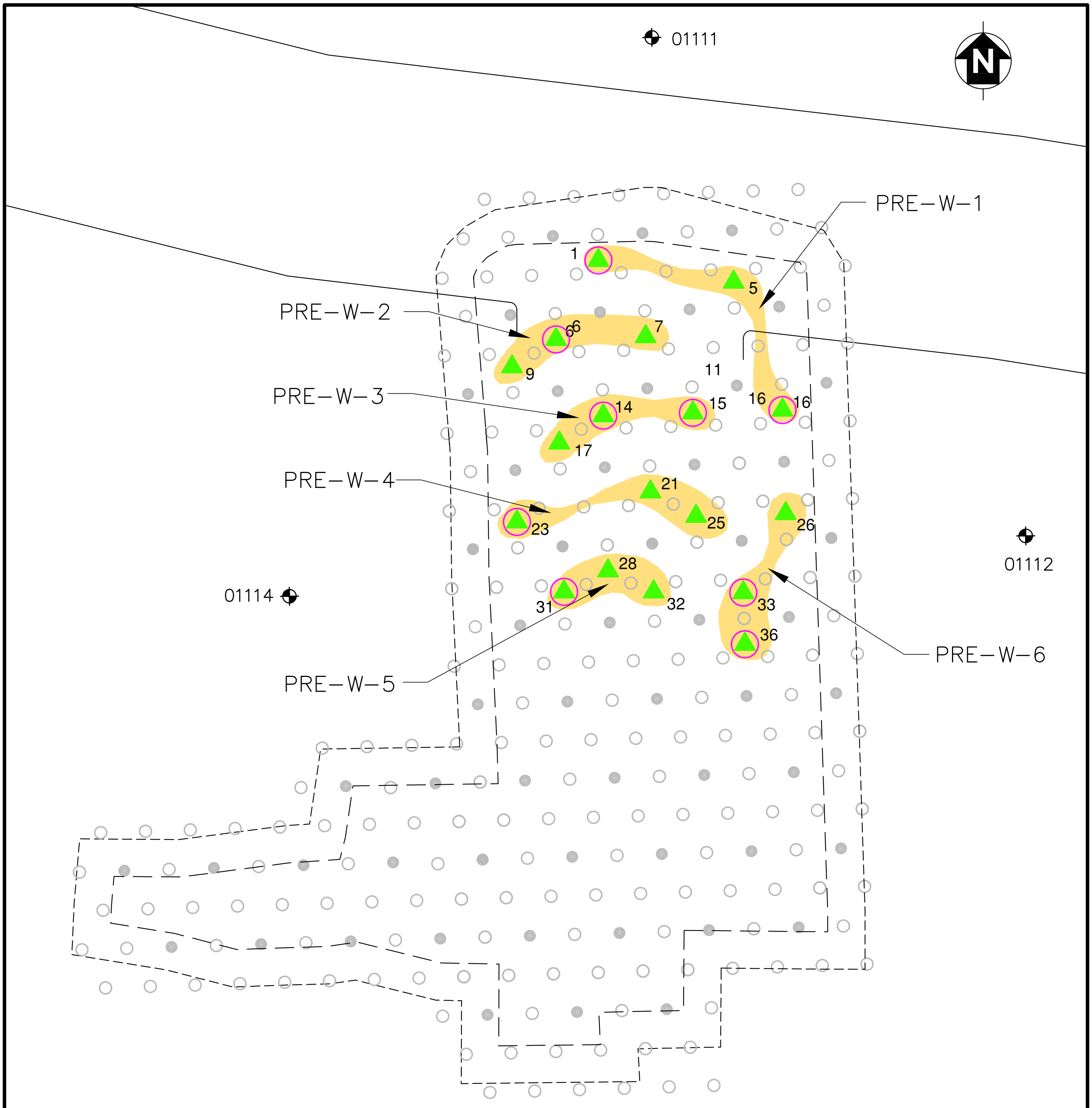
SITE PRE-TREATMENT HEX PIT SAMPLING SUMMARY

Contiguous Soil, Outside Pit Boundaries - Pre-Treatment (Figure 3-2)		
Sample Identification	**Depth Range (feet bgs)**	**Analyses**
PRE-S-E1 through E12[d]	2 - 10	Hex

Groundwater - Pre-Treatment	
Sample Identification	**Analyses**
PRE-GW-01111	Hex
PRE-GW-01112	Hex
PRE-GW-01113	Hex
PRE-GW-01114	Hex

Notes:

[a]	Samples collected in triplicate for field replicate
bgs	Below ground surface
COCs	Contaminants of concern (hexachlorocyclopentadiene, aldrin, chlordane, dieldrin, endrin, and isodrin)
D&F	Dioxin and furan congeners
Hex	Hexachlorocyclopentadiene
SVOCs	Semivolatile organic compounds
VOCs	Volatile organic compounds



LEGEND

- – – HEX PIT BOUNDARY
- - - - TREATMENT AREA BOUNDARY
- ▲ HEX PIT INTERIOR PRETREATMENT SAMPLING LOCATION
- ◉ PRETREATMENT VOC SAMPLING LOCATION
- ○ HEATER–ONLY WELLS
- ● HEATER–VACUUM WELLS
- ⊕ PIEZOMETER WELL LOCATION
- ╱╲╱ DIRT ROAD
- ▬ 2'–10' COMPOSITES

10' 0 10' 20'

SCALE: 1" = 20'

NOTE: BASE MAP PROVIDED BY DP ASSOCIATES, INC.

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FIGURE 3–1

SITE PRETREATMENT SOIL AND WASTE MATERIAL SAMPLING LOCATIONS

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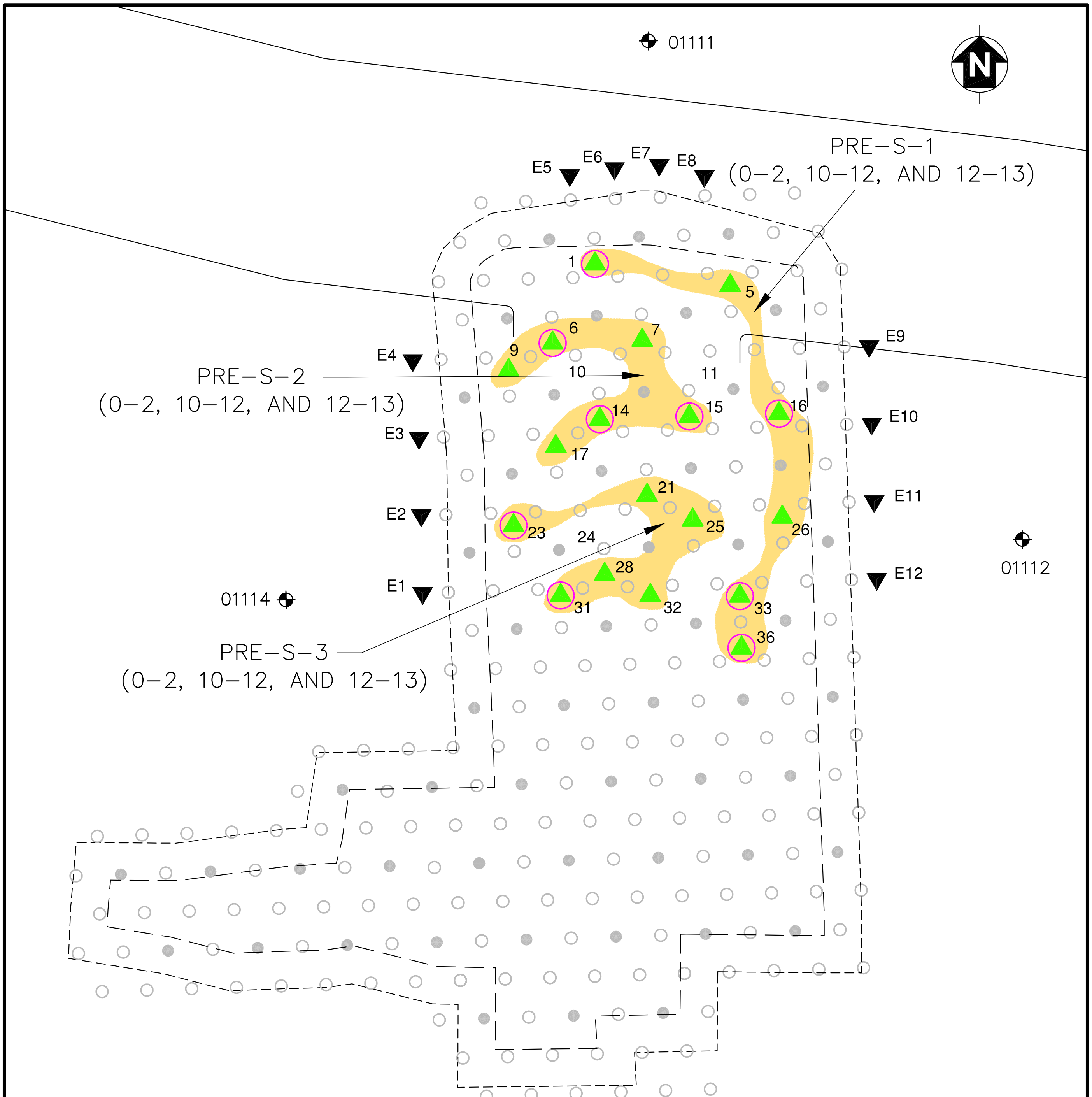

LEGEND

— — — HEX PIT BOUNDARY

- - - - - TREATMENT AREA BOUNDARY

▲ PRETREATMENT VOC SAMPLING LOCATION

▲ HEX PIT INTERIOR PRETREATMENT SAMPLING LOCATION

▼ HEX PIT EXTERIOR SAMPLING LOCATION

○ HEATER–ONLY WELLS

● HEATER–VACUUM WELLS

⊕ PIEZOMETER WELL LOCATION

/\/ DIRT ROAD

▨ 0'–2', 10'–12', 12'–13' COMPOSITES

⊕ 01113

10' 0 10' 20'

SCALE: 1" = 20'

NOTE: BASE MAP PROVIDED BY DP ASSOCIATES, INC.

ISTD DEMONSTRATION
ROCKY MT. ARSENAL

FIGURE 3–2

SITE PRETREATMENT CONTIGUOUS SOIL SAMPLING LOCATIONS

Tetra Tech EM Inc.

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The SITE post-treatment sampling objectives and procedures were re-evaluated in the SITE post-treatment SAP (EPA 2002). The post-treatment sampling consisted of collecting six samples from the soil-and-waste material unit from close proximity (approximately 0.5 foot) to six ISTD HV wells. Table 3-2 summarizes the SITE post-treatment sampling, and Figure 3-3 shows the sampling locations. The post-treatment sampling results are summarized in Section 3.2.4.

Following the failure of the ISTD system, the site was buried under approximately 3 feet of imported fill material. Since the southern portion of the site was lost to physical disturbance and was unavailable for sampling, the SITE post-treatment sampling was completed by first marking the presumed locations of buried HV wells in the northern half of the Hex Pit. Hand digging through the fill material was then conducted to find the tops of the HV wells. Once the tops were verified, offsets were measured to locate where an angled borehole would be started to collect cores from the soil-and-waste material unit adjacent to the HV well casing. The boreholes were angled to avoid steel plates welded to the well casings and to position the borehole approximately 0.5 foot from the HV well at depths of 2 to 10 feet below the original surface of the Hex Pit cover material. Figure 3-4 diagrams this approach to drilling the SITE post-treatment sampling boreholes. Similar to the SITE pre-treatment sampling effort, the boreholes were drilled by direct-push techniques, and core samples were collected using dual-tube sampling equipment. The samples were created by homogenizing core material collected from 2 to 10 feet below the original top of the Hex Pit cover material. Six grab samples were also collected for analysis of VOCs from a depth of 5 feet below the top of the soil-and-waste material unit.

3.1.4 SITE Data Quality

SITE pre- and post-treatment laboratory analytical data were validated to confirm that the results were satisfactory for use in addressing the project objectives. Appendix A includes the validation reports for all SITE pre- and post-treatment laboratory analytical data generated for this project. The validation reports discuss the performance of the internal quality control (QC) checks conducted by the laboratory during the sample analyses, such as results for matrix spike/matrix spike duplicate (MS/MSD) samples and surrogate spikes. In addition to the internal QC checks, field replicate samples were collected during the treatment demonstration as external (field) QC samples. These co-located samples included one triplicate sample of contiguous soil and another of soil-and-waste material collected during the pre-treatment sampling, and one duplicate soil-and-waste material sample collected during the post-treatment sampling.

Overall, the findings of the QC checks and data validation indicated that the sample analyses were acceptable as qualified; no results were considered unusable. All validation qualifiers are listed with the analytical results summarized in the validation reports in Appendix A. As described in the validation reports, the analyses rendered an expected level of data quality, given the nature of the analytical methods and the samples. The analytical methods were designed to identify and quantitate low concentrations of organic compounds in relatively uncontaminated soil matrices. However, many of the samples contained relatively high concentrations of many organic compounds. This complexity produced many failures of QC measures, such as matrix interferences manifested in irregular MS/MSD results, surrogate recoveries, and internal standard results. In other instances, QC data were lost entirely due to the high dilutions required for many samples prior to analysis. Required dilutions produced very high quantitation limits for many analytes and samples.

TABLE 3-2

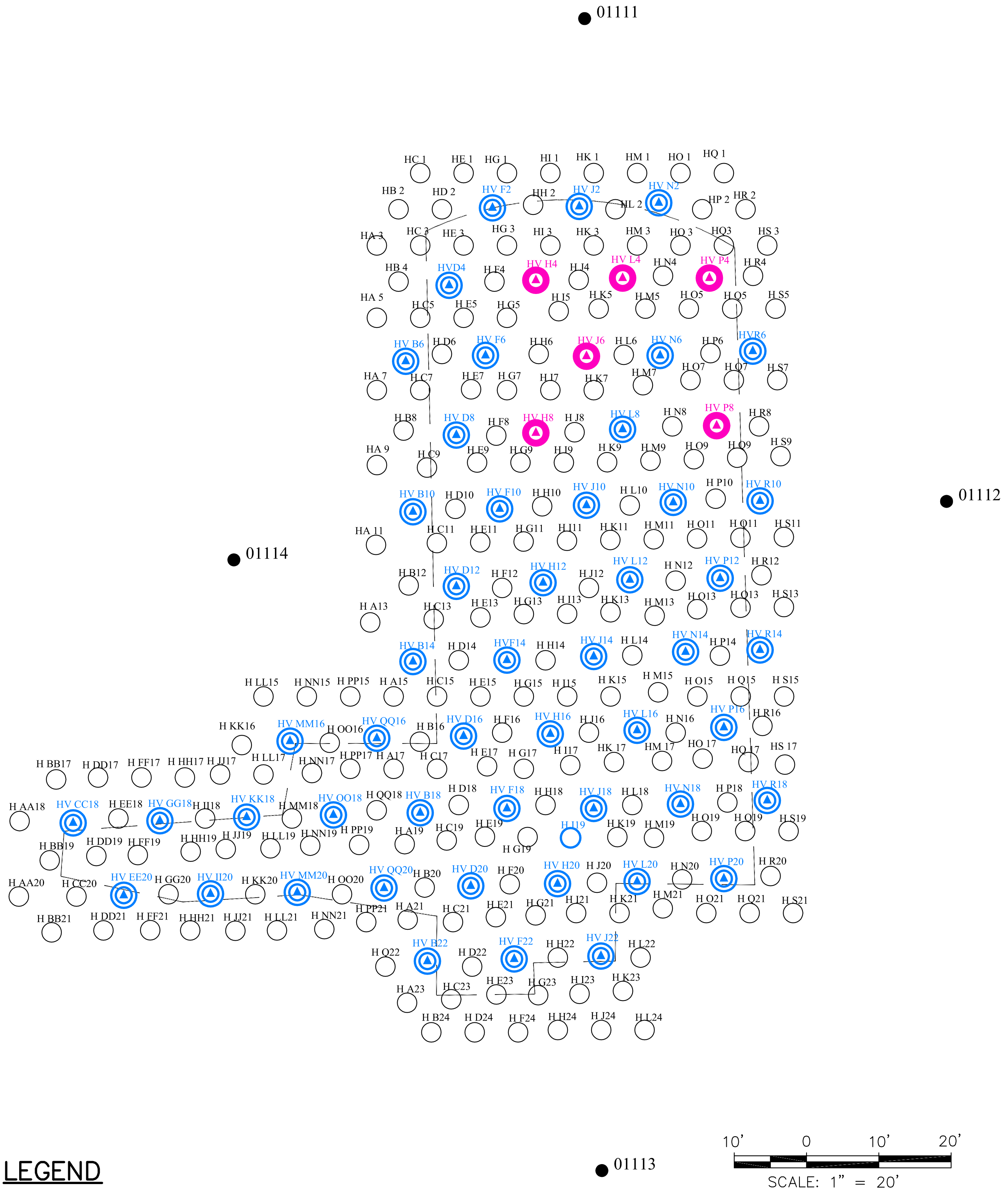
SITE POST-TREATMENT HEX PIT SAMPLING SUMMARY

Sample Identification	Depth (feet bgs)	Analyses
POST-W-HVH4[a]	7.6 - 15.6	COCs, SVOCs
		D&F
	12.6	VOCs
POST-W-HVP4	4.8 - 12.8	COCs, SVOCs
		D&F
	7.8	VOCs
POST-W-HVL4	5.5 - 13.5	COCs, SVOCs
		D&F
	8.5	VOCs
POST-W-HVJ6	5.7 - 13.7	COCs, SVOCs
		D&F
	8.7	VOCs
POST-W-HVH8	5.8 - 13.8	COCs, SVOCs
		D&F
	8.8	VOCs
POST-W-HVP8	6 - 14	COCs, SVOCs
		D&F
	7.5	VOCs

Notes:

[a] Samples collected in duplicate for field replicate

bgs	Below original ground surface
COCs	Contaminants of concern (hexachlorocyclopentadiene, aldrin, chlordane, dieldrin, endrin, and isodrin)
D&F	Dioxin and furan congeners
SVOCs	Semivolatile organic compounds
VOCs	Volatile organic compounds



LEGEND

HV B6 ◉ POST–TREATMENT SAMPLING LOCATION

HV L20 ◉ HEATER–VACUUM WELL LOCATION

H B24 ○ HEATER–ONLY WELL LOCATION

0113 ● PIEZOMETER WELL LOCATION

— HEX PIT BOUNDARY

ISTD DEMONSTRATION
ROCKY MT. ARSENAL

FIGURE 3–3

SITE POST–TREATMENT SAMPLING LOCATIONS

Tetra Tech EM Inc.

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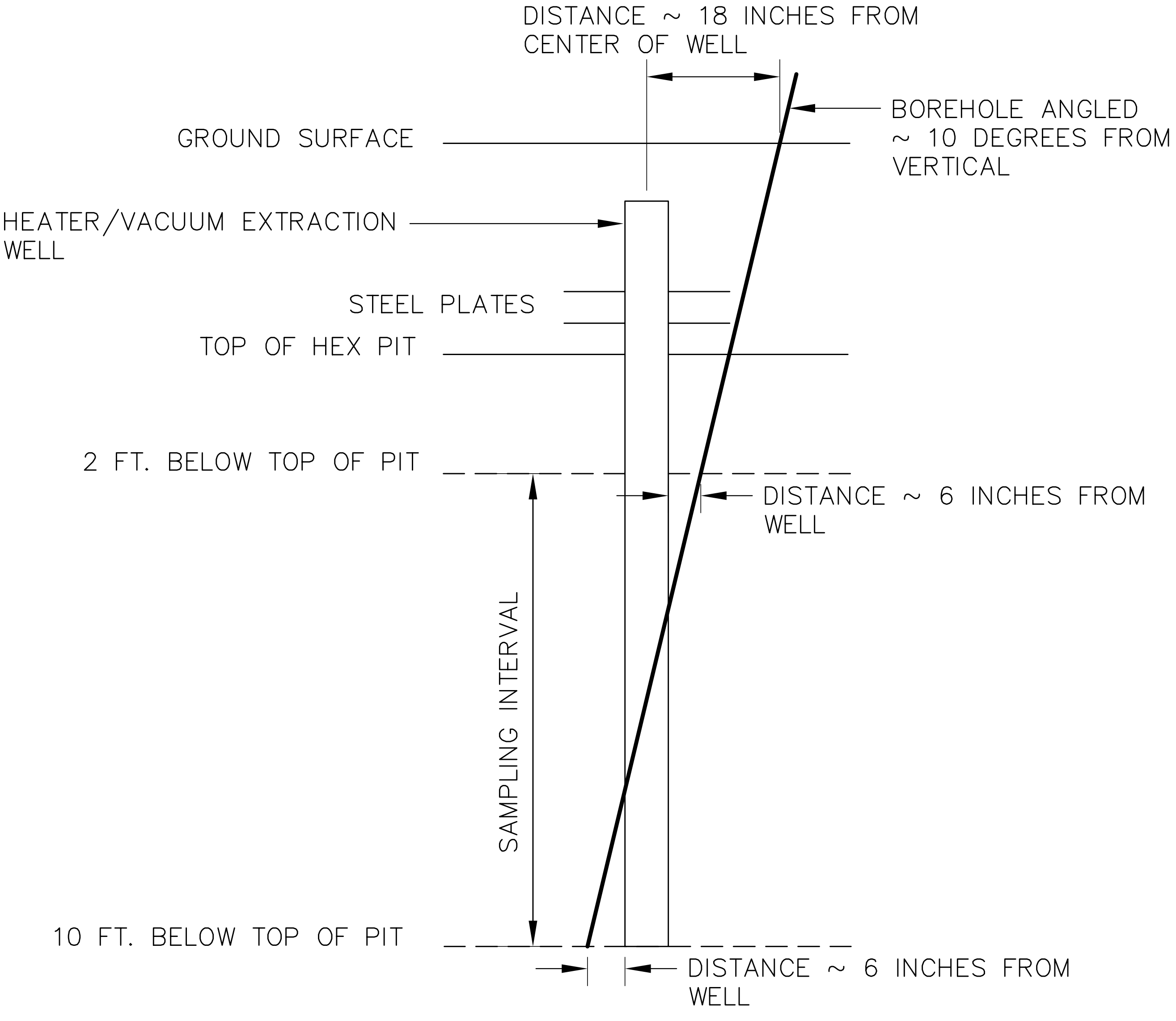

ISTD DEMONSTRATION
ROCKY MT. ARSENAL

FIGURE 3–4

POST–TREATMENT SAMPLING BOREHOLE DRILLING PLAN

Tetra Tech EM Inc.

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In general, the high concentrations and complex sample matrices increase the potential for false positives in the data sets and give the quantitative results an "estimated" character. Although the complex nature of the samples remained consistent between the SITE pre- and post-treatment samples, the comparability of the two data sets is limited by the different sampling approaches applied for the pre- and post-treatment events. The utility of the data sets for assessing the effects of the ISTD treatment process is further limited by the inherent heterogeneity of the soil-and-waste material in the treatment zone. The comparability of the two sampling events is further discussed in Section 3.2.5.

The SITE pre- and post-treatment analytical data were compared to precision, accuracy, representativeness, completeness, and comparability (PARCC) objectives outlined in the project QAPP (EPA 2001). The following sections summarize the evaluation of the PARCC objectives.

Precision

Precision is a measure of the reproducibility of an experimental value without regard to a true or referenced value. The primary indicators of precision were the relative percent difference (RPD) results for the MS/MSD analyses, the RPD between the field duplicate pair collected during the post-treatment sampling, and the percent relative standard deviation (%RSD) between the three replicate field samples collected during the pre-treatment sampling. The RPD and %RSD values for the duplicate and replicate samples are shown in Table 3-3. The inherent heterogeneity of soil samples often result in high RPD and %RSD values in duplicate and replicate analyses. This heterogeneity is apparent in some of the field replicate results shown in Table 3-3, particularly in the high RPDs calculated for the VOCs in the post-treatment duplicate. Due the high concentration of analytes, the MS/MSD spiking amounts were diluted out for many samples and could not be used to evaluate the level of precision. Overall, however, acceptable precision was found for the pre- and post-treatment analytical results for the field, given the high analyte concentrations and complex matrices in the samples analyzed.

Accuracy

Accuracy assesses the proximity of an experimental value to a true or referenced value. The primary indicators of accuracy are compound recoveries in surrogate, MS, and laboratory control sample (LCS) analyses. Accuracy is expressed as percent recovery. Due to the high concentration of analytes in the samples, the MS spiking amount was often diluted out and could not be used to evaluate accuracy. Having only partial data to evaluate the overall accuracy, leads to an inconclusive judgement. Though the surrogate and LCS recoveries were adequate, the overall accuracy of these data could not be determined.

Representativeness

Representativeness refers to the ability of data to reflect true environmental conditions. Results were evaluated for representativeness by examining items that were related to the collection of the samples, such as the chain-of-custody documentation, which included accurate sample labeling, recording correct sample collection dates, and confirming the condition of the samples when they were received at the laboratory. Laboratory procedures were also examined, including anomalies reported by the laboratory either when the samples were received or during the analytical process, including evaluating sample holding times, appropriate calibration of laboratory instruments, adherence to analytical methods, appropriate quantitation limits, and the completeness of the data package documentation. Items not meeting the criteria are documented in the validation reports. Overall, acceptable representativeness was found for the pre- and post-treatment analytical results.

Completeness

Completeness is defined as the percentage of measurements that are considered valid. The validity of the analytical results is assessed through the data validation process. All results that are rejected and any missing values are considered incomplete. Data that are qualified as estimated or nondetected are considered valid. Completeness is measured by comparing the total number of samples planned in the QAPP to the total number of samples collected, and the total number valid results compared to the total number of analytical results. Analytical completeness is measured by dividing the total number of valid results by the total number of results and multiplying by 100. Each analyte from each method is multiplied by the number of samples analyzed to calculate the total number of results. As no data were rejected and all data were collected and analyzed as specified in the SITE project QAPP (EPA 2001) and post-treatment SAP (EPA 2002), completeness for this investigation was 100 percent.

Comparability

Comparability is a qualitative parameter that expresses the confidence with which one data set may be compared to another. Comparability of data is achieved by the use of uniform sampling procedures, standard methods of analysis, standard quantitation limits, and standardized data validation procedures. The use of approved laboratories, specified and well-documented analyses, and standard processes of data review and validation give the pre- and post-treatment data sets a high degree of analytical comparability. However, as discussed in Section 3.5.2, the need to modify the post-treatment sample collection and preparation procedures relative to those procedures used to obtain the pre-treatment samples renders accurate comparability of the data sets somewhat questionable.

3.2 DEMONSTRATION RESULTS

The following sections summarize evaluations of the ISTD system at the RMA Hex Pit. Pre-construction evaluations are summarized that were not completed by EPA's SITE Program, but by the technology developer, to estimate the performance of the system to assist in the design process. A brief chronology of system operations at the Hex Pit is presented as well as SITE's pre- and post-treatment sampling results. Finally, a comparison of the SITE pre- and post-treatment sampling results is presented.

3.2.1 Pre-construction Evaluations

Pre-construction evaluations completed by the technology developer included a treatability study of the effectiveness of thermal treatment on representative contaminated soil-and-waste samples from the Hex Pit, computer simulation modeling to optimize the subsurface thermal and vapor flow operating parameters, and field testing of the ISTD well design at a separate test site. The results of these evaluations are summarized below.

Treatability Study

A bench-scale treatability study of the ISTD technology was conducted on contaminated samples collected from the Hex Pit (ENSR 2000). The treatability study samples were collected during the characterization study (ENSR 1999) and included the Master Composite and the Waste Composite. Table 2-1 includes a summary of contaminant concentrations detected in the Master and Waste Composite samples before treatment. The purpose of the treatability study was to evaluate whether the ISTD technology could achieve a 90 percent DRE for each of the site COCs.

Additional objectives of the study included comparing post-treatment concentrations of the site COCs to the site-specific clean-up goals, and evaluating the off-gas stream produced for use in designing an emission control system.

In the treatability study, the test samples were thermally treated at a target temperature range of approximately 1,000 to 1,900 °F under controlled vapor flow conditions to simulate treatment of the Hex Pit material by the ISTD process. After treatment, the test samples were recovered and analyzed for residual contaminant concentrations. The post-treatment sampling results indicated that DREs of 99 percent were achieved for the site COCs and that the site cleanup goals could be met. Dioxin and furan concentrations were reduced by more than 90 percent, and test results indicated that dioxins and furans were not created by the thermal treatment process. Evaluation of off-gas emissions from the test indicated that a significant quantity of HCl vapor or chlorine gas was emitted during thermal treatment. However, it was postulated by the developer that actual field emission rates would be lower because of the buffering capacity of the soils in the Hex Pit.

TABLE 3-3

SITE FIELD REPLICATE COMPARISON

Target Analyte		**%RSD or RPD**
Pre-Treatment Contiguous Soil (one triplicate)		**%RSD**
	Hexachlorocyclopentadiene	18.7
Pre-Treatment Soil-and-Waste Material (one triplicate)		**%RSD**
	Hexachlorocyclopentadiene	6.9
	Hexachlorobenzene	16.5
	Hexachlorobutadiene	12.8
	Chlorinated pesticides[a]	14 - 44
	Chlorinated dioxins/furans	27.7
Post-Treatment Soil-and-Waste Material (one duplicate)[b]		**RPD**
	Carbon tetrachloride	177
	Chloroform	81
	Tetrachloroethene (PCE)	192
	Hexachlorocyclopentadiene	69
	Hexachlorobenzene	14
	Chlorinated pesticides[a]	5 - 6
	Chlorinated dioxins/furans	13

Notes:

a	For multi-parameter analytes, the range of %RSDs is reported for the individual compounds that were detected in all samples of the replicate.
b	The post-treatment duplicate results include data for selected VOCs of interest. No pre-treatment replicates were collected for VOC analysis.
%RSD	Percent relative standard deviation
RPD	Relative percent difference

Simulation Modeling

The developer conducted simulation modeling as part of the ISTD system design effort to evaluate optimal subsurface thermal and vapor flow operating parameters. The simulation modeling report was included as Appendix I to the Final 100 Percent Design Package (TerraTherm 2001). Simulations were conducted using a three-dimensional, multiphase flow, multicomponent, non-isothermal model to evaluate the following:

- The optimal placement of HV and heater-only wells and the required electrical load per heater.
- The expected time-course and duration of heating to achieve the target temperature throughout the treatment zone.
- The extraction vacuum and flow rate required to accommodate the predicted water vapor and emissions generation rates.
- The length of time required after heating for soil to cool to ambient temperatures.

The simulation results indicated that a ratio of 3 to 1 heater-only to HV wells set at a 6-foot inter-well spacing was optimal to achieve the site clean-up goals in a relatively short period of time. An edge-well 3:1 triangular well placement pattern best ensured the capture of volatilized contaminants. Simulation results also indicated that soil temperatures in portions of the treated area may remain in the range of 450 to 500 °F for up to 120 days after heating, and may remain as hot as 300 °F for up to 180 days after heating ceases.

Field Testing

Field testing of ISTD wells at a location in Houston, Texas was completed as part of the 95 percent design effort. The field testing report was included as Appendix J to the Final 100 Percent Design Package (TerraTherm 2001). The purpose of the field test was to evaluate a new generation of HV and heater-only wells for use at the Hex Pit site. ISTD wells used during previous applications were relatively complex in design and expensive to construct. Field testing identified a new well design that could result in substantial cost savings for the Hex Pit project by using materials that were readily available and that could be routinely fabricated. Problem-free performance over the course of a 63-day field trial resulted in the new well design being incorporated into the ISTD system at the Hex Pit.

3.2.2 Chronology of System Operation at the Hex Pit

The following is a summary of the chronology for the ISTD system operation at the Hex Pit (adapted from TerraTherm 2002 and FWENC 2002):

- October 4, 2001 - The technology developer (TerraTherm) mobilizes to the Hex Pit site.
- October 9, 2001 through February 18, 2002 - Construction of the ISTD system at the Hex Pit. Activities include site preparation, installation of wells, placement of the surface cover and aboveground piping network, installation of the electrical system, and assembly of the off-gas treatment system. In addition, RVO installed three horizontal wells under the Hex Pit as a contingency for dewatering should the water table surface rise to a level that would be detrimental to operation of the ISTD system.
- February 19 through March 2, 2002 - System shakedown testing and checking, and preheating of the piping network and FTO.
- March 3, 2002 - Start of ISTD heating operation. All 56 HV wells were energized and vapors were drawn from the wellfield.
- March 5, 2002 - 84 heater-only wells were energized in the southern third of the wellfield
- March 11, 2002 - Liquid observed collecting in flexible hoses connecting the HV wells to the aboveground piping network.
- March 11, 2002 - Sagging noticed in aboveground piping at the southern end of the well field and a faint odor noticed from the wellfield.
- March 14, 2002 - Two manifold pipe taps in the aboveground piping network observed to be leaning, closer inspection concluded that tap welds had corroded. During investigation of the damage, a seal on an HV well was damaged and steam leaked out at the base plate.
- March 15, 2002 - Steam and strong odors emitted from an HV well. Loss of vacuum pressure noticed in southern end of wellfield. Several heaters experience electrical shorting, including an insertion heater in the aboveground piping network and a down-hole heater in an HV well. Power to the wellfield heaters was shut down. The piping network insertion heaters and off-gas treatment system continue to operate.
- March 17, 2002 - All wellfield manifold valves were

closed and the off-gas treatment system and insertion heaters were shut down.

Soil temperatures were variable in the northern portion of the Hex Pit (location of EPA SITE's pre- and post-treatment sampling efforts) during the 12-day heating period. By heating day 5, thermocouples located 1 foot from HV well HVD16, located in the row immediately north of the southern third of the well field, reached temperatures of approximately 70 °F, 120 to 170 °F, and 250 °F at near the ground surface, the 4- to 7-foot-deep, and the 10-foot-deep locations, respectively. By heating day 12, temperatures were 120 °F near the ground surface, just over 200 °F at 4 to 7 feet, and 416 °F at 10 feet. Farther north in the wellfield, temperatures within 1 foot of HVP8 at heating day 5 were 200 to 220 °F, except at a depth of 4 feet, where the temperature was approximately 125 °F. By heating day 12, temperatures at that location reached a maximum of 237, 237, 398, and 458 °F at depths of 1, 4, 7, and 10 feet, respectively. Soil temperatures measured by thermocouples installed in the far northern end of the pit were still below 100 °F after 12 days of heating. Following shutdown of the wellfield heaters, soil temperatures in the vicinity of the operating HV wells in the northern half of the pit generally dropped 50 to 100 °F or more within 1 week of shutdown.

3.2.3 SITE Pre-Treatment Sampling Results

As described in Section 3.1.2, SITE pre-treatment samples were collected of soil-and-waste material originally disposed of in the pit; contiguous soil above, below, and laterally adjacent to the pit; and groundwater from piezometers flanking the pit. Table 3-1 summarizes the SITE pre-treatment sampling completed, and Figures 3-1 and 3-2 show the sampling locations. All SITE pre-treatment sample analytical results are included in the validation summary reports in Appendix A. All results are included in the validation summary reports, even though only analytical results from the soil-and-waste material samples are necessary to address the project objectives that were modified after failure of the ISTD system. For completeness, Appendix B includes all borehole logs completed as part of the pre-treatment sampling event.

As expected from previous investigations, the soil-and-waste material unit consisted primarily of soil (primarily silty sand) layered with waste material. The soil was often stained dark brown, rust orange, or black, and often contained granules of probable hex. Tar-like, relatively pure hex waste material often occurred as bands or layers, usually less than 1 foot thick. Other substances observed in the soil-and-waste material unit included rusted metal fragments (probably from corroded drums), black to orange and occasionally white crystalline substances, layers of a light bluish-gray paste-like material that was probably lime, and wood fragments. The SITE pre-treatment soil-and-waste material samples were composited from core samples collected from 2 to 10 feet bgs. In general, most of the tar-like hex waste material occurred between depths of 4 to 7 feet bgs. Soil from 7 to 10 feet bgs was often stained with small amounts of contamination. In general, a distinct contact between soil-and-waste material disposed of in the pit and native soil was difficult to determine. Table 2-1 in Section 2.2.3 includes selected analytical results from SITE pre-treatment sampling of the soil-and-waste-material unit.

Contiguous soil above the soil-and-waste material unit generally consisted of a surficial cover, often about 1 foot thick, consisting primarily of silty sand and gravel. SITE pre-treatment samples were collected from 0 to 2 feet bgs and often the lower half of this interval included the silty sand material characteristic of the soil-and-waste material unit, often containing minor amounts of probable hex granules. Contiguous soil beneath the soil-and-waste material unit was collected from two intervals: 10 to 12 feet bgs and 12 to 13 feet bgs. Although the base of the Hex Pit was often difficult to accurately determine, it appeared that soil below 10 feet bgs was probably in-place native soil. Minor contaminant staining, including streaks of black hex, was occasionally observed in the native soil beneath the Hex Pit.

Contiguous soil was also sampled adjacent to the Hex Pit. These soil samples all appeared as uncontaminated native soil. Samples of the laterally contiguous soil were only analyzed for hex concentrations, and no hex was detected in these samples.

3.2.4 SITE Post-Treatment Sampling Results

As described in Section 3.1.3, the SITE post-treatment sampling boreholes were drilled through a soil cover that was placed over the site following failure of the ISTD system. Core samples were examined to determine when the borehole had reached the surface of the soil-and-waste material unit. Once into the soil-and-waste material unit, core samples were collected and prepared for laboratory analysis. The SITE post-treatment samples were created by homogenizing core material from single boreholes drilled through the soil-and-waste material unit. The SITE post-treatment sampling procedure was different from the SITE pre-treatment sampling procedure, which composited core material from three separate boreholes for each soil-and-waste material sample.

In general, the post-treatment core samples from the soil-and-waste material unit appeared similar to the pre-treatment cores. That is, the unit did not appear to have undergone a significant change in physical characteristics as a result of the relatively short-term operation of the HV wells. All SITE post-treatment sample analytical results are included in the validation summary reports in Appendix A. Appendix B includes all borehole logs completed as part of the post-treatment sampling event.

3.2.5 Comparison of SITE Pre- and Post-Treatment Sampling Results

The objective of collecting the SITE post-treatment samples was to evaluate if contaminant concentrations in the soil-and-waste material in close proximity to the HV wells were appreciably different from concentrations detected in the SITE pre-treatment samples. Table 3-4 lists the concentrations of selected compounds detected in SITE pre- and post-treatment samples collected from the soil-and-waste material unit. The selected compounds shown in Table 3-4 were consistently detected in historical and SITE pre-treatment samples and include the site COCs hex, aldrin, and dieldrin; VOCs carbon tetrachloride, chloroform, and PCE; and total TEQs calculated for dioxins and furans. The comparison between contaminant concentrations detected in the SITE pre- and post-treatment samples is intended to evaluate whether any contaminant destruction or removal took place during the brief operation of the ISTD system. Two different evaluations are presented, including a qualitative comparison and a statistical comparison conducted according to procedures specified in the SITE post-treatment SAP (EPA 2002).

Qualitative Comparison of SITE Pre- and Post-Treatment Sampling Results

The following sections describe a qualitative comparison of SITE pre- and post-treatment sampling data for the site COCs, VOCs, and dioxin and furan TEQs. Various plots were generated to evaluate the data including frequency plots, normal probability plots, box-and-whisker plots, and scatter plots (Figures 3-5 through 3-9). The frequency plots are similar to histograms and show the number of observations (y-axis) per concentration grouping (x-axis) for the pre-treatment and post-treatment samples. The scatter plot simply shows the concentration (y-axis) of the chemical in each sample (x-axis). The box and whisker plots show the median concentration (50th percentile) as the small square, the interquartile range (25th to 75th percentile) as the larger rectangular box, and the whiskers extending out to the minimum and maximum concentrations. The symmetry (or lack thereof) of the box and whiskers around the median reflects the data distribution (that is, normal or skewed). Finally, the normal probability plots show the concentration of each chemical in each sample in a manner that also shows how well the data set fits a normal distribution. Specifically, a probability plot is a graph of values, ordered from lowest to highest and plotted against a standard normal distribution function. The horizontal axis is scaled in units of concentration and the vertical axis is scaled in units of the normal distribution function (normal quantile). The straight line on the probability plots shows the normal distribution, which is a theoretical probability distribution that is symmetric and has other specific attributes (Gilbert 1987).

Site COCs

Evaluations for the selected site COCs assessed the range, variability, and distribution of SITE pre- and post-treatment sampling data, and compared results from the two sampling events. A review of the box-and-whisker plot in Figure 3-5 suggests that hex concentrations may have decreased from the SITE pre- to post-treatment sampling events. The same trend is evident for aldrin and dieldrin (Figures 3-6 and 3-7), although the evaluation is complicated by the number of non-detected results in the SITE post-treatment data set.

TABLE 3-4

SUMMARY OF SITE PRE- AND POST-TREATMENT ANALYTICAL RESULTS

Sample	Hexachlorocyclopentadiene (mg/kg)	Aldrin (mg/kg)	Dieldrin (mg/kg)	Dioxin/furan TEQ (ppb)
Composite Samples from Pre-Treatment Sampling				
PRE-W-1	5,500	110	1,300	581
PRE-W-2	8,600	700	1,700	376
PRE-W-201[a]	8,900	490	1,200	260
PRE-W-202[a]	9,800	570	1,200	224
PRE-W-3	7,800	110	360	596
PRE-W-4	6,000	40	280	147
PRE-W-5	11,000	1,400	1,500	178
PRE-W-6	9,500	3.8	23	430
Composite Samples from Post-Treatment Sampling				
POST-HVH4	4,700	21	190	305
POST-HVP4	5,000	14 U	14 U	432
POST-HVL4	190	14 U	14 U	798
POST-HVL401[b]	93	14 U	14 U	910
POST-HVJ6	1,500	16 U	40	62
POST-HVH8	4	68	480	19
POST-HVP8	7,300	14U	14 U	674

Notes:

[a] Field replicate of sample PRE-W-2

[b] Field replicate of sample POST-HVL4

mg/kg	Milligrams per kilogram
ppb	Parts per billion
TEQ	Toxicity equivalent
U	Not detected above detection limit shown

Sample results reported on a dry-weight basis

TABLE 3-4 (Continued)

SUMMARY OF SITE PRE- AND POST-TREATMENT ANALYTICAL RESULTS

Sample	Carbon Tetrachloride (mg/kg)	Chloroform (mg/kg)	Tetrachloroethene (mg/kg)
Grab Samples from Pre-Treatment Sampling			
PRE-W-1 (VOC)	8.6	22	4.8
PRE-W-6 (VOC)	0.01	0.17	0.084
PRE-W-14 (VOC)	0.035	0.15	0.2
PRE-W-15 (VOC)	0.49	2.3	1.2
PRE-W-16 (VOC)	3.8	2.4	6.7
PRE-W-23 (VOC)	0.58	1.1	0.48
PRE-W-31 (VOC)	13	4.6	3.7
PRE-W-33 (VOC)	4.6	0.58	0.35
PRE-W-36 (VOC)	5.6	0.47	4.3
Grab Samples from Post-Treatment Sampling			
POST-HVH4	5.2	4.4	3.7
POST-HVP4	3.8	2.3	2.5
POST-HVL4	0.87	1.1	1.4
POST-HVL401[b]	0.054	2.6	0.028
POST-HVJ6	8.3	0.67	0.1
POST-HVH8	0.63	0.18	0.055
POST-HVP8	1	4.4	0.09

Notes:

[a] Field replicate of sample PRE-W-2
[b] Field replicate of sample POST-HVL4
mg/kg Milligrams per kilogram

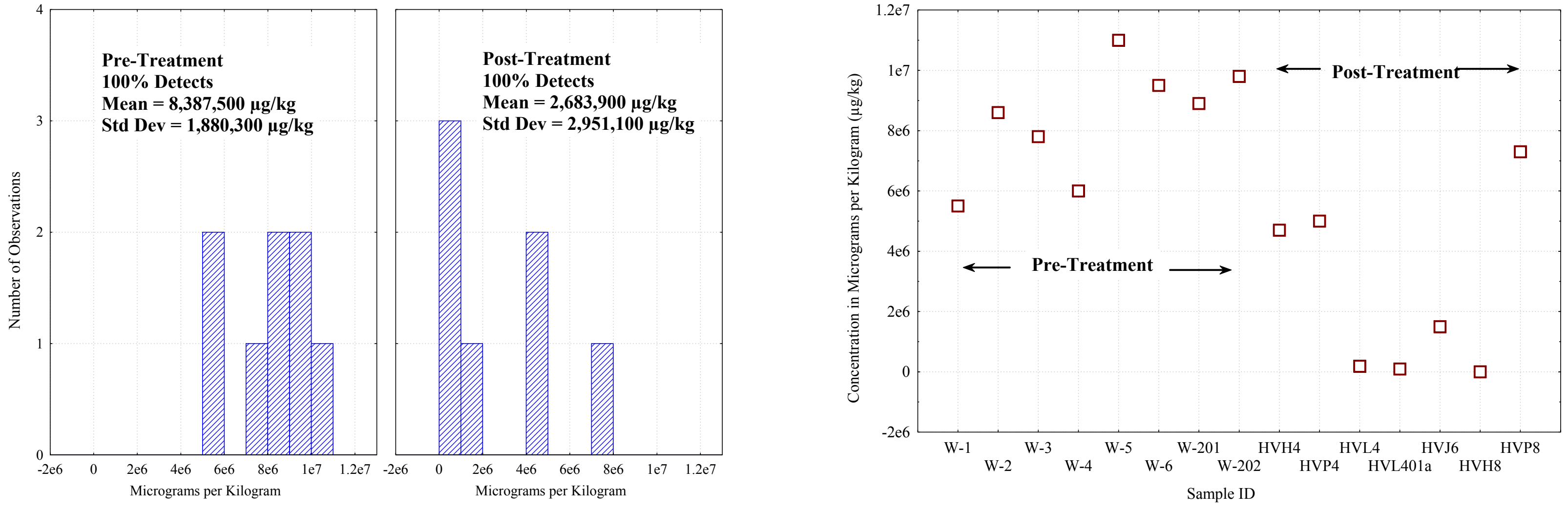
Sample results reported on a dry-weight basis

Figure 3-5

Data Comparison for Hexachlorocyclopentadiene

Frequency Plots of Hexachlorocyclopentadiene

Plot of Hexachlorocyclopentadiene Concentration (µg/kg) in Each Sample



Normal Probability Plots of Hexachlorocyclopentadiene

Box and Whisker Plots of Hexachlorocyclopentadiene

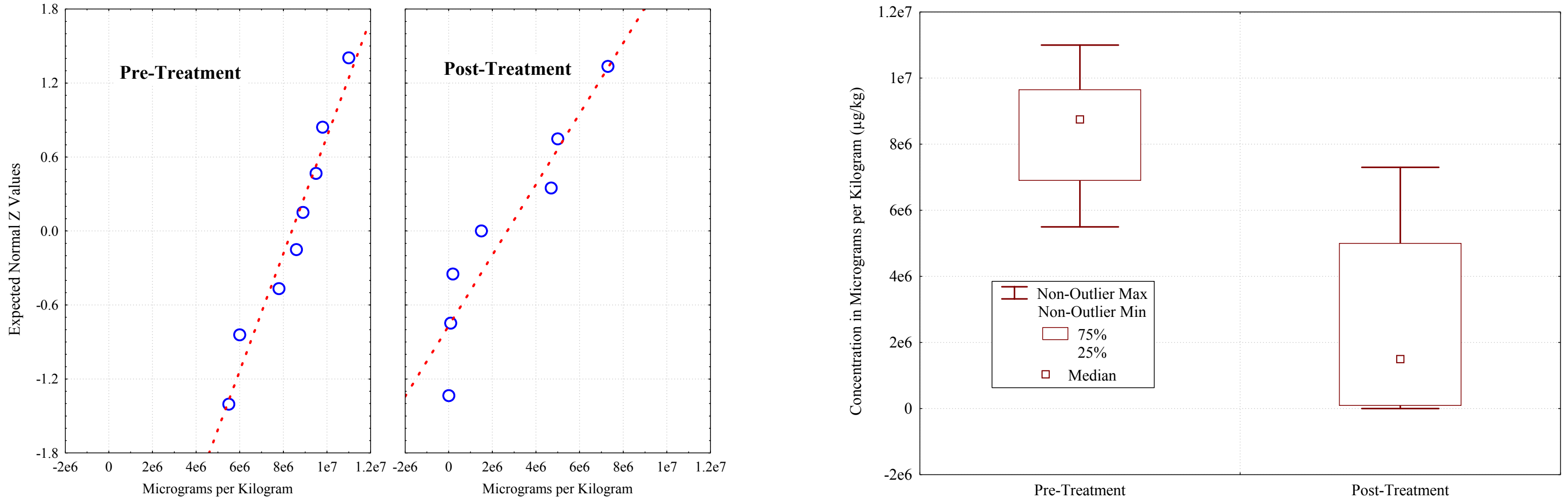
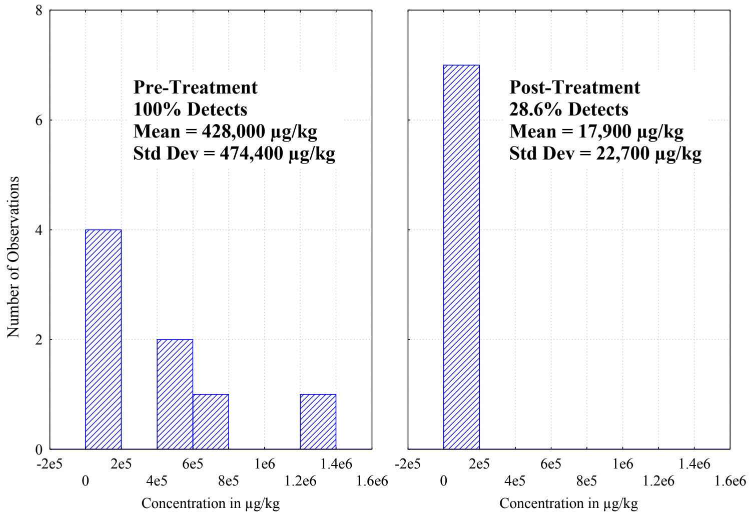


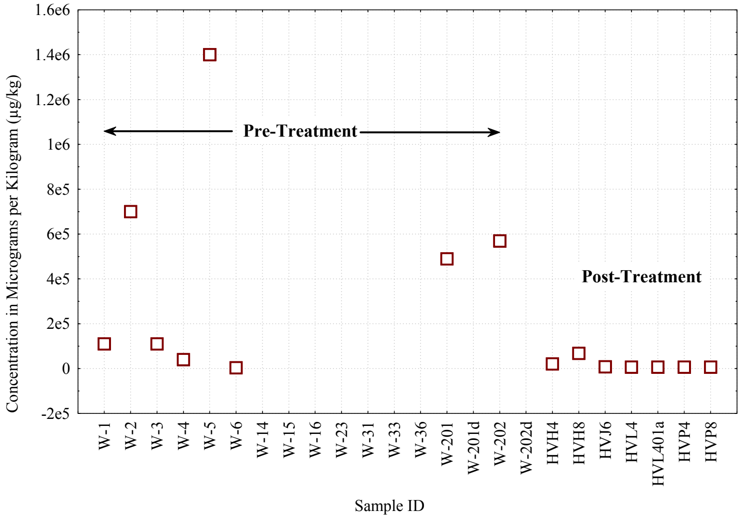
Figure 3-6

Data Comparison for Aldrin

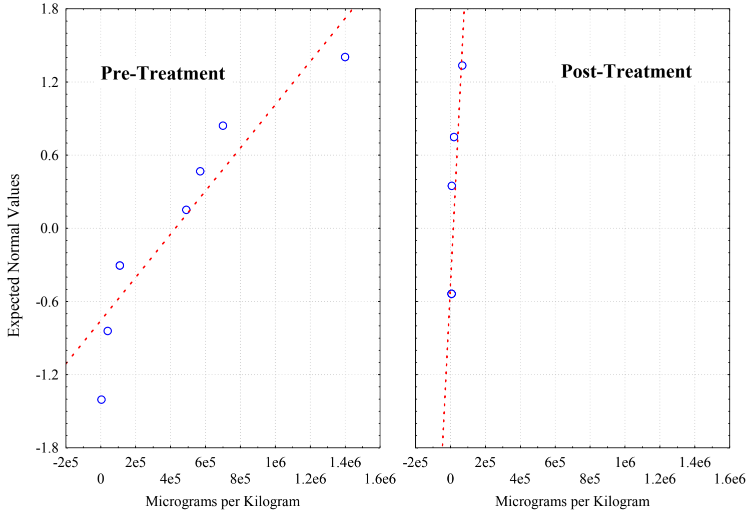
Frequency Plot of Aldrin



Plot of Aldrin Concentration (µg/kg) in Each Sample



Normal Probability Plots of Aldrin



Box and Whisker Plots of Aldrin

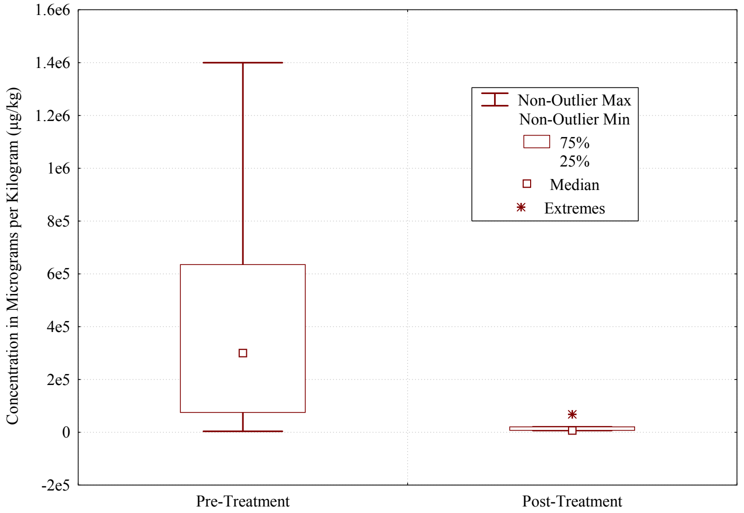
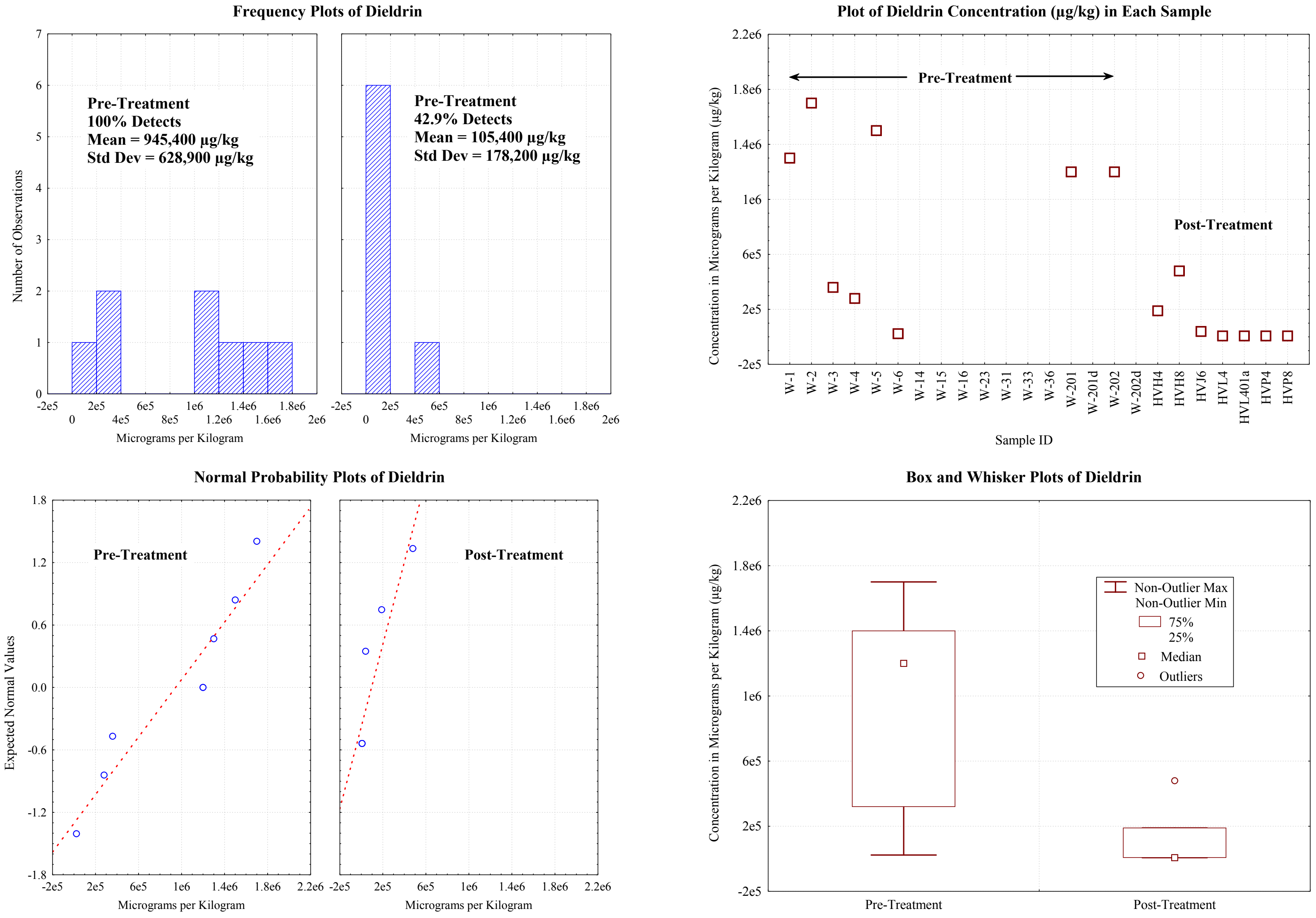


Figure 3-7

Data Comparison for Dieldrin



Frequency Plots of Dieldrin

Plot of Dieldrin Concentration (µg/kg) in Each Sample

Normal Probability Plots of Dieldrin

Box and Whisker Plots of Dieldrin

Comparison of the SITE pre- and post-treatment data sets, however, must take into account differences in the way samples were collected during the two events. As described in Section 3.1.1, each pre-treatment sample was obtained by compositing soil-and-waste material from three separate boreholes. For the post-treatment samples, however, core material was not composited from multiple boreholes; instead, samples were collected from single boreholes (see Section 3.1.2). Post-treatment samples from several boreholes contained relatively low concentrations of the site COCs, including samples HVH8, HVJ6, and HVL4 (Table 3-4). A review of the borehole logs (Appendix A) indicates that layers or bands of relatively pure, tar-like hex were not observed in these borings. Relatively thick layers of probable lime material (approximately 3.5 feet thick) were observed through the sampled intervals in borings HVH8 and HVJ6. The high pH values (12) measured in these samples supports the observation of probable lime material in the borehole logs (see sample analytical results summarized in Appendix A). The relatively low concentrations of COCs in samples from these borings may or may not be representative of typical concentrations remaining in the Hex Pit.

VOCs

Grab samples were collected for analysis of VOC concentrations from predetermined depths during both the SITE pre- and post-treatment sampling events. These samples were collected without regard to sample matrix and may have been obtained from relatively uncontaminated soil or highly contaminated waste material. Figure 3-8 presents an evaluation of analytical results for PCE, which is representative of trends observed for VOCs frequently detected in the pre- and post-treatment soil-and-waste material samples. The box plot shown in Figure 3-8 illustrates the relatively broad range of PCE concentrations detected in both the pre- and post-treatment samples. The broad range of PCE concentrations detected probably results from the different sample matrices collected. The box-and-whisker plot shown in Figure 3-8 suggests a slight decrease in PCE concentrations from the pre- to post-treatment sampling events. However, the wide scatter in both the pre- and post-treatment data sets complicates any comparison. Presumably, VOCs should have been quickly volatilized and removed had the ISTD system reached the intended operating temperatures. As described in Section 3.2.3, the chronology of system operation, soil temperatures measured near HV wells in the northern part of the Hex Pit did not reach the minimum treatment temperatures designed for the system.

Dioxin and Furan TEQs

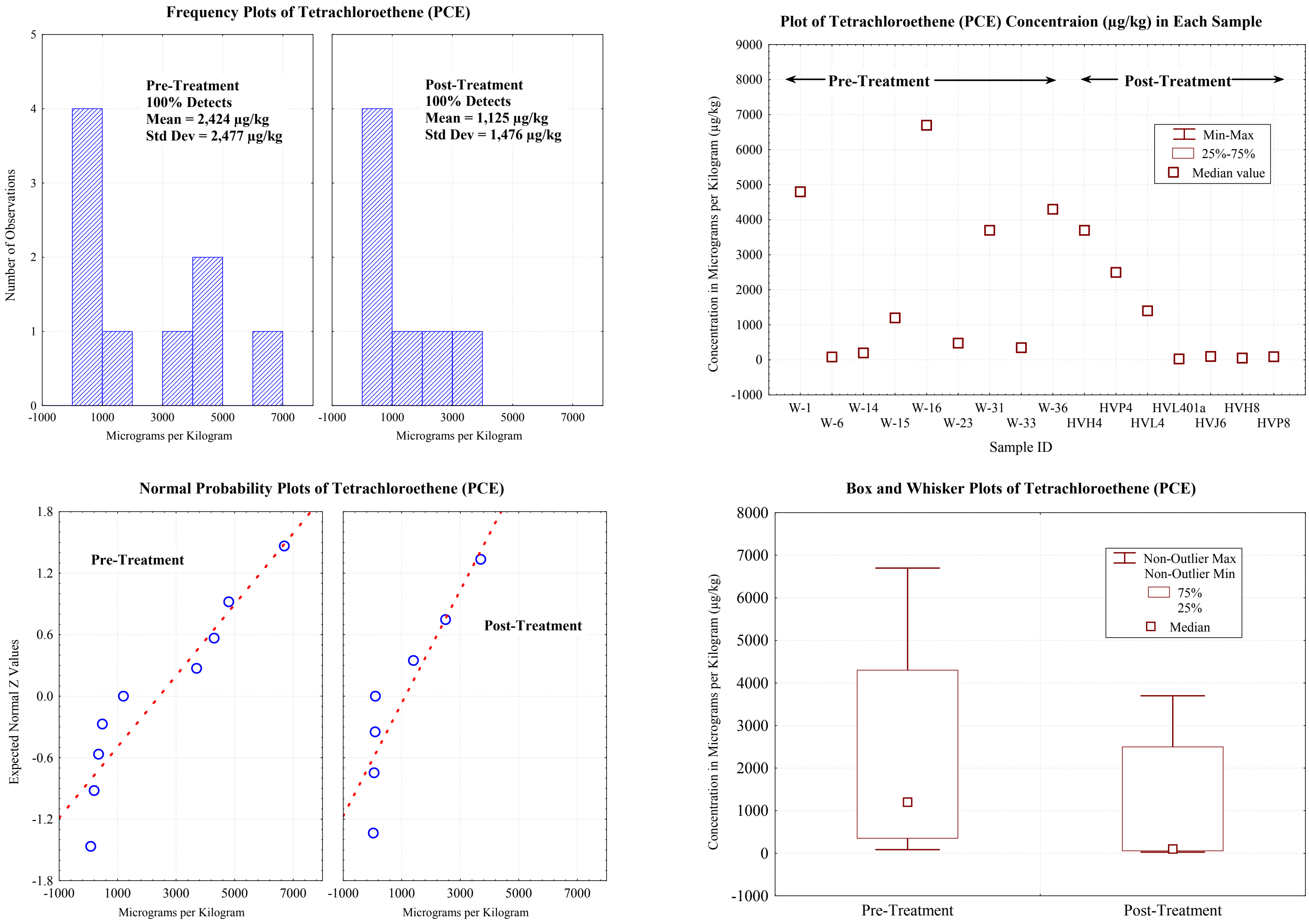
Figure 3-9 presents an evaluation of analytical results for total TEQs calculated for dioxins and furans. A review of the box-and-whisker plot in Figure 3-9 suggests that TEQ concentrations may have increased slightly from the SITE pre- to post-treatment sampling events. However, the wide scatter of TEQ concentrations in the post-treatment data set suggests that a meaningful comparison with the pre-treatment data set may not be possible. In addition, soil temperatures measured near HV wells did not reach minimum treatment temperatures

Statistical Comparison of SITE Pre- and Post-Treatment Sampling Results

The SITE post-treatment SAP specified two types of statistical tests to compare the SITE pre- and post-treatment sampling results (EPA 2002). The following sections describe these statistical tests, test assumptions (hence, applicability to the data collected), and the results of the comparison of SITE pre- and post-treatment sampling results. Three representative compounds were selected for the statistical comparison, including hex, PCE, and TEQs for dioxins and furans. Hex was selected as a representative compound because in was the site COC detected in greatest concentration in the SITE pre-treatment samples. PCE, although not a site COC, was selected to evaluate whether brief operation of the thermal treatment system had any affect on a volatile compound. Dioxin and furan TEQs were evaluated to assess potential creation of these compounds from operation of the thermal treatment process. Summary statistics for these selected compounds are presented in Table 3-5.

Figure 3-8

Data Comparison for Tetrachloroethene



Method 1: Linearized Ratios

Method 1 evaluated the SITE pre- and post-treatment means for contaminant concentrations using a linearized ratio test and a null hypothesis of a 50 percent reduction in contaminant concentrations; that is, the null hypothesis stated that a 50 percent reduction in contaminant concentrations occurred between the SITE pre- and post-treatment sampling results. The test was to be applied to data for the three representative compounds discussed in the qualitative comparison (hex, PCE, and TEQs for dioxins and furans); however, one of the fundamental assumptions of this test – that data sets have approximately equal variance – was violated. Another test assumption – that data sets be normally or log-normally distributed – could not be quantitatively evaluated, but qualitative review of the data suggests that this assumption was also violated in some cases. As a result of these violations, the linearized ratio test was not performed. The second statistical test described in the work plan (Wilcoxon Signed Rank Test) is a non-parametric test (that is, the test does not assume data are normally or log-normally distributed). Results from this non-parametric test (Method 2) are discussed in the following paragraphs.

Method 2: Bootstrapping and the Wilcoxon Signed Rank Test

A second statistical method to evaluate the data used the "bootstrap" method to provide a better estimate of the SITE pre-treatment mean concentrations for the three representative compounds. “Bootstrapping” is a tool that uses random re-sampling of the original data sets, then provides an estimate of the mean for (in this case) 1,000 samples instead of the eight or nine samples that composed the original data sets. Bootstrapping or re-sampling methods take the combined samples as a representation of the population from which the data came, and create 1,000 or more bootstrapped samples. The bootstrapping process was applied 10 times (10 iterations) to produce 10 different estimates of the mean for pre-treatment concentrations of the three representative compounds (Tables 3-6 through 3-8).

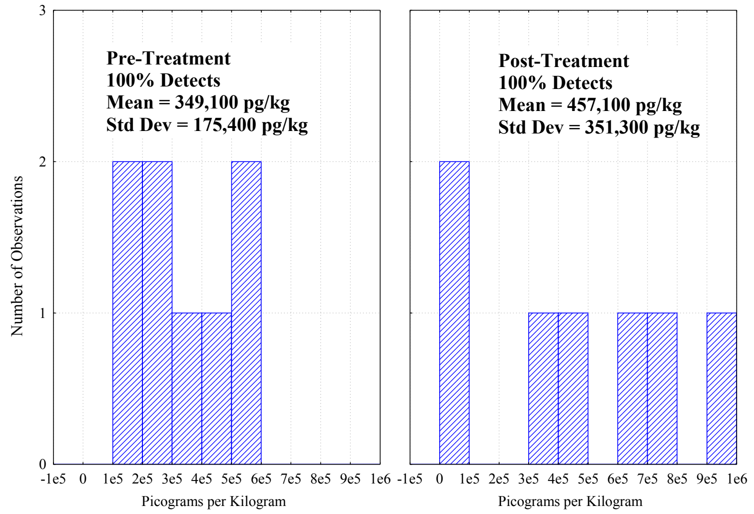
The Wilcoxon Signed Rank test (a non-parametric one-sample test) was used to compare the SITE post-treatment data to each of the 10 bootstrapped estimates of the SITE pre-treatment mean concentrations of the representative compounds (hex, PCE, and TEQs for dioxins and furans). The SITE post-treatment SAP specified a null hypothesis stating that a 50 percent reduction in contaminant concentrations was not achieved (EPA 2002). That is, the null hypothesis stated that the post-treatment concentration of a compound was greater than the threshold value. The threshold value in this case, was one-half of each of the 10 bootstrapped pre-treatment mean concentrations.

To conduct the Wilcoxon Signed Rank test, the SITE post-treatment data were compared with each iteration value of the SITE pre-treatment bootstrapped mean, then the absolute values of the difference between the estimated mean and the post-treatment data were assigned a rank based on their magnitude. After the results were ranked, then the rank values were assigned the appropriate sign (negative or positive value) and the positive values of rank were summed. If the sum was greater than the critical value (from a lookup table), which is based on sample size and the specified confidence (95 percent in this case), then the null hypothesis was rejected. In all cases, there was a failure to reject the null hypothesis; thereby indicating that the post-treatment data could not be shown to indicate a 50 percent reduction in contaminant concentrations. In these tests, however, failure to reject the null hypothesis was due to extreme variability in sample concentrations and too few samples to adequately characterize post-treatment conditions. These two factors resulted in poor power of the statistical test to reject the null hypothesis. Results of the Wilcoxon Signed Rank test for the three representative compounds are summarized in Tables 3-6 through 3-8.

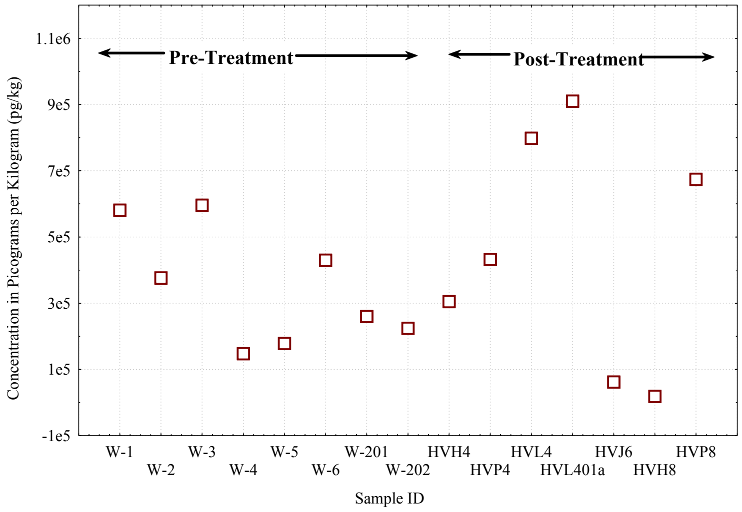
Figure 3-9

Data Comparison for Dioxins and Furans (as Toxicity Equivalents, TEQs)

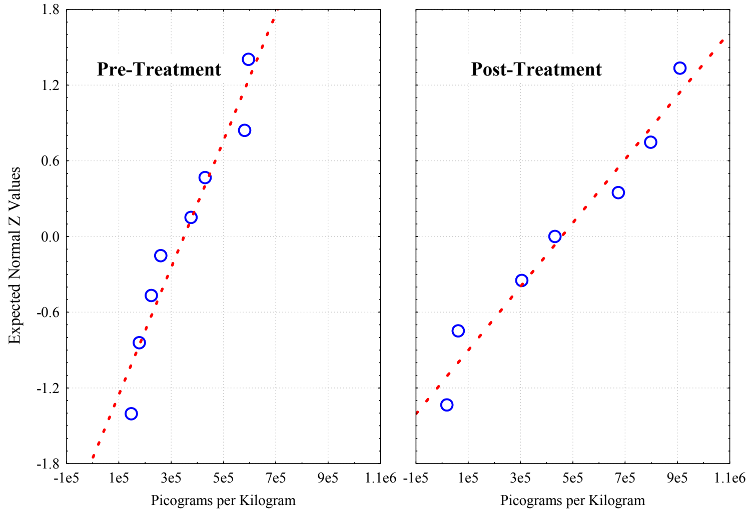
Frequency Plots of Dioxins as Toxicity Equivalents



Plot of Dioxins as Toxicity Equivalents (pg/kg) in Each Sample



Frequency Plots of Dioxins as Toxicity Equivalents



Box and Whisker Plots of Dioxins as Toxicity Equivalents

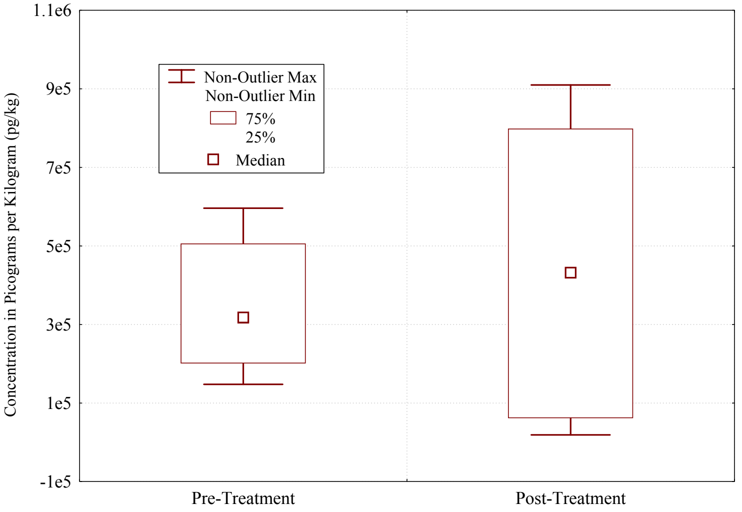


TABLE 3-5

SUMMARY STATISTICS FOR PRE- AND POST-TREATMENT DATA

Event	Analyte	N	Mean	SD	Variance	Units
Pre	Aldrin	8	428,000	474,000	225,000,000,000	ug/kg
Pre	Dieldrin	8	945,000	629,000	396,000,000,000	ug/kg
Pre	Hex	8	8,390,000	1,880,000	3,540,000,000,000	ug/kg
Pre	PCE	9	2,420	2,480	6,130,000	ug/kg
Pre	TEQ	8	349,000	175,000	30,800,000,000	pg/kg
Post	Aldrin	7	17,900	22,700	515,000,000	ug/kg
Post	Dieldrin	7	105,000	178,000	31,700,000,000	ug/kg
Post	Hex	7	2,680,000	2,950,000	8,710,000,000,000	ug/kg
Post	PCE	7	1,120	1,480	2,180,000	ug/kg
Post	TEQ	7	457,000	351,000	123,000,000,000	pg/kg

Notes:

Event	Specifies SITE pre-treatment or post-treatment results
Hex	Hexachlorocyclopentadiene
PCE	Tetrachloroethene
TEQ	Toxicity equivalents reported for dioxins and furans
N	Number of samples
Mean	Arithmetic mean
SD	Standard deviation
Variance	Square of the standard deviation
ug/kg	Micrograms per kilogram
pg/kg	Picograms per kilogram

TABLE 3-6

WILCOXON SIGNED RANK TEST PERFORMED USING BOOTSTRAP MEANS FOR PRE-TREATMENT DATA (ug/kg) FOR HEXACHLOROCYCLOPENTADIENE

Bootstrap N for Pre-Treatment Data Set	Pre-Treatment Threshold (One-half of estimated bootstrapped mean)	N for Post-treatment Data Set	R = sum of positive ranks	Value for $w_{0.95}$	Calculated Value	Does R > Calculated Value?	Reject Null Hypothesis?
1,000	4,115,625	7	21	4	24	No	No
1,000	4,203,125	7	21	4	24	No	No
1,000	4,146,875	7	21	4	24	No	No
1,000	4,115,625	7	21	4	24	No	No
1,000	4,146,875	7	21	4	24	No	No
1,000	4,046,875	7	21	4	24	No	No
1,000	4,084,375	7	21	4	24	No	No
1,000	4,043,750	7	21	4	24	No	No
1,000	4,006,250	7	21	4	24	No	No
1,000	4,031,250	7	21	4	24	No	No

Notes:

Bootstrap N	Number of times the pre-treatment data set (N = 8) was resampled ("bootstrapped")
Pre-Treatment Threshold Value	The threshold value, as specified in the SAP (EPA 2002), is one-half the value of the bootstrapped mean for pre-treatment data
N for Post-Treatment	The actual number of samples collected and analyzed for post-treatment conditions
R	R is the sum of positive ranks, generated as part of the Wilcoxon Signed Rank test (EPA 2000)
Critical Value for $w_{0.95}$	Critical value obtained from a lookup table of critical values for w (EPA 2000, Table A-6)

Calculated Value = (n x (n + 1)/2) - w
Where n = number of post-treatment samples and w is from the lookup table

If R > [n x (n + 1)/2] - w , then reject Ho
Where Ho, the null hypothesis, states that the post-treatment mean exceeds the threshold value (EPA 2002)

ug/kg	Micrograms per kilogram

TABLE 3-7

WILCOXON SIGNED RANK TEST PERFORMED USING BOOTSTRAP MEANS FOR PRE-TREATMENT DATA (ug/kg) FOR TETRACHLOROETHENE (PCE)

Bootstrap N for Pre-Treatment Data Set	Pre-Treatment Threshold (One-half of estimated bootstrapped mean)	N for Post-Treatment Data Set	R = sum of positive ranks	Value for $w_{0.95}$	Calculated Value	Does R > Calculated Value?	Reject Null Hypothesis?
1,000	1,390	7	6	4	24	No	No
1,000	1,291	7	13	4	24	No	No
1,000	1,341	7	10	4	24	No	No
1,000	1,356	7	10	4	24	No	No
1,000	1,259	7	10	4	24	No	No
1,000	1,359	7	10	4	24	No	No
1,000	1,270	7	14	4	24	No	No
1,000	1,408	7	16	4	24	No	No
1,000	1,321	7	10	4	24	No	No
1,000	1,481	7	16	4	24	No	No

Notes:

Bootstrap N	Number of times the pre-treatment data set (N = 8) was resampled ("bootstrapped")
Pre-Treatment Threshold Value	The threshold value, as specified in the SAP (EPA 2002), is one-half the value of the bootstrapped mean for pre-treatment data
N for Post-Treatment	The actual number of samples collected and analyzed for post-treatment conditions
R	R is the sum of positive ranks, generated as part of the Wilcoxon Signed Rank test (EPA 2000)
Critical Value for $w_{0.95}$	Critical value obtained from a lookup table of critical values for w (EPA 2000, Table A-6)

Calculated Value = (n x (n + 1)/2) - w

Where n = number of post-treatment samples and w is from the lookup table

If R > [n x (n + 1)/2] - w , then reject Ho

Where Ho, the null hypothesis, states that the post-treatment mean exceeds the threshold value (EPA 2002)

ug/kg	Micrograms per kilogram

TABLE 3-8

WILCOXON SIGNED RANK TEST PERFORMED USING BOOTSTRAP MEANS FOR PRE-TREATMENT DATA (ug/kg) FOR DIOXINS AND FURANS AS TEQS

Bootstrap N for Pre-Treatment Data Set	Pre-Treatment Threshold (One-half of estimated bootstrapped mean)	N for Post-Treatment Data Set	R = sum of positive ranks	Value for $w_{0.95}$	Calculated Value	Does R > Calculated Value?	Reject Null Hypothesis?
1,000	183,700	7	5	4	24	No	No
1,000	178,206	7	4	4	24	No	No
1,000	176,357	7	4	4	24	No	No
1,000	180,825	7	4	4	24	No	No
1,000	185,419	7	5	4	24	No	No
1,000	180,381	7	4	4	24	No	No
1,000	186,113	7	5	4	24	No	No
1,000	179,438	7	4	4	24	No	No
1,000	176,906	7	4	4	24	No	No
1,000	172,994	7	4	4	24	No	No

Notes:

Bootstrap N	Number of times the pre-treatment data set (N = 8) was resampled ("bootstrapped")
Pre-treatment Threshold Value	The threshold value, as specified in the SAP (EPA 2002), is one-half the value of the bootstrapped mean for pre-treatment data
N for Post-Treatment	The actual number of samples collected and analyzed for post-treatment conditions
R	R is the sum of positive ranks, generated as part of the Wilcoxon Signed Rank test (EPA 2000)
Critical Value for $w_{0.95}$	Critical value obtained from a lookup table of critical values for w (EPA 2000, Table A-6)

Calculated Value = (n x (n + 1)/2) - w
Where n = number of post-treatment samples and w is from the lookup table

If R > [n x (n + 1)/2] - w , then reject Ho
Where Ho, the null hypothesis, states that the post-treatment mean exceeds the threshold value (EPA 2002)

ug/kg	Micrograms per kilogram

With regard to assumptions, the Wilcoxon Signed Rank test assumes the data constitute a random sample from a symmetric continuous population. The statistical plots (Figures 3-5 through 3-7) show that the data for hex and dioxins and furans (as TEQs) are roughly symmetrical; however the data for PCE are not symmetrical, which violates this test assumption. Nonetheless, the results from the Wilcoxon Signed Rank test offer information to be evaluated in the context of other evidence.

Summary of Statistical Test Results

A statistical hypothesis is a statement that may be supported or rejected based on relevant data. In statistical hypothesis testing, the "burden of proof" rests on the alternative hypothesis, which is the logical opposite of the null hypothesis.

When testing a statistical hypothesis, two types of errors may occur; these are termed Type I error (false rejection of the null hypothesis) and Type II error (false acceptance of the null hypothesis). The Type I error is specified by the confidence level; for example, a 95-percent confidence level means there is a 5 percent probability of making a Type I error. The probability of making a Type II error is related to the "power" of the test. Power can simply be defined as "the probability of rejecting the null hypothesis when it is indeed false." Poor power means that the probability of correctly rejecting the null hypothesis is low.

For the statistical test (Wilcoxon Signed Rank test) used on the SITE pre- and post-treatment data, a confidence level of 95 percent was specified. The null hypothesis stated that the contaminant concentrations **were not reduced** by 50 percent. Results of the Wilcoxon Signed Rank Test indicate that, in every case, there was a failure to reject the null hypothesis. In other words, results of the statistical test do not indicate that contaminant concentrations were reduced by 50 percent.

Results for the Wilcoxon Signed Rank Test may appear to contradict what is visible in the data plots (see Figures 3-5 through 3-9), until one reviews the summary statistics. The table of summary statistics (Table 3-5) shows extremely large variability (quantified as the standard deviation and variance) in contaminant concentrations. In six out of ten cases, the standard deviation was larger than the mean. The consequence of this variability is that any statistical test will have poor power to reject the null hypothesis. The power of a statistical test can be checked to determine if an adequate number of samples were collected to achieve a specified level of confidence (here, 95 percent). When the power of the tests is examined, for all data sets, the power of the test to reject the null hypothesis using data from the seven post-treatment samples, was poor in all cases.

In the case of the data examined here, poor power to resolve differences and reject the null hypothesis is a consequence of examining populations with high variance for which there are too few samples. Generally, the desired performance for a statistical test is spelled out in project data quality objectives and includes the selection of a minimum detectable difference, which is the width of the gray region on a test performance plot, the confidence level, and the power desired. The number of samples required can then be estimated using existing information on population variance. Because information on population variance was not available for this SITE demonstration, the number of samples collected was not based on existing data. As a result, the extreme variance (standard deviation approximately equal to or greater than the mean value in many cases, see Table 3-5) translated into poor power and poor performance for the statistical tests to reject the null hypothesis.

Due to the extreme variance in contaminant concentrations, there are insufficient data to statistically determine whether or not contaminant concentrations were reduced by 50 percent or more of their pre-treatment concentrations during this SITE demonstration. In summary, the results of the statistical tests are inconclusive.

SECTION 4
TECHNOLOGY STATUS

The following sections describe the physical destruction of ISTD system components, and summarize the results of investigations conducted to determine the cause of the component destruction.

4.1 DESTRUCTION OF SYSTEM COMPONENTS

Thermal treatment at the Hex Pit was terminated 12 days after startup of all the HV wells and 10 days after startup of heater-only wells along the southern one-third of the well field. Electrical power to the well-field heaters was shut down after corrosion that resulted in structural and containment failure of segments of the aboveground stainless steel piping network was observed and heaters began shorting, including an insertion heater in the aboveground piping and a down-hole heater in one of the HV wells. All insertion heaters and the off-gas treatment system were shut down three days later. Evaluation of damage to the ISTD system focused on several areas as described below, including the aboveground piping network and insertion heaters, the down-hole heater cans and well screens in the HV wells, and the off-gas treatment system components. This discussion is summarized from TerraTherm (2002), except where referenced otherwise.

4.1.1 Aboveground Piping Network and Insertion Heaters

Initial visual observations of disassembled portions of the aboveground piping network indicated significant corrosion of the pipe interior in the immediate vicinity (within 1 to 4 inches) of corroded manifold pipe taps. (The manifold pipe taps were short pieces of vertical piping that connected flexible hoses from tee fittings at the HV wellheads to the aboveground piping network. Observations of leaning pipe taps caused by disintegration of the stainless steel were initial indications of corrosion problems with the ISTD system.) Vendor-acquired metallurgical evaluation of the corroded piping indicated that several forms of corrosion had occurred, including stress corrosion cracking and intergranular corrosion or end grain attack (Colorado Metallurgical Services [CMS] 2002). No other visual evidence of significant corrosion and only minor heat discoloration or rust-colored staining in areas was noted throughout the rest of the aboveground piping network. However, metallurgical laboratory evaluation of selected sections of piping reported that general corrosive attack was evidenced by a reduction in wall thickness from the initial 0.125 inch to 0.108 inch, considered a high rate of metal loss (CMS 2002).

The flexible, high-temperature rubber hoses that connected tee fittings at the HV wellheads to the manifold pipe taps were also disassembled and evaluated. During operation of the ISTD system, these hoses trapped liquids that prevented the vacuum from pulling vapors into the off-gas treatment system (Versaw 2003). TerraTherm operators attempted to drain the hoses periodically during system operation to prevent the blockage. A majority of the tee fittings and hose end connections were observed to be encrusted with materials and in some cases were completely blocked. The deposits ranged from crystalline or fibrous to tarry, muddy, powdery, or cake-like material. Chemical analysis of these precipitates indicated that they included metallic salts and both amorphous and crystalline organic materials containing high concentrations of hex. The flexible hoses did not appear to be corroded.

One of the insertion heaters near the location of a failed manifold pipe tap that experienced an electrical short was removed and evaluated. The insertion heaters were contained in sections of stainless steel pipe or “cans” designed to protect the heater elements. The heater can reportedly showed some heat discoloration and visible pitting in one area, and was substantially unaffected in other areas. The insertion heater can was pressure tested and appeared tight. The electrical failure appeared to be from the melting of a thin-gauge wire and was claimed not to be related to the corrosion observed at the failed manifold pipe tap.

4.1.2 Heater Cans and Well Screens

Damage to heater cans and well screens in the HV wells was evaluated by visual inspection following removal of the heater cans, down-hole video camera inspection, and metallurgical laboratory analysis. During removal of the heater cans, several wells were corroded to the extent that the cans broke off below ground surface. Heater cans remained stuck in several other wells and at five locations, the entire units including the well screen were pulled from the ground when attempting to remove the heater cans.

The well screens were observed to be severely corroded and some sections of well screen were completely corroded away. One well was completely corroded through the screen and into the heater can, and hex material was observed to have accumulated in the heater can to a depth of 6 to 7 feet bgs (approximately 5 to 6 feet of hex had accumulated in the heater can). Video camera inspection revealed that hex material could be seen on, and coming through, the screen slots in several wells. In some wells, "streamers" of hex material could be seen running down the inside of the screen interval from highly corroded areas.

Metallurgical laboratory evaluation of corroded screen intervals indicated corrosion resulted from preferential corrosive attack (Rocky Mountain Engineering and Materials Technology, Inc. [EMTEC] 2002) or "molten salt corrosion" (CMS 2002). An overall assessment of the pipe corrosion in EMTEC's 2002 report was described as "classic manifestations of chloride attack of austenitic stainless steels, from stress corrosion cracking and knifeline attack to pitting and preferential attack caused by chromium depletion."

4.1.3 Off-Gas Treatment System

Several components of the off-gas treatment system were evaluated for potential corrosion problems following shutdown of the ISTD system. Visual inspection of the interior of the cyclone separator and the base of the FTO did not reveal any significant corrosion. The knockout pot storage tank was also visually inspected. The tank had accumulated approximately 200 gallons of corrosive liquids (pH approximately 0) during operation of the off-gas treatment system. The tank was flushed and no visual evidence of corrosion was evident, except corrosion on the tank sight glass holder from contact with corrosive liquid that escaped through a small leak. However, a transfer pump and discharge line used in an initial attempt to drain liquids from the knockout pot tank were corroded and damaged (Versaw 2003).

The off-gas treatment system was shut down under emergency conditions because of an operational failure (Versaw 2003). Some liquid appeared to escape the knockout pot to the acid scrubbers and some discoloration of acid scrubber media in Scrubber Bed No. 1 was observed. Samples of this discolored acid scrubber media were analyzed for remaining neutralization potential and analytical results indicated that 75 percent of the neutralization potential remained in the discolored media. However, in an attempt to dry out the scrubber bed, the heat exchanger between the FTO and the scrubber bed was bypassed. The resulting hot air caused the combustion of carbon in the final carbon bed that precipitated the emergency shutdown.

4.2 FAILURE ASSESSMENT

In general, components of the ISTD system at the Hex Pit failed due to severe and rapid corrosive attack. Conditions that led to the corrosive attack appeared to include the following:

- Higher than anticipated production of chloride and HCl
- Lower than anticipated buffering or neutralization of HCl by other materials disposed of in the Hex Pit and in the surrounding soil
- Higher than anticipated heat losses in the aboveground piping network

As discussed in TerraTherm (2002), the high level of HCl production could have resulted from the occurrence of layers or lenses of highly concentrated hex residues disposed of in the Hex Pit. The tar-like waste material was disposed of in bulk or thin-walled drums, many of which probably broke when dumped or later corroded in the highly acidic environment. The waste material was periodically covered with soil or lime, eventually resulting in a mix of relatively pure waste material sandwiched between layers of soil and lime (see also descriptions of the Hex Pit contents in Section 2.2.3 and the soil borehole logs in Appendix B). With the start of thermal treatment, the tar-like waste material may have lost viscosity and flowed into the HV wells. The heat and vacuum pressure, combined with the presence of steam, may have allowed the waste material to rapidly produce HCl as it flowed into and was drawn up inside the HV wells. The waste material may have undergone very little *in situ* treatment (thermal destruction) and the HCl produced may not have been significantly neutralized by the soil and lime also disposed of in the pit.

It appears that vaporized or steam-stripped contaminants cooled in the un-heated flexible hoses that connected the HV wells to the aboveground piping network. Cooling may have allowed precipitates to form at the tee fittings and in the hose end connectors, which restricted or completely blocked the vapor flow. The resulting loss of flow velocity in the vapor stream may have allowed the formation of corrosive liquid condensates. Conversely, cooling may have led directly to the formation of liquid condensates, which restricted or completely blocked the vapor flow. Precipitates may have formed primarily after the cessation of heating. Regardless of the mechanism of condensate formation, the resulting aqueous HCl is much more corrosive than HCl in the vapor phase, and its contact with the system components at temperatures around the boiling point of water was likely to lead to the corrosion observed.

In summary, destruction of the ISTD system at the Hex Pit appears to have been primarily due to the occurrence of layers of virtually pure, tar-like waste material, which was not destroyed *in situ*; the generation of HCl, which was not adequately neutralized by *in situ* materials; the choice of 304 stainless steel for both aboveground and subsurface components, which were exposed to chloride attack during system operation; and the inability of the system to maintain the vaporized or stream-stripped contaminants in the vapor phase for transport to the off-gas treatment system.

SECTION 5
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APPENDIX A

TERRATHERM, INC. VENDOR REPORT: IN-SITU THERMAL DESTRUCTION (ISTD) AT ROCKY MOUNTAIN ARSENAL HEX PIT

TERRATHERM, INC. VENDOR REPORT: *IN-SITU* THERMAL DESTRUCTION (ISTD) AT ROCKY MOUNTAIN ARSENAL HEX PIT

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EXECUTIVE SUMMARY

Rocky Mountain Arsenal (RMA) is a former U.S. Dept. of Defense facility located in Commerce City, CO, just outside of Denver, that is in the process of undergoing remediation and conversion to one of the nation's largest urban wildlife refuges. A unit at RMA known as the Hex Pit contains buried organochlorine pesticide wastes, tars and residues derived from a period of post-World War II conversion of chemical weapons facilities to commercial pesticide manufacturing. Contaminants of Concern (COCs) identified at the Hex Pit included hexachlorocyclopentadiene (Hex), aldrin, dieldrin, endrin, isodrin and chlordane, compounds that all have high boiling points and are highly chlorinated. Delineation efforts identified approximately 2,550 cubic yards of impacted soil that required treatment.

Comprehensive treatability study and remedial design efforts led to the selection of TerraTherm's patented *In-Situ* Thermal Destruction (ISTD) technology, also known as *In-Situ* Thermal Desorption, for remediation of the Hex Pit. TerraTherm's ISTD technology utilizes simultaneous application of thermal conduction heating and vacuum to treat contaminated soil without excavation. As demonstrated in completed projects, the applied heat volatilizes both water and organic contaminants within the soil, enabling them to be carried in the vapor stream toward vacuum extraction wells. Because of the high inter-well temperatures possible (e.g., 300-600°C) and the fact that the vacuum extraction wells are also heater wells (operating at temperatures of 700-800°C), extracted vapors are exposed to high temperatures over a long residence time, and a significant percentage of the contaminant mass present in the subsurface is destroyed *in situ*. Contaminants not destroyed *in situ* are removed with the vapor stream and treated in an aboveground Air Quality Control (AQC) system consisting of a flameless thermal oxizider, dry scrubbers and granular activated carbon. Based on treatability and design work, it was anticipated that >98% of the contaminant mass present would be destroyed in the heated soil at the Hex Pit, and that the remainder would be destroyed in the AQC system. In addition to oversight by federal, state and local regulatory agencies, the United States Environmental Protection Agency (USEPA) Superfund Innovative Technology Evaluation (SITE) program, as detailed in the accompanying report, scrutinized full-scale implementation of ISTD at the Hex Pit.

Upon the completion of the Hex Pit Treatability Study in February 2000, TerraTherm was selected to prepare the Remedial Design, which was prepared as four deliverables (30%, 95%, 95% Design Addendum, and 100%), the last of which was issued as the Final Design package in March 2001. TerraTherm was awarded the

remedial implementation contract in August 2001, initiated ISTD construction in September 2001, and completed construction and shakedown in February 2002.

On March 15, 2002, 12 days into the initial heating period, acidic corrosion of segments of the aboveground piping began to be observed, and TerraTherm recognized it as a potentially serious problem that, if allowed to continue, could have jeopardized the ability to collect and treat gases that were being generated from the subsurface. Therefore, TerraTherm shut down power to the thermal wells. Air sampling and analysis confirmed that none of the stipulated hourly rolling average air quality standards for off-gas emissions were exceeded. Site workers were protected from exposure to contaminants through appropriate use of Personal Protective Equipment throughout the subsequent assessment period.

With the concurrence of our client, Foster Wheeler Environmental Corporation (FWENC), which serves as the Program Management Contractor (PMC) at RMA; their client, the Remediation Venture Office (RVO) which represents the responsible parties at RMA; and the various Regulatory Agencies, TerraTherm commenced a comprehensive assessment of the damage to its piping system, the results of which were presented in a document entitled “Hex Pit Material Failure Assessment Report” [Assessment Report][1], and summarized herein.

TerraTherm found a total of three manifold stubs in the aboveground piping that failed due to acidic corrosion during operation. It appears that those failures were due to a combination of a higher than anticipated production of hydrochloric acid (HCl) coming out of the heater-vacuum wells, and, when exposed to the abnormally cold, subzero wind chill, in higher than anticipated heat losses from the short uninsulated piping legs located between the hot thermal wells and the heated manifolds. This enabled the temperature of the vapor stream (including steam, pesticides and HCl) at such portions of the piping to drop below the condensation points of the constituents. The resulting liquid condensate may then, at adjacent heated locations, have reboiled, possibly repeatedly, and become more concentrated with respect to HCl, causing acidic corrosion and failure of the manifold stubs. TerraTherm later found that acidic corrosion of the subsurface components was widespread, with at least some corrosion evident in approximately half of the 56 heater-vacuum wells, but believes that most of the subsurface corrosion may have occurred following shutdown, rather than prior to it.

All piping components, including the wells, had been constructed of stainless steel, except for high-temperature rubber steam hose between the wells and manifolds, which exhibited no damage. TerraTherm selected materials based on past experience with the ISTD technology and the concentrations of HCl vapors that were expected, as outlined in the Design Analysis[2].

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[1] TerraTherm, Inc. 2002. *Hex Pit Material Failure Assessment Report.* Submitted to Foster Wheeler Environmental Corporation – Program Management Contract, Rocky Mountain Arsenal, Commerce City, Colorado. April.

[2] TerraTherm, Inc. 2001. *Hex Pit Remediation Final (100%) Design Package*. Document No. 2001-FWENC-007. Prepared for Foster Wheeler Environmental Corporation – Program Management Contract, Rocky Mountain Arsenal, Commerce City, Colorado. March.

Substantial amounts of solid deposits of corrosion products such as metallic salts and of both amorphous and crystalline organic materials were found to have accumulated within the subsurface and aboveground piping system. It is not known to what extent such precipitates occurred during heating, versus after the thermal wells were shut off, at which point the wells cooled faster than the adjacent soil.

The acidic corrosion damage that occurred is without precedent considering all seven previous completed ISTD field projects[3], five of which were performed at sites with polychlorinated biphenyls (PCBs) being present in the soil at concentrations as high as 2% by weight (20,000 mg/kg)[4], and one at a chlorinated solvent site contaminated with tetrachloroethene (PCE) and trichloroethene (TCE). The Hex Pit piping design was similar to what had been proven successful at those past projects. By contrast with concentrations of contaminants present at past ISTD projects, the highest concentration of Hex reported during the various pre-remedial investigations at the Hex Pit was 1.8% (18,000 mg/kg)[5,6]. Nevertheless, it is recognized that at some locations, concentrations of chlorinated liquid waste within the Hex Pit were probably much higher. In several of the soil borings, tarry non-aqueous phase liquid (NAPL) pesticide wastes had been visually observed without any intervening soil (and therefore at local concentrations of approaching 100%, although no samples of such materials were analyzed). TerraTherm now believes that heating enabled the pesticide NAPL to hydrolyze to HCl as it flowed into the heater-vacuum wells, or after it flowed into them, but in either case before it could undergo a significant amount of in-situ treatment within the soil as had been expected based on past ISTD projects. Hot aqueous HCl then corroded the piping, as confirmed by subsequent metallurgical testing.

After reconsidering what happened, it is noteworthy that as confirmed through interviews of site workers, thin-walled drums of liquid pesticide wastes had been dumped directly into the Hex Pit when it was filled in the early 1950s, whereupon most broke and some limited infiltration into the soil occurred. The liquid waste was then allowed to cool and harden, after which it was covered with lime and soil. The resulting occurrence of neat layers or lenses of highly chlorinated tar in between layers of soil is an unusual condition whereby the tar bodies did not occupy a porous medium. As such, the heated tar was apparently able to flow unimpeded into heater-vacuum wells. This effect was not anticipated.

Another contributing factor was the horizontal drilling performed by another subcontractor to FWENC, after construction of the ISTD well field but prior to the start of ISTD heating. During the drilling of three horizontal wells beneath the Hex Pit in February 2002, TerraTherm observed a number of "frac-out" incidents. The horizontal

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[3] Stegemeier, G.L., and Vinegar, H.J. 2001. "Thermal Conduction Heating for In-Situ Thermal Desorption of Soils." Ch. 4.6-1 in: Chang H. Oh (ed.), *Hazardous and Radioactive Waste Treatment Technologies Handbook*, CRC Press, Boca Raton, FL.

[4] France–Isetts, P. 1998. "In Situ Thermal Blankets and Wells for PCB Removal in Tight Clay Soils," *Tech Trends*, EPA Region 7. (February, 1998). Available at: http://clu-in.org/products/newsltrs/TTREND/tt0298.htm

[5] ENSR Corporation. 1999. Hex Pit Site Characterization Report, Rocky Mountain Arsenal, Commerce City, Colorado. Doc. No. 2840-005-500. August.

[6] Tetra Tech EMI. 2001. Draft Screening Investigation Report, Rocky Mountain Arsenal, Commerce City, Colorado. January.

drilling method involved injection of drilling fluids (e.g., water and drilling mud) into each borehole under high pressure for the purpose of advancing the borehole and clearing the cuttings from it. Resistance at the cutting head can cause the drilling fluids to over-pressurize. A frac-out occurs when the drilling fluids, rather than returning back out the entry point of the borehole, instead suddenly fracture the subsurface formation and emerge at the ground surface in a pool of fluid. TerraTherm observed such pools at several locations of the exposed soils around the ISTD well field and underneath its surface seal at several locations during the installation of the horizontal wells. The locations of the known frac-outs appear to correlate with locations of the earliest as well as the most severe cases of corrosion during ISTD operation. The first known frac-out occurred during the drilling of the westernmost horizontal well, and emerged close to the location where the first two manifold taps subsequently failed. In addition, a number of frac-outs occurred while the easternmost horizontal well was being drilled. During the Assessment, TerraTherm noticed that seven out of the nine most severely corroded heater-vacuum wells, plus the third failed manifold tap and the sole instance of a corroded heater-only well, all occurred directly above the path of that easternmost horizontal well. This seems more than can be explained by chance. TerraTherm believes that the frac-out incidents must have caused a displacement of the pit liquids, and in doing so the over-pressurization may have forced chlorinated tarry liquids into a large number of the thermal wells (the open annuli of which served as paths of least resistance providing pressure relief). Injection of tarry liquids into some of the well screens would have loaded them with corrosive materials, predisposing them to failure. Installation of these horizontal wells was not anticipated in the 100% Design and was added to the project after TerraTherm was awarded the implementation contract, without any technical input or comment from TerraTherm. The frac-outs and their effects constitute a changed condition relative to what was known about the Hex Pit prior to design and installation, one that TerraTherm could not have anticipated.

Conclusions of the Assessment Report included the following:

(1) TerraTherm's materials and methods of construction were not defective, and were consistent with generally accepted practices in the remediation field. Furthermore, the material selections (e.g., 304 stainless steel) were reasonable based on past experience with the ISTD technology at highly chlorinated sites and with the concentrations of HCl that were expected. The subsurface component design did not, however, anticipate the potential for fluid tar and very concentrated HCl to flow into the wells screens with virtually no *in-situ* treatment or neutralization. This led to much more harshly corrosive conditions than anticipated within the aboveground piping system.

(2) The process design was appropriate, based on what was known about the site conditions and past experience with the ISTD technology. Specifically, the aboveground piping was designed to withstand the expected concentrations of vaporous constituents emanating from the heater-vacuum wells. The system operated properly for 12 days, and the soil heated up according to expectations. Every one of the 266 wells was equipped with a heater. That, along with

extensive use of heated manifold piping and short uninsulated piping segments between the heated wells and the heated manifold piping was believed, based on past project experience, to be adequate to maintain the off-gas in the vapor state.

(3) The combination of pre-existing subsurface conditions, changes in subsurface conditions caused by others (i.e., the "frac-outs"), and excessive heat losses within the aboveground piping due to abnormally cold weather led to unanticipated levels of acidic corrosion that TerraTherm did not and could not anticipate. Such results might have been evident had a pilot study been performed, but this step was not taken for the project. The Hex Pit project itself was somewhat experimental by nature, in that an *in-situ* remediation at such a highly concentrated chlorinated waste pit had never before been attempted. It was in large part for this reason that it was being conducted as a USEPA-SITE Program demonstration. The destruction of portions of the stainless steel piping within such a short duration of heating was unprecedented with respect to past ISTD projects conducted at similarly high temperatures and on similarly highly chlorinated compounds, and therefore unanticipated.

Had there been sufficient time and funding, TerraTherm believes that a suitable pilot test could have been designed and performed to determine what metallurgy would be necessary to prevent corrosion, and/or what modifications would need to be made to the heater-vacuum wells to address the presence of neat waste liquids. Such a pilot test, however, would have conflicted with major remedial actions scheduled for implementation in adjacent and surrounding RMA soils, and was thus FWENC and RVO indicated that it was not an option.

In May of 2002, FWENC terminated TerraTherm's contract for the convenience of the government, i.e., without fault. Under FWENC's direction, TerraTherm demobilized from the site, and FWENC subsequently covered the Hex Pit with an interim soil cover pending a decision on its disposition. The post-treatment sampling described in the accompanying SITE report was conducted following its placement.

INTRODUCTION

The Rocky Mountain Arsenal (RMA) is located in Commerce City, Colorado, 10 miles northeast of Denver. The U.S. Army originally developed the 27-square mile facility in 1942, primarily for manufacturing chemical weapons. After World War II, parts of the facility were leased to private industry for pesticide manufacturing. RMA is one of the U.S. Department of Defense's most complex CERCLA sites and is administered through the RMA Remediation Venture Office (RVO), consisting of U.S. Army, Shell Oil Co., and U.S. Fish & Wildlife Service.

Hexachlorocyclopentadiene (Hex) is an intermediary used in the production of pesticides and was manufactured at RMA's South Plants Manufacturing Complex (South Plants) between 1947 and 1955 (see Figure 1). Between 1951 and 1952, distillation bottoms from the production of Hex were dumped into an unlined earthen disposal pit (the Hex Pit), located near the northern edge of the South Plants (see Figure 1). The black, tar-like substance was placed in the pit in drums and bulk form. It has been estimated that the Hex Pit contains approximately 3,200 cubic yards (cy) of pesticide contaminated soil and waste.[7] Table 1 summarizes the physical/chemical properties of constituents of concern (COCs) identified in the Hex Pit.

Figure 1 – 1999 View of RMA's South Plants Mannufacturing Complex. None of the structures shown remained at the time of the 2002 Hex Pit remediation.

Table 1 - Physical/Chemical Properties of Hex Pit COCs

Hex Pit COC	Formula	MW	BP	VP
Hex	C_5Cl_6	272.7	239 °C	~20 mm @ 100 °C
Aldrin	$C_{12}H_8Cl_6$	364.9	Similar to Hex	Similar to Hex
Isodrin	$C_{12}H_8Cl_6$	364.9	Similar to Hex	Similar to Hex
Dieldrin	$C_{12}H_8Cl_6O$	380.9	Decomposes before boiling	<1 mm @ 100 °C 200 mm @ 340 °C
Endrin	$C_{12}H_8Cl_6O$	380.9	Decomposes before boiling	Similar to Dieldrin
Chlordane	$C_{12}H_8Cl_8$	409.8	Decomposes before boiling	Similar to Dieldrin

MW = Molecular Weight; BP = Boiling Point; VP = Vapor Pressure.

Following detailed treatability studies and design efforts, the Hex Pit Working Group, comprised of USEPA Region 8, Colorado Dept. of Public Health and Environment (CDPHE), Tri-County Public Health Dept. (TCPHD), and the RVO selected the TerraTherm *In-Situ* Thermal Destruction (ISTD) technology for remediation of the Hex Pit. As demonstrated in previous completed projects, TerraTherm's patented ISTD technology utilizes simultaneous application of thermal conduction heating and vacuum to treat contaminated soil without excavation. The applied heat volatilizes both water and organic contaminants within the soil, enabling them to be carried in the vapor stream toward vacuum extraction wells. Because of the high inter-well temperatures possible (e.g., 300-600°C) and the fact that the vacuum extraction wells are also heater wells (at temperatures of 700-800°C), a significant percentage of the contaminant mass present in the subsurface is destroyed *in situ*. Contaminants not destroyed *in situ* are removed with the vapor stream and treated in an aboveground vapor treatment system. Based on treatability and design work, it was anticipated that >98% of the contaminant mass present would be destroyed in the heated soil at the Hex Pit, and that the remainder would be destroyed in the Air Quality Control (AQC) unit.

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[7] TerraTherm, Inc. 2001. Ibid.

This report provides a description of pre-treatment conditions at the Hex Pit, a summary of TerraTherm's ISTD design basis, including the remedial goals and the extent of treatment predicted, and a summary of the failure that occurred following startup, with TerraTherm's data and evaluation of the causes of the failure.

SITE CONDITIONS/GEOLOGY

At the time of TerraTherm's remedial design effort in 2000-2001, a total of 117 soil borings had been performed in Hex Pit pre-design studies to identify the geology, delineate the boundaries of the pit (i.e., determine the horizontal and vertical limits of the waste), and evaluate the potential for lateral migration of the contaminants.[8,9] In addition, 8 piezometer/monitoring wells were installed around the pit to determine the local depth to groundwater (see Figure 2). The main portion of the Hex Pit is approximately 94 feet long (north-to-south) and 45 feet wide (east-to-west). There is also a narrow 10 foot wide portion that runs approximately 55 feet to the west of the southern portion of the pit. For design purposes, the vertical extent of the pit and the depth to groundwater were approximately 10 and 14 feet, respectively.

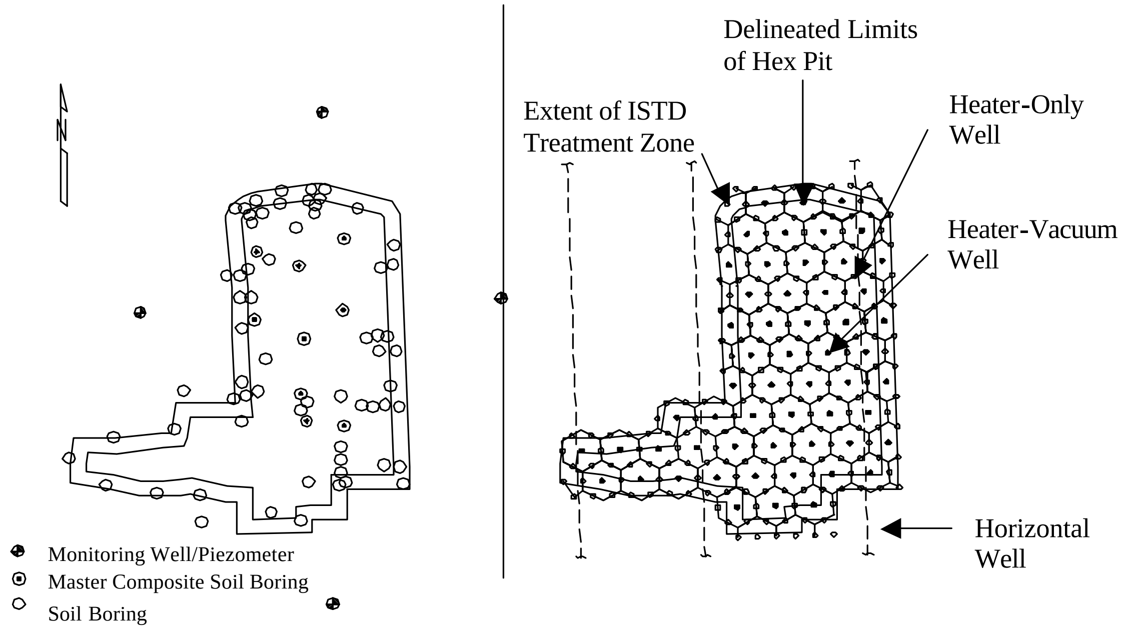

Figure 2 – Hex Pit Delineation and ISTD Heater/Heater-Vacuum Well Layout. a) Locations of soil borings used to delineate limits of Hex Pit and to produce Master Composite for Treatability Study; b) Positions of thermal wells within and outside delineated limits of Hex Pit, and of horizontal wells installed beneath ISTD well field.

The Hex Pit was excavated in alluvial material generally consisting of silty to clayey sand. The alluvial material extends to a depth of approximately 25 feet.

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[8] ENSR Corporation. 1999. Ibid.

[9] Tetra Tech EMI. 2001. Ibid.

Underlying the alluvial material is the Denver Formation bedrock, which consists of weathered clayey sandstone and sandy shale. Material within the pit consists of cover material (a mixture of sand, gravel, and silt) and native soil and/or imported fill mixed with waste material.

FWENC contracted with ENSR in 1999 to perform a pre-design site characterization and treatability study. The authors of this report were employed by ENSR at the time. The lead author assembled and analyzed a Master Composite sample for the purpose of developing an average concentration of chlorinated pesticides (i.e., the COCs) within the Hex Pit. In the presence of SITE Program staff, the lead author constructed the Master Composite by mixing the entire soil column (a mixture of soil and waste material) collected from nine soil borings installed along three transects through the Hex Pit (three borings per transect). Table 2 presents the average pretreatment concentrations of COCs in the Master Composite. Although pretreatment concentrations of Polychlorinated Dibenzo-Dioxin/Furan (PCDD/F) congeners in the Hex Pit were non-calculable due to matrix interferences, the average PCDD/F concentration in soil expressed in units of 2,3,7,8-tetrachlorodibenzodioxin (TCDD) Toxicity Equivalence (TEQ) was estimated to be at least 120 ng/g. Prior to this finding, the presence of PCDD/Fs in Hex Pit wastes had not been known, nor were PCDD/Fs stipulated as COCs during the ISTD design or implementation.

REMEDIAL GOALS

The target performance goal set by the RMA RVO and the Hex Pit Working Group for application of TerraTherm's ISTD technology at the Hex Pit was to achieve a 90% destruction and removal efficiency (DRE) for each of the COCs (see Table 2). The 90% DRE goals were calculated based on the average COC concentration in the Master Composite sample (see Table 2). An additional objective critical to determining the success of ISTD at the Hex Pit was evaluation of whether the technology could achieve the RMA human health evaluation (HHE) cleanup criteria for COCs in soil within the treatment area (see Table 2).

Table 2 – COC Concentrations in Master Composite and ISTD Performance Goals

Hex Pit COC	Master Composite Average Concentrations[1] (mg/kg)	Human Health Exceedance Criteria (mg/kg)	Target Performance Goal 90% DRE (mg/kg)
Hex	7,600	1100	760
Aldrin	<170	71	N/A
Chlordane (total)	670	55	67
Dieldrin	3,100	41	335
Endrin	<280	230	N/A
Isodrin	<200	52	N/A

[1] Average of duplicate samples from Master Composite Pre-Treatment. Less-than sign indicates concentrations were less than the stated detection limits.

TREATABILITY STUDY

A bench-scale treatability study designed by ENSR and performed by an independent laboratory (Kiber, a division of Kemron) was intended to simulate the ISTD process and enable analysis of key process parameters including temperature and off-gas concentrations. Hex Pit composite samples were heated in an 8-in. wide x 2-in. high x 14-in. long test cell to temperatures of 300-500°C over a 30-hr period. DREs exceeded

99.5% for the COCs (Table 3), with the mass balance indicating that >99% of the DRE was attributable to in-situ destruction.[10]

Table 3 – Treatability Study: Comparison of Pre- and Post-Treatment Results

Hex Pit COC	MC Pre-Treatment Avg. Concentrations (mg/kg)	HHE Criteria (mg/kg)	TPG Criteria (mg/kg)	Treated @400 °C (mg/kg)	Treated @300 °C (mg/kg)	DRE %
Hex	7,600	1,100	760	2.80	2.80	99.981
Aldrin	<170	71	N/A	3.39	3.39	NC
Isodrin	<200	52	N/A	3.96	3.96	NC
Dieldrin	3,100	41	335	2.50	2.50	99.960
Endrin	<280	230	N/A	5.63	5.63	NC
Chlordane (total)	670	55	67	2.50	2.50	99.610

MC – Master Composite
TPG – Target Performance Goal
NC – Not calculable
HHE – Human Health Evaluation
DRE – Destruction and Removal Efficiency
N/A – Not applicable

Additional findings of the treatability study included the following:

- Permeability of the soil/waste in both the composite samples became much greater (e.g., 10,000 to 100,000-fold increase) following treatment. This was primarily due to a desiccation of the clay and removal of organic material, and is an important benefit in low permeability soils as the increased permeability allows efficient and effective vapor capture and treatment.
- Analyses of post-treatment samples indicated that ISTD also has the potential to destroy >90% of the PCCD/F isomers tentatively identified at the Hex Pit site.
- Steam distillation and volatilization were not significant removal mechanisms of the site COCs and detected PCDD/Fs. Instead, most of these compounds were destroyed within the soil (i.e., *in situ* within the test cell).
- ISTD combined with vapor treatment processes (flameless thermal oxidation; carbon adsorption) having an accumulative efficiency of >99.99999 % can be expected to produce a 2,3,7,8-TCDD TEQ emission rate of less than 0.002 ng/m^3. This emission rate is five orders of magnitude less than published discharge rates from municipal solid waste incinerators and two orders of magnitude less than the recently promulgated Maximum Achievable Control Technology (MACT) standards for new hazardous waste incinerators.

These results are consistent with past ISTD field and laboratory results.

ISTD DESIGN FOR HEX PIT

Under contract to and oversight of FWENC, TerraTherm prepared the remedial design of the Hex Pit ISTD system, beginning in 2000. The ISTD design for the Hex Pit was developed based on the results of the treatability studies and consideration of the following design criteria: 1) Target treatment temperatures, 2) Heating duration, 3) Spacing between wells, 4) Power input, and 5) Above ground treatment.

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[10] ENSR. 2000. *Hex Pit Treatability Study Report*, Rocky Mountain Arsenal, Commerce City, CO. February.

TerraTherm selected the target treatment temperature (325°C) based on consideration of the boiling points of the COCs (Table 1) and how the vapor pressures and reaction kinetics (e.g., pyrolysis and oxidation reaction rates) vary as a function of temperature. The spacing between wells and the heating duration were designed to optimize the cost of well installation and the cost of heating (a function of power consumption and treatment and operational costs). Consideration was also given to the capacity of the soil to accept heat when dry, as the upper limit of the amount of power or heat that can be input at a well is a function of the soil's dry thermal conductivity and diffusivity. TerraTherm also conducted a field trial of the thermal wells at a clean site as a component of the Hex Pit remedial design program.

Numerical Modeling

TerraTherm commissioned a three-dimensional, multiphase, multicomponent, non-isothermal numerical model to simulate the behavior of water and the COCs in the subsurface as a function of temperature and to aid in the design of the Hex Pit ISTD system.[11] The model also provided valuable predictions of COC loading during various phases of the ISTD treatment process at the Hex Pit. These phases included: 1) Heat up of the treatment area (increase in temperatures from ~20°C up to 100°C), 2) Boiling off of the soil moisture within the treatment zone (initial steam production or steam drive, temperatures at 100°C), 3) Superheat phase (temperatures from 100°C to >325°C), and 4) Cool down.

Figure 3 presents an example of the model's prediction of soil temperature immediately adjacent to a heater-vacuum (H-V) well and the steam and hex production from one of the H-V wells during ISTD treatment at the Hex Pit. Figure 3 indicates that the initial heating was predicted to be rapid and that steam production (corresponding to temperatures of approximately 100°C) was expected to be significant during the first 10 days. The initial steam flood represents the boiling off of the soil moisture present within the Hex Pit at locations adjacent to the H-V wells. Following removal of this water, temperatures increase above 100°C. Some steam continues to be produced after the initial steam flood, and represents water entering the H-V well from points farther from the well, and eventually includes water entering the treatment zone from the underlying aquifer. A small amount of hex was expected to be produced at the tail end of the initial steam flood as a result of steam stripping. At the predicted end of the primary steam flood (~day 11), temperatures at the H-V wells were expected to rapidly increase up to peak operating temperatures (600-700°C) and continue through the ensuing superheat phase of the ISTD process. After day 18 (corresponding to H-V temperatures of approximately 1000°F or 540°C), most of the hex was expected to be destroyed *in situ* and no longer produced in significant amounts. Dieldrin and the other similar COCs are known to decompose at these temperatures and were expected to be destroyed *in situ*. The superheating of the subsurface is responsible for the very high *in situ* destruction removal efficiencies predicted for the Hex Pit ISTD system. These simulation results agreed with the bench-scale treatability studies described earlier.

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[11] Kuhlman, M. 2000. *Simulations of In Situ Thermal Desorption at Rocky Mountian Arsenal Hex Pit*, Prepared for TerraTherm, Inc., by MK Tech Solutions, Inc., Houston, TX.

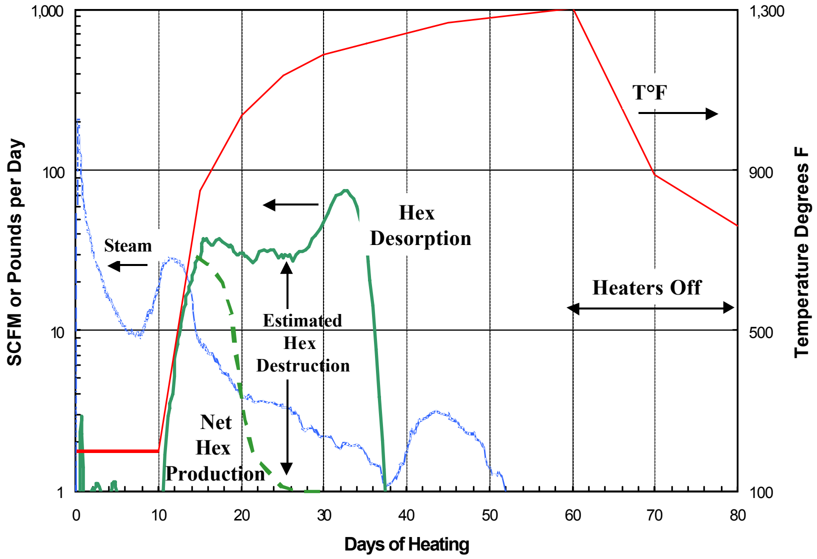

Figure 3 – Simulated Performance of the Hex Pit ISTD System

The figure can be interpreted in the following manner: Water is predicted to boil at the heater-vacuum well for ten days, during which the soil temperature immediately adjacent to the heater-vacuum well (red curve) is 199°F (water boiling temperature at 20 inches vacuum at Denver's average atmospheric pressure). Around day 10, when enough pore water has been produced as steam (blue curve), the temperature begins to rise, the near-heater soil volume dries out, and hex production (dashed green curve) begins. The production rapidly rises as Hex is vaporized in the steam. Hex's partial pressure in the steam at day 12 is about 0.01 ppm. About day 14, as the temperature of the soil adjacent to the heater-vacuum well reaches 700°F, steam pyrolysis of Hex becomes important. Thus, while Hex desorption (solid green curve) continues to increase for over 20 days, the concentration of Hex in the produced gases decreases with the increasing temperature of the soil adjacent to the heater-vacuum well. Only traces of Hex are being produced by the time the soil adjacent to the heater-vacuum well reaches 1,000°F (20 days). The temperature of the soil adjacent to the heater-vacuum well continues to rise to 1300°F before the heaters are turned off. Approximately 99% of the Hex that is desorbed is predicted to be destroyed *in-situ* or in the heater-vacuum well. Courtesy of MK Tech Solutions, Houston, TX.

TerraTherm selected a design heating duration of 60 to 70 days at a thermal well spacing of 6.0 ft, with a power input rate of 315 W/ft in the non-boosted segment of the heaters (0.5 to 10.0 ft bgs), and 400 W/ft in the boosted segment (10.0 to 12.0 ft bgs). To reduce and spread out the anticipated peak production of steam, TerraTherm planned to start up the well field in two to three phases several days apart. Thus, the overall period TerraTherm allotted for heating was 85 days.

Predicted Vapor Production and Acid Gas Neutralization

TerraTherm designed the Hex Pit AQC unit by considering the amount of vapor produced, the peak COC loads, the total amount of COC expected, the degree of treatment required (air discharge permit requirements), the need for acid gas treatment, and the criteria that dioxins not be produced. As a rule of thumb, each kilowatt of power delivered to the subsurface is capable of generating 1 cubic foot/minute (CFM) of steam. The Hex Pit AQC unit also included an acid-gas scrubber because of the levels of HCl (e.g., 100s of ppm) that TerraTherm expected to be produced by the ISTD system. The production of HCl, and the need for acid-gas treatment was determined based on the nature of the hydrocarbons being treated (i.e., ISTD of chlorinated compounds was expected to produce HCl), their concentrations, and the degree of natural acid-buffering capacity of the soil (i.e., calcium [Ca^{+2}] and iron [Fe^{+3}] present in the soil). TerraTherm calculated the soil's buffering capacity based on concentrations in the Master Composite soil of 98,500 mg/kg for Ca^{+2} and 28,500 mg/kg for Fe^{+3}. Even after assuming that only 20% of the buffering capacity would be accessible to HCl vapors, it was estimated to be capable of providing several times the required neutralizing capacity, when compared to the total amount of chloride present within the Hex Pit.[12] It was thus expected, based on past experience, that the presence of these buffering agents would result in neutralization *in-situ* of a very high percentage of the HCl vapors generated *in-situ*.

Materials of Construction

TerraTherm's design utilized materials and associated methods of construction consistent with generally accepted practices in the remediation field. Furthermore, the material selections (e.g., 304 stainless steel well and manifold piping) were based on past experience with the ISTD technology as successfully used at previous ISTD field projects, five of which were performed at sites with polychlorinated biphenyls (PCBs) being present in the soil at concentrations as high as 2% by weight (20,000 mg/kg).[13] In contrast with concentrations of contaminants present at past ISTD projects, the highest concentration of hex reported during the various pre-remedial design investigations was 1.8% (18,000 mg/kg).[14,15] Material selections were also based on the concentrations of hydrochloric acid vapors that were expected (e.g., 100s of ppm), as mentioned in the previous paragraph. The adverse effects of installing horizontal wells beneath a completed ISTD well field and the resulting frac-out events were not taken into consideration, since these horizontal wells were not even contemplated during the Hex Pit ISTD remediation design period. The subsurface component design did not incorporate the possibility that neat tar and/or very concentrated liquid HCl would flow into the wells screens with virtually no *in-situ* treatment or neutralization. The actual subsurface corrosion conditions encountered were thus much harsher than had been anticipated.

Overall Design and Installation

TerraTherm's final design of the Hex Pit ISTD system[16] consisted of 266 thermal wells, including 210 heater-only and 56 heater-vacuum wells installed in a hexagonal pattern at 6.0 foot spacing and to a depth of 12.5 feet bgs (see Figures 2 and 6). The treatment zone was to be heated over an 85-day period to inter-well temperatures of at least 325°C, under an applied vacuum of 20 inches of water. A surface seal consisting of 6 inches of mineral wool insulation board sandwiched between a vapor barrier and a rain

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[12] TerraTherm, Inc. 2001. Ibid.

[13] France–Isetts, P. 1998. "In Situ Thermal Blankets and Wells for PCB Removal in Tight Clay Soils," *Tech Trends*, EPA Region 7. (February, 1998). Available at: http://clu-in.org/products/newsltrs/TTREND/tt0298.htm

[14] ENSR Corporation. 1999. Hex Pit Site Characterization Report, Rocky Mountain Arsenal, Commerce City, Colorado. Doc. No. 2840-005-500. August.

[15] Tetra Tech EMI. 2001. Draft Screening Investigation Report, Rocky Mountain Arsenal, Commerce City, Colorado. January.

[16] TerraTherm, Inc. 2001. Ibid.

cover was designed to ensure that the boundaries of the treatment zone would be maintained under a net negative pressure.

The off-gas was to be treated in an AQC unit consisting of the following major components (Figure 4): cyclone separator; Thermatrix™ Flameless Thermal Oxidizer with demonstrated capability of achieving 99.99% DRE; high-efficiency air-to-air heat exchanger; dual acid-gas scrubber beds; and dual granular activated carbon (GAC) beds. Redundant process blowers maintained the entire system under vacuum. A continuous emissions monitoring system (CEMS) at the stack was used to monitor progress of ISTD treatment and to ensure compliance with the air quality discharge limits. As a precaution, TerraTherm provided an emergency generator connected so that in the event of a loss of grid power, an automatic transfer switch would cause the generator to start within 30 seconds and continue to power the blowers and AQC equipment throughout such an outage. This application of ISTD in conjunction with the vapor treatment processes utilizing destructive and/or adsorption technologies was expected to achieve an accumulative DRE of >99.99999 %.

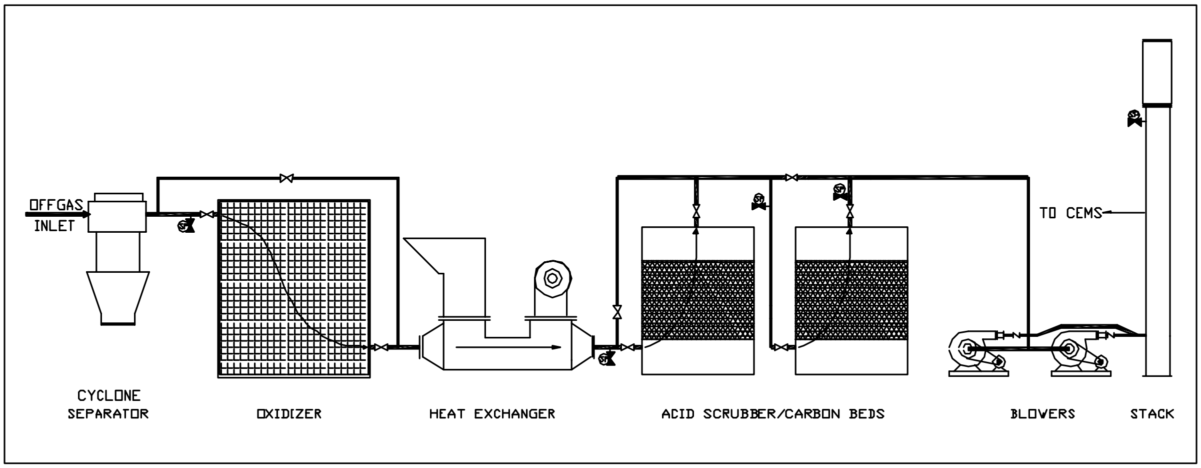

Figure 4 - Process Flow Diagram of AQC System

Post-treatment sampling of soil and waste material was to have been performed by FWENC and by the USEPA's SITE program. Soil samples were to be collected from within and around the perimeter of the Hex Pit, analyzed for COCs, and compared with pre-treatment samples to evaluate the performance of the ISTD treatment. Additional sampling of groundwater and off-gas vapors were also intended to be conducted as part of the USEPA's SITE program and compared with initial conditions and cleanup criteria. As discussed within the accompanying USEPA SITE Report, it was decided during the design of the SITE demonstration to focus the post-treatment soil sampling within the northern half of the Hex Pit, as soils within the southern half had been disturbed by removal of the deep foundations of former Building 571B. Pre- and post-treatment soil concentrations within the northern half of the Hex Pit were believed to be more suitable for comparison.[17]

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[17] TetraTech. 2001. *Draft Quality Assurance Project Plan, In Situ Thermal Destruction Technology Evaluation at the Hex Pit*, Rocky Mountain Arsenal, Commerce City, CO.

Figure 5 presents photographs of portions of the ISTD well field and associated surface completions at the Hex Pit, while Figure 6 presents a schematic of a cross-section passing east-to-west through the ISTD treatment zone.

Figure 5 – Photographs of Installation and Operation of Hex Pit ISTD Well Field. Several inches of snow cover the surface seal. In the foreground of photo at left is a row of heater-only wells (shorter wells with electrical junction boxes on top). In the left foreground of photo at right is a heater-vacuum well (taller well with black vapor extraction line leading into jacketed and insulated horizontal manifold piping). The AQC system in the background of the photo at right includes thermal oxidizer in rear center (behind light stand); blowers and stack are at right.

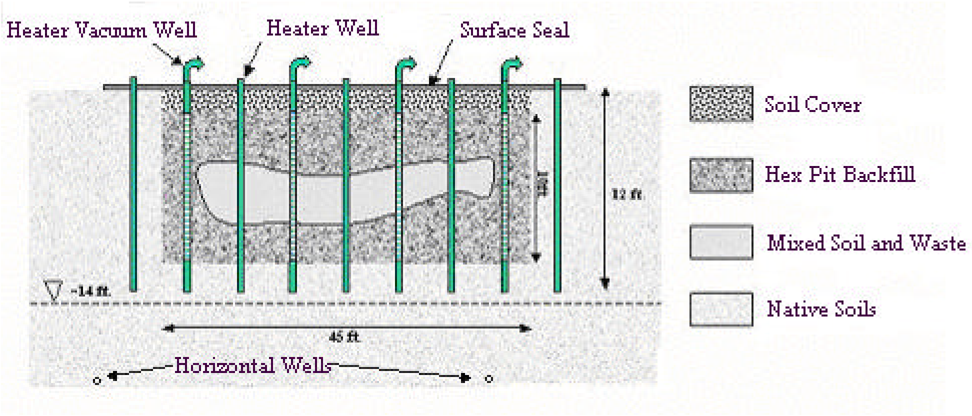

Figure 6 – Typical Cross-Section through the Hex Pit ISTD Treatment Zone, looking from south towards north. During installation of the horizontal wells by others, a number of "frac-outs" occurred, several above the eastern-most horizontal well. Subsequently, during the Failure Assessment, seven out of the nine most seriously corroded heater-vacuum wells were found to be in column "P", located almost directly above the eastern-most of the horizontal wells. It is believed that the "frac-outs" forced movement of hex fluids into the heater-vacuum well annuli prior to heating, compromising their operation.

ISTD IMPLEMENTATION, CESSATION AND DAMAGE ASSESSMENT

Chronology Leading to Curtailment of Operation

TerraTherm's installation of the heater and heater-vacuum wells, above ground electrical and piping systems, the surface seal, and the off-gas treatment system components began in November 2001 and was completed by February 15, 2002. System shakedown followed over the next two weeks. Startup of the ISTD treatment system began on March 3, 2002. Treatment had been expected to occur for 85 days and to be completed by the end of May 2002, but was curtailed after only 12 days of heating. The events leading up to this cessation, and the reasons for it, are described below.

Frac-Out Events

Prior to the start of ISTD heating operation, in February 2002, a drilling subcontractor to FWENC installed three horizontal wells beneath the completed ISTD well field (refer to locations indicated in Figure 2b and Figure 5), during which "frac-out" events occurred that resulted in emergence of drilling fluids around the ISTD well field and beneath the ISTD surface seal at a number of known locations. The horizontal wells were an afterthought on the part of FWENC, intended to enable the water table to be depressed in the event that wet weather caused the groundwater table to rise to near the bottom of the Hex pit during ISTD. TerraTherm agreed with this in concept, but did not participate in the design or implementation of the drilling itself, nor was TerraTherm consulted on the drilling methods and their possible impacts on the ISTD project. The horizontal drilling method that FWENC selected involved injection of drilling fluids (e.g., water and drilling mud) into each borehole under high pressure for the purpose of advancing the borehole and clearing the cuttings from it. Resistance at the cutting head can cause the drilling fluids to over-pressurize. A frac-out occurs when the drilling fluids, rather than returning back out the entry point of the borehole, instead suddenly fracture the subsurface formation above it and emerge at the ground surface in a pool of fluid. TerraTherm observed such pools around the completed ISTD well field and at several locations underneath its surface seal during the installation of the horizontal wells. TerraTherm reported these events to FWENC on February 19, 2002 in a Notice of Changed Conditions. FWENC's response was to downplay the significance of the frac-outs.

The locations of the known frac-outs appear to correlate with locations of the earliest as well as the most severe cases of corrosion during ISTD operation. The first known frac-out occurred during the drilling of the westernmost horizontal well, and emerged close to the location where the first two manifold taps subsequently failed. In addition, a number of frac-outs occurred while the easternmost horizontal well was being drilled. In the Assessment Report, TerraTherm reported that seven out of the nine most severely corroded heater-vacuum wells, plus the third failed manifold tap and the sole instance of a corroded heater-only well, all occurred directly above the path of that easternmost horizontal well. Considering the relatively large number of heater-vacuum wells (56) and heater-only wells (210), this linear co-location of frac-out events and wells showing severe corrosion is, in TerraTherm's opinion, more than can be explained by chance.

TerraTherm believes that the over-pressurization that produced the frac-out incidents must have caused a displacement of the pit liquids, and in doing so the injection pressure may have forced tarry liquids into a large number of the thermal wells (the open annuli of which would have served as paths of least resistance providing pressure relief). Injection of tarry liquids into some of the well screens would have pre-loaded them with hex and other chlorinated pesticides. Upon being heated, they quickly hydrolyzed within the well annuli into boiling HCl. We believe that this, in large part, led to the premature destruction of the piping system. Absent the frac-out events, hydrolysis of the pit contents would have occurred outside the heater-vacuum wells, and the HCl that would have arrived there would have been in the vapor phase, which is what the materials of construction were designed to withstand. 304SS is far more resistant to HCl in the vapor phase than as a liquid. There would also have been more in-situ neutralization of acid gas by buffering within the soil than could occur with acidic liquids forming directly in the wells. The frac-outs and their effects constitute a changed condition relative to what was known about the Hex Pit prior to design and installation.

Weather Conditions

Ambient temperatures during the last week of shakedown/pre-heating and during ISTD operation were abnormally cold. Minimum ambient temperatures for the period March 3 through March 15, 2002 are presented in Figure 7. These cold ambient temperatures, along with average winds of 10-15 mph, had the effect of reducing the near-surface soil temperatures prior to the start of heating. However, more significantly, these cold temperatures may have resulted in greater than anticipated heat losses in the vapor tees, the short (approx. 2”) exposed stubs of the manifold taps, and flexible hoses connecting these points, based on the field observations described in subsequent sections. This, we believe, contributed to the condensation of steam, pesticide vapors and HCl vapors and resulting accumulation of acidic, corrosive liquids at such locations.

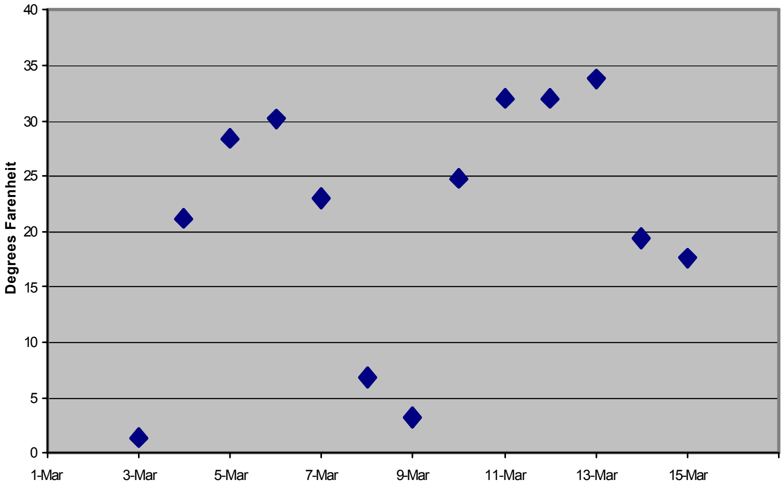

Figure 7 – Minimum daily temperatures during the period of ISTD operation as reported by the National Weather Bureau, Denver, CO. Startup began on March 3, and ISTD operation continued until March 15, 2002.

ISTD Startup and Discovery of Initial Corrosion

Prior to energizing the well field, TerraTherm pre-heated the oxidizer and energized all of the manifold insertion heaters to pre-heat the well field piping manifold. The off-gas treatment system was drawing only ambient air during this pre-heating period. On March 3, 2002, after all 56 of the heater-vacuum wells were energized and reached their operating temperature, the fresh air inlet valves on the manifold lines were gradually closed to allow vapors to be drawn from the subsurface into the AQC system. On March 5, TerraTherm also energized 84 heater-only wells in the southern third of the well field (rows 17-24). Thermocouple data (reviewed below) indicated that the well field was heating up as expected, and the AQC system was also functioning well.

On March 15, 12 days into the initial heating period, TerraTherm operators reported that two 1-½" diameter manifold pipe taps (i.e., vertical "tees") on manifold leg #9 (southwestern quadrant of the well field) had tipped. These 304SS taps were located where the steam hose leading from two adjacent heater-vacuum wells connected down into a horizontal piping manifold. Each of the piping manifolds was being heated to >200^{o}C (>390^{o}F) with insertion heaters running the lengths of the manifolds, which were in turn insulated with calcium silicate insulation and jacketed with stainless steel. The lower ends of the manifold pipe taps, situated inside the manifold insulation, had been eaten away by corrosion.

ISTD Shutdown and Actions Taken

TerraTherm recognized this corrosion as a potentially serious problem that, if allowed to continue, might jeopardize the ability to collect and treat gases that were being generated from the heated subsurface. Therefore, TerraTherm shut down power to the thermal wells, but continued to operate the AQC system for the next two days. Air sampling and analysis confirmed that none of the stipulated hourly rolling average air quality standards for off-gas emissions had been or were ever exceeded. Site workers were protected from exposure to contaminants through appropriate use of Personal Protective Equipment throughout the damage assessment that followed.

With the concurrence of FWENC, the RVO and the various Regulatory Agencies, TerraTherm commenced a comprehensive assessment of the damage to its piping system, the results of which TerraTherm presented in a document entitled "Hex Pit Material Failure Assessment Report" [Assessment Report][18].

Evaluation of the Initial Corrosion

TerraTherm found a total of three manifold taps in the aboveground piping that failed due to acidic corrosion during operation. It appeared that those failures were due to a combination of a much higher-than-anticipated production of hydrochloric acid (HCl) coming out of the heater-vacuum wells, and, in the abnormally cold, near-zero weather, higher-than-anticipated heat losses from the uninsulated piping connections

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[18] TerraTherm, Inc. 2002. Ibid.

located between the hot thermal wells and the heated manifolds. More specifically, the upper ends of the vertical well field heaters within each heater-vacuum well terminated at least 12 inches beneath the surface seal, while the connection from the wellhead to the heated horizontal manifold consisting of heat-resistant flexible rubber steam hose (visible in Figure 5) ranged from approximately 4 to 8 ft in length. This arrangement, coupled with the low ambient temperatures, enabled the temperature of the vapor stream (including steam, pesticides and HCl) at such portions of the piping to drop below the condensation points of the constituents.

For several days during heating, TerraTherm's operators had noted the presence of liquid condensate in a number of the flexible steam hoses, which had to be manually emptied each shift to relieve the liquid obstruction in the hoses. Accumulation of some liquid condensate in abnormally cold weather is not unexpected during ISTD operation and has been observed on past ISTD projects. Nevertheless, these flow restrictions, along with the much higher-than-expected production of HCl (at percent levels) from the heater-vacuum wells, are believed to have led to the corrosion of the failed manifold taps.

Under normal operating conditions, the vapor stream velocity through the manifold taps was designed to be fairly high, estimated to be on the order of 24 ft/sec. This flow velocity, along with the imposed vacuum of 20 to 30" water column should have been enough to sweep liquid droplets and corrosive vapors rapidly through the taps and minimize formation of a liquid condensate film on the interior walls of the manifold tap. It appears, however, that as the flow obstruction became more substantial, the vapor flow through the affected taps was reduced and eventually may have ceased. Without the sweeping effect of the high velocity vapor stream, corrosive liquids may have been able to condense in the approximately 2" length of exposed, uninsulated manifold tap that protruded above the manifold pipe insulation, where the temperature dropped below the condensation points of steam and/or contaminants. Boiling aqueous HCl is approximately 1000 times more corrosive than HCl in the vapor phase. A very aggressively corrosive liquid film may have condensed on the interior wall of the uninsulated tap segment where it streamed down along the hot, insulated segment of the tap. As the liquid reached the hotter segment of the tap (or possibly entered the hot 4" manifold pipe), it is believed that the water vapor flashed to steam and carried the corrosive acid back up into the uninsulated segment of the tap where it subsequently re-condensed on the interior walls and again streamed down. Such a reflux cycle, if repeated, may have had the effect of concentrating the acid to its constant-boiling azeotrope, containing approximately 20% HCl by weight.[19] Metallurgical analysis of the failed taps indicated they had undergone general corrosive attack, evidenced by a reduction in wall thickness from the initial 0.125" to 0.108" over a period of several days, which is a very high rate of metal loss. Note that TerraTherm does not believe this could have occurred had the levels of HCl entering the heater-vacuum wells not been so elevated to begin with. Thus the root cause is believed to be the changed subsurface conditions, as discussed above.

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[19] McGraw-Hill, Inc. 1974. *Chemical and Process Technology Encyclopedia*, p. 588.

AQC Shutdown

TerraTherm mobilized its Project Engineer to the site immediately upon the decision to shut down the well field heaters. Upon his arrival on March 16, 2002, he discovered the presence of approximately 200 gallons of highly acidic (pH 0) condensate in the knockout pot located between the heat exchanger and the dry scrubber vessels, and proceeded to transfer it to the condensate storage tank that was on-site for this purpose. While pumping an additional 300 to 500 gallons of rinse water through the knockout pot and into condensate storage tank, some liquid was accidentally drafted over into Scrubber Bed #1 and accumulated at the bottom of the bed. The Project Engineer immediately bypassed Scrubber Bed #1 due to the excessive pressure drop created by the liquid accumulation.

On March 17, attempts were made to drain water out of Scrubber Bed #1, and later to dry it out using hot air from the oxidizer, which resulted in excess heat inadvertently arriving at Carbon Bed #1. A brief carbon monoxide excursion was noted, and the elevated carbon bed temperature tripped the system interlock. The TerraTherm Operator immediately isolated the carbon and scrubber beds, closed the well field manifold valves, and shut down the blower. Upon investigation, TerraTherm concluded that incomplete combustion (a carbon vessel fire quenched by lack of air) had briefly occurred in Carbon Bed #1. Neither the ISTD well field nor the AQC system were subsequently restarted during the Assessment phase that followed.

Well Field Temperatures

It is pertinent to review the data collected by the well field thermocouples throughout the period leading up to and following cessation of the ISTD system. Following is a summary of the well field temperature data trends:

One heater-vacuum well in the north end of the field (HVD4) had been outfitted with thermocouples within the heater can, in the annulus between the heater can and the well screen, and within the sand pack just outside the well screen. A heater-only well at the southern end of the pit (HOO16), located just south of the zone where heater-only wells were operating, was also outfitted with thermocouples just outside the well screen. Within 24 hours in the instrumented heater-vacuum well at the northern end of the site (HVD4), the temperature inside the heater can was over 900°F, while the temperature of the annulus between the vacuum well screen and heater can was nearly 700°F, and the temperature in the sand pack just outside the well screen was over 100°F. However, the soil temperature just outside the instrumented heater-only well just north of the southern end of the pit (HOO16) remained between 50 and 60°F for approximately 5 days.

Heating in the southern third of the pit (Heater Rows 17-24) where heater-only and heater-vacuum wells were all operating was progressing normally, and appeared to be slightly ahead of schedule relative to what had been simulated during the Remedial Design. By Day 5 of heating, soil temperatures measured in the south end thermocouple arrays located approximately 2 feet from the wells and 7-10' deep were at or above

150°F, while the shallower (1 to 4’ deep) thermocouples were approximately 100-120°F. At this time, soil temperatures approximately 3 feet from the wells were 75-100°F. By heating Day 10, temperatures measured in thermocouples located 2 feet from south-end wells were at or above the boiling point of water at the 5280-ft elevation of RMA (200°F), and temperatures 3 feet from the wells were very nearly 200°F, again with the exception of the 1’-deep zone which was lagging 20 to 30 degrees behind.

In the northern two-thirds of the pit (Heater Rows 1-16) where only heater-vacuum wells were operating, the temperature distributions were somewhat more irregular, as this area did not have the benefit of superposition of heating, as did the fully operational southern end. By Heating Day 5, thermocouples located at the southern edge of that portion of the pit, approximately 1 foot from heater vacuum well HVD16 (Figure 8a) were approximately 250°F at 10’ depth, and ranged from 120 to 170°F at the 4 to 7 foot depth ranges, while the near-surface temperature was approximately 70°F. By the end of the 12-day heating period, the 10’-deep thermocouple at this location had reached a temperature of 416°F, and the mid-depth thermocouples were just over 200°F, while the shallow thermocouple was lagging behind at approximately 120°F. Further north in the field, temperatures within 1 foot of an energized heater-vacuum well in Row 8 (HVP8) on Heating Day 5 were at or above 200°F (Figure 8b), with the exception of the mid-depth 4’ deep thermocouple reading, which was approximately 125°F. This may be indicative of locally saturated conditions in the mid-depth region. In contrast, soil temperatures measured by thermocouples installed in the far northern end of the pit had typically increased only 20 to 30°F and were still below 100°F after 12 days of heating. Those locations that increased by 30°F were nearer to the operating heater vacuum wells. This rate of heating was normal and as expected.

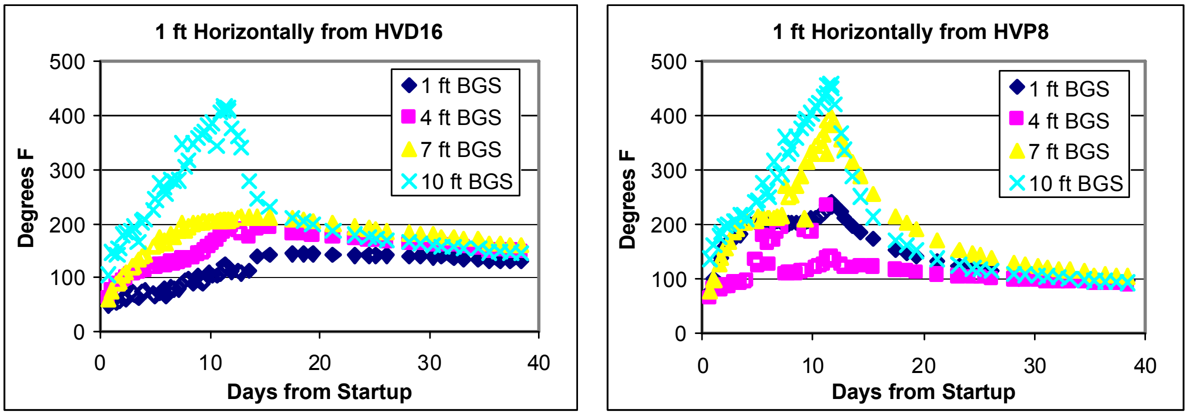

Figure 8a,b – Representative temperature data from thermocouple arrays located 1.0 ft horizontally from each of two heater-vacuum wells. Maximum temperatures were achieved on day 12, at which time heaters were turned off. Deeper locations were generally hotter, attributable to the boosted wattage in the lower two feet of the heaters. After shutdown, temperatures equilibrated and gradually declined.

Following shutdown of the well field heaters, the soil in the pit remained hot. Thermocouple temperatures in the southern portion of the pit generally held steady or dropped only a few degrees for the first several days after the heaters were shut down. In some cases, the temperatures actually increased as a result of equilibration from the radially advancing heat front to adjacent, cooler soil. One week after shutdown of the heaters, soil temperatures in the southern end of the well field were still within 2 to 10 degrees of where they had been prior to shutdown, ranging from 170 to 210°F, with a few exceptions. In the northern end of the pit where only the more widely-spaced heater-vacuum wells were operating, temperatures changed more dramatically. Although some soil temperatures increased slightly as a result of equilibration, the temperature of the soil in the vicinity of the operating heater-vacuum wells generally dropped 50 to 100°F or more within 1 week of shutdown. As expected, thermocouples that were more distant from an operating heater-vacuum well, where the soil temperature was only 20 to 40°F above ambient soil temperatures did not exhibit as significant a drop in temperature.

Post-Shutdown Findings

As reported in the Assessment Report, TerraTherm made numerous observations concerning the post-shutdown conditions within the ISTD well field. These included most prominently blockages within the aboveground vapor tees, and blockages and corrosion within subsurface portions of the heater-vacuum wells. The following paragraphs summarize these findings.

Approximately 30 of the 56 vapor tees (located near the tops of each of the heater-vacuum wells) were observed to have deposits and varying degrees of clogging, with 11 being completely clogged. In addition, both ends of the steam hose connecting the vapor tees to the manifold pipe taps had flanged end connections. The flanged ends of approximately 40 of the 56 flexible hoses were observed to have accumulated deposits. Of these, approximately 12 exhibited only minor accumulations of damp red or black tarry material. Eighteen of the hose end connections were more than 50% clogged, while 4 segments were found to be completely clogged. In most cases when significant clogging was observed in either the vapor tee or hose connection, it was observed in both locations.

Deposits observed ranged from yellow/orange/brown needle-like crystalline or fibrous material, to black tarry residue and red/black muddy residue, to tan/yellow/green or white powdery or cake-like material, in no particular pattern of occurrence. Based on visual observations, the yellowish fibrous material was initially believed to be dieldrin or aldrin crystals; however, laboratory testing results discussed in the Assessment Report appear to indicate that the material was comprised predominantly of Hex rather than of dieldrin or aldrin. There did not appear to be a discernable pattern of clogging in the heater-vacuum wells or flexible hoses. Significant clogging, (>50% obstruction in either the vapor tee or hose connections), was observed in heater-vacuum wells in both the fully energized southern end and the partially energized northern end of the Hex Pit.

It is not known whether these vapor tee and hose end deposits accumulated at the same time as the highly acidic liquid condensate that is believed to have resulted in failure of the manifold pipe taps described above, or whether they formed afterwards, during the period when the well field was beginning to cool. As suggested by the thermocouple data, vapors may have continued to be produced from the still hot soils for some time after shutdown. During this time, the AQC was shut down and the well field piping manifold was isolated such that vapors could have risen into the vacuum wells and accumulated in the pipe manifold. The simulation (Figure 3) furthermore indicates that the shutdown occurred when the production of Hex was starting to peak, but prior to when Hex destruction (and therefore reduced production of Hex) would have been expected to become predominant. Thus, the presence of Hex and related deposits within the heater-vacuum vapor tees and hose end fittings, although undoubtedly exacerbated by the abnormally low temperatures, may be a transient artifact of the shutdown that would have literally evaporated and been swept into the AQC system as the well field continued to heat up, had highly acidic and corrosive liquids not compromised the piping system first. The few locations completely blocked with crystalline deposits may have experienced liquid blockage of the steam hoses first, as a precondition. Otherwise, the velocity of the vapor extraction would have tended to keep the deposits in check. It is not possible to say what fraction of the vapor tee and hose connection clogging occurred during the heating operation and what fraction occurred after the heating was shut down. Based on the loss-of-flow scenario described above, it is believed that some of the clogging occurred during the heating operation. However, the majority of the clogging is believed to have occurred after the well heaters were shut down.

TerraTherm also found that acidic corrosion of the subsurface components, including chloride stress corrosion cracking was widespread, with at least some corrosion evident in approximately half of the 56 heater-vacuum wells. Most of the subsurface corrosion probably occurred following shutdown, rather than prior to it.[20] This conclusion is based on the self-protective characteristics of thermal wells. As mentioned above, gaseous HCl is approximately 1000-fold less corrosive than liquid HCl. Whenever thermal wells are energized, their operational temperatures are so high (as exemplified by the very high 1000-1100°F operating temperature measured within the annulus of HVD4, and presumably representative of all the heater-vacuum wells) that liquids in contact with them will instantly flash to steam or other gases unless there is a significant source of recharge of liquid to the well. It is not believed that there was such a source of recharge within the Hex Pit. Although small, localized pockets of perched liquid were evident during the Hex Pit site investigation, most (>95%) of the volume of soil and waste was observed to be far below saturation. However, once the thermal wells were de-energized, they could no longer protect themselves. The soil and waste around them remained near the boiling temperature of water for weeks, during which it is believed that conditions remained highly corrosive. Thus the conditions following shutdown probably produced most of the subsurface damage observed during the Assessment.

SITE Program Findings

TerraTherm was given the opportunity to review the final draft of the accompanying SITE Program Hex Pit Demonstration Report. It is noteworthy that the mean concentration of hex reported in Table 2-1 of the SITE report for the various

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[20] TerraTherm, Inc. 2002. Ibid.

"Composite Samples from SITE Pre-treatment Sampling" (8,150 mg/kg) corresponded well to the concentration of hex observed in the Master Composite (8,100 mg/kg), which was the basis for the Hex Pit treatability study and the remedial design described above.

In our comments on the final draft SITE Program Hex Pit Demonstration Report, we pointed out that given the obvious data trends, it was surprising that the authors chose not to perform a statistical evaluation of pre- versus post-treatment concentrations of dieldrin, the second most important COC, and aldrin, while instead including an evaluation of trichloroethylene, a compound that was not even included among the COCs and not present at significant concentrations. An examination of the data trends in the SITE Program data (Table 3-4, "Summary of SITE Pre- and Post-Treatment Analytical Results") suggests that despite the short period of operation, a significant amount of *in-situ* destruction occurred with respect to dieldrin (for which the mean pre- and post-treatment concentrations were 805 and 122 mg/kg, respectively) and aldrin (mean pre- and post-treatment concentrations of 375 and 20 mg/kg, respectively).

LESSONS LEARNED

TerraTherm learned the following lessons from this experience, and is applying them in current ISTD projects:

- Horizontal drilling should never be conducted beneath an already completed ISTD well field, especially if there is any possibility of over-pressurization leading to frac-outs.
- Include the worst-case conditions encountered in treatability studies, design calculations and simulations.
- When contemplating applications of ISTD to treat wastes that are qualitatively different than those previously encountered (e.g., a waste lagoon like the Hex Pit in which the wastes may reside as neat layers of tar, rather than as residual NAPL within a porous medium), perform a pilot test first. Such a pilot test affords the opportunity to examine the suitability of materials of construction; assumptions regarding off-gas production and loading rates; the time periods required to treat the waste at a given wattage and spacing of thermal wells; etc. Consider performing such pilot tests in worst-case locations.
- If there is a possibility that abnormally cold weather may occur during startup, insulate and/or heat as many sections of the above-ground ISTD piping as possible, without producing overheating of sensitive components.
- Lateral connections from ISTD heater-vacuum well vapor tees to the piping manifold have been re-designed to prevent sagging of the flexible connector and eliminate low-points that may serve as liquid accumulation/flow obstruction points.
- Do not assume 90% *in-situ* neutralization of acids, especially in the case of mobile, highly chlorinated NAPL.
- Use of Magnehelic gauge taps and ball valves at the vapor tee of each heater-vacuum well, while slightly more expensive, affords the ability to confirm flow from each heater-vacuum well, and to rebalance such flows under changing conditions during treatment.

CLOSING

As mentioned in the Executive Summary, in May 2002, FWENC Terminated TerraTherm's Subcontract for the Convenience of the Government, and subsequently reached a settlement with TerraTherm that recognized no fault on the part of either party. TerraTherm is releasing this report in an effort to promote a better understanding of the conditions that led to and resulted in the cessation of this project, in hopes that future applications of the ISTD technology will benefit from what was learned.

It must be emphasized that what occurred at the Hex Pit was unprecedented relative to prior applications of the ISTD technology, five of which were performed at sites with polychlorinated biphenyls (PCBs) being present in the soil at concentrations as high as 2% by weight (20,000 mg/kg), and one at a chlorinated solvent (PCE/TCE) site. The Hex Pit ISTD piping design was similar to what had been proven successful at those past projects. By contrast with concentrations of contaminants present at past ISTD projects, the highest concentration of hex reported during the various pre-remedial investigations was 1.8% (18,000 mg/kg). Field project experience from the completed ISTD projects and laboratory treatability studies, including the treatability test performed on Hex Pit waste material, indicate that high subsurface temperatures maintained over a period of days are capable of extremely high *in situ* destruction removal efficiencies of even high boiling point contaminants such as PCBs, pesticides, PAHs and other heavy hydrocarbons. Despite high pre-treatment concentrations, post-treatment soil concentrations have typically been non-detect. ISTD thus offers a means to reliably achieve stringent cleanup goals that have not been previously possible by other *in situ* treatment technologies.[21,22]

ACKNOWLEDGEMENTS

The authors wish to acknowledge Keith Bowden of TerraTherm, Inc. for supervising the ISTD construction, Glenn Anderson for supervising the Damage Assessment and demobilization, Denis M. Conley of Haley and Aldrich, Inc., Houston, TX for providing emissions-related technical support, Myron Kuhlman of MK Tech Solutions, Inc., Houston, TX for providing numerical modeling simulations of the ISTD processes, Steve Hall of Kemron Environmental Services Inc., Norcross, GA for performing the treatability study, and John LaChance of TerraTherm for support.

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[21] Baker, R.S., J. M. Bierschenk. 2001. "In-Situ Thermal Destruction Makes Stringent Soil and Sediment Cleanup Goals Attainable," Fourth Tri-Services Environmental Technology Symposium, San Diego, CA.

[22] Stegemeier and Vinegar, 2001. Ibid.

APPENDIX B

RVO REPORT: HEX PIT REMEDIATION PROJECT: IN-SITU THERMAL DESORPTION (ISTD) REMEDY FAILURE ASSESSMENT REPORT 2002

Hex Pit Remediation Project
In-Situ Thermal Desorption (ISTD) Remedy
Failure Assessment Report
2002

This Failure Assessment Report was prepared by the Remediation Venture Office (RVO). This failure assessment summarizes information in documents in the Administrative Record, which present the hex pit history, technology selection, remedial design, treatability study, field implementation, and subsequent failure of the In-Situ Thermal Desorption (ISTD) remedy.

Record of Decision (ROD) Remedy Description

The ROD for Rocky Mountain Arsenal (RMA) identifies the remedy for the Hex Pit site as, "Treatment of approximately 1,000 bank cubic yards (bcy) of principal threat material using an innovative thermal technology. The remaining 2,300 bcy are excavated and disposed in the on-post hazardous waste landfill. Remediation activities are conducted using vapor- and odor-suppression measures as required. Treatability testing will be performed during remedial design to verify the effectiveness of the innovative thermal process and establish operating parameters for the design of the full-scale operation. The innovative thermal technology must meet the treatability study technology evaluation criteria described in the dispute resolution agreement (PMRMA 1996). Solidification/stabilization will become the selected remedy if all evaluation criteria for the innovative thermal technology are not met. Treatability testing for solidification will be performed to verify the effectiveness of the solidification process and determine appropriate solidification/stabilization agents. Treatability testing and technology evaluation will be conducted in accordance with EPA guidance (OSWER-EPA 1989a) and EPA's "Guide for Conducting Treatability Studies under CERCLA" (1992)."

Technology Choice

The Innovative Thermal Technology Evaluation Report for the Hex Pit Site at RMA, prepared by the Colorado Department of Public Health and the Environment (CDPHE), Tri-County Health Department (TCHD), and the United States Environmental Protection Agency (EPA), was finalized on September 10, 1998. (HPWG 1998) This report documented the comparative analyses and evaluation process that lead to the final selection of ISTD as the most technically appropriate technology for this site. Of the 12 innovative thermal technologies investigated, ISTD was chosen to be the most technically appropriate using characteristics of effectiveness, implementability, and cost. At the time of selection of this technology, no full-scale ISTD operations had been conducted on sludge or buried drums. However, bench-scale tests indicated the operation was likely to be successful for both. (ENSR 2000)

Site History

The Hex Pit site covers approximately 205 square yards and is located in Section 1 of the RMA near the north boundary of the South Plants Central Processing Area (SPCPA). The Hex Pit was used between 1950 and 1952 to dispose of residual materials (tar-like, chlorinated organic, resinous material called Hex bottoms or Hex residue) resulting from the production of hexachlorocyclopentadiene (Hex, also known as HCCPD and CL6CP). The material was buried in drums and in bulk and the pit was covered with several feet of soil. During site investigation work, it was clearly demonstrated that the site contained not only contaminated soil but also lenses of pure waste. Concentrations of HCCPD obtained through sampling ranged up to 160,000 parts per million (ppm). The primary contaminant of concern at the site is HCCPD. However, other organic pesticide and dioxin contamination is present at the site as well. HCCPD characteristics include a relatively high boiling point and the tendency to corrode iron and other metals. It is a semi-volatile organic compound with a strong tendency to adsorb onto organic matter. It has low water solubility and a high organic partitioning coefficient, which indicates a relatively immobile contaminant. Immobility of the waste pit material was demonstrated through synthetic precipitation leaching procedure (SPLP) testing performed July 2002, after system failure. (RVO 2002)

ISTD Technology Description

ISTD is an in-situ remediation process involving the application of heat and a vacuum simultaneously to subsurface contaminated soils. Heat and vacuum are applied to the subsurface through the use of heater and heater vacuum wells. As heat is applied and soil temperatures rise, the vaporized contaminated fluids are collected by the vacuum system and drawn into an off-gas treatment system. Destruction of contamination is most effective once heater wells have reached higher temperatures (>250 C). At the start of heating, higher amounts of water vapor, carbon dioxide, and hydrochloric acid (HCl) are present. As configured for the Hex Pit remediation, the vacuum system delivers the vapors to a mobile off gas treatment unit consisting of six major components: cyclone separator, flameless thermal oxidizer (FTO), heat exchanger, two acid gas scrubber beds, two carbon adsorber beds, and main process blower. The system also contained a knockout pot for collection of HCl. The knockout pot was located between the heat exchanger and the acid gas scrubber beds.

Treatability Study Report (TSR), Feb 2000

A Treatability Study (TS) was performed in late 1999 with its report completed February 2000. (ENSR 2000) Some of the conclusions reached by the TS were:

- HCl vapor and sulfur dioxide (SO_2) gas were produced from the thermal oxidation and/or pyrolysis of the site contaminants of concern (COCs), and may require treatment during full-scale remediation.
- PCDD/F cogeners (dioxins) were detected in the Master and Waste Composite samples and in the post-treatment samples
- Analytical PCDD/F results for the Waste Composite test sample could not be quantitated due to their high concentration
- Steam distillation and volatilization were not significant removal mechanisms of the site COCs

System Failure

Construction of the ISTD system started in October 2001, and field implementation of the process began in March 2002. As the soil and waste became heated, the contaminants were being destroyed as planned, releasing the chlorine present in the waste. When mixed with heated water from the surrounding soil, HCl vapor was formed.

The sequence of events leading to system shutdown are:

- On the morning of Thursday 3/14/02, one of the 1.5-inch by 6-inch long flanged nipples that were welded to the 4 inch manifold piping on the western most vacuum pipe spool appeared to be leaning over. The manifold tap was connected to well HVGG18. Inspection determined the welded joint between the 1.5 inch flanged tap and the 4 inch manifold pipe had failed. The reason for the failure (faulty weld or corrosion) could not be readily determined with the insulation in place. During the overnight shift on Thursday 3/14/02 PM - Friday 3/15/02 AM, a second flanged nipple, this one connected to well HVKK18, was observed to be leaning over, and, upon inspection, appeared to be in a similar condition.
- During the overnight shift on Thursday 3/14/02 PM - Friday 3/15/02 AM, the RTV caulk between the well and the steel plate was apparently pulled apart while the ISTD operator was walking in the vicinity of well HVGG18. As a result, steam began escaping from the torn RTV seal. It should be noted that due to the thermal expansion the ISTD thermal wells undergo upon

heating, the RTV seals would need to be regularly checked and re-applied as necessary throughout the project. The appearance of vapor was disconcerting and an indication of low vacuum in the well field.

- On the afternoon of Friday, 3/15/02, it was discovered there was no amperage to heater circuit CB7 and that CB7 in DP2 was in the tripped position. Since there appeared to be a problem with the heaters in one of the heater-vacuum well circuits, TerraTherm decided to shut down all of the currently operating well heaters.
- The electricians determined the location of the failed heater element in the heater vacuum well. The NEMA housing was removed revealing that acidic material had collected in the housing. Several unsuccessful attempts (in Level B) were made to remove the heater element and/or the heater can (3 inch Stainless Steel pipe) housing the heater element. Apparently, when the heater element shorted, it arced sufficiently to weld the heater can to the Stainless Steel vacuum well casing that surrounds it. The determined cause for failure of the heater element was extensive acid corrosion.
- TerraTherm donned Level B personal protective equipment (PPE) and went into the well field Saturday, 03/16/02. The flanged nipples were easily removed as only the RTV caulk was holding them in place. It was clear failure occurred because of acidic corrosion from the HCl produced by the system. Approximately 2 inches of the pipe was completely corroded and the rest was very thin or perforated. The apparent cause was rapid cooling and condensation of the hot HCl vapors emerging from the heater vacuum wells after hitting the exposed metal flange and nipple. Liquid HCl is many times more corrosive than the hot vapor phase gas.
- The in-line insertion heater in the same manifold pipe as the two failed nipples, shorted against the thermocouple wire. The pipe housing the insertion heater was pressure tested and held meaning it had not also been compromised to the point of failure yet by the acid in the manifold. The failure of this heater and thermocouple precipitated the first of the two FTO shutdowns. The FTO shut down twice over the weekend.
- The knockout pot sight glass was discovered to be slowly leaking. Upon investigation, approximately 200 gallons of nearly 0 pH HCl were discovered in the tank.
- In the process of removing the HCl from the knockout pot and rinsing the tank, excessive water was drawn by vacuum into the first acid gas scrubber bed. The acid gas scrubber bed was flooded, effectively making it impermeable. When this occurred, there was such vacuum loss through the tank that the flow out of the well field dramatically dropped and caused the second FTO shutdown. As much weakly acidic liquid as possible was pumped from the acid gas scrubber bed. The ambient airflow through the heat exchanger was dropped to raise the exhaust temperature in hopes of drying the acid gas scrubber bed. In the meantime most of the airflow was diverted through the carbon absorber beds. This resulted in a fire in the first carbon adsorber bed. The entire system had to be shut down.
- Upon further inspection of various wellfield components it was determined that most of the system had some degree of damage due to corrosive HCl.
- As part of the ISTD subcontractor assessment, 23 samples of liquid and solid residues were collected from various locations throughout the wellfield and off-gas treatment system. The pH of all samples was acidic and Hex was the most commonly detected and most concentrated organochlorine pesticides in the solid samples. The maximum concentration detected was 148,000 ug/g (comparable to maximum level identified in previous studies). Chloride was the most common anion detected with a maximum value of 237,000 ug/g in solids and a maximum of 284,000 mg/L in liquid samples.

The corrosion resulted in failure of some of the ISTD process equipment and forced a shutdown of the entire system. The ISTD design anticipated that the HCl formed would be largely neutralized by the higher pH of the surrounding soil; however, this did not occur. Assessment of the system indicated that the corrosion rate of the HCl for the system materials was greater than anticipated resulting in the failure. Large volumes of highly concentrated HCl vapor were drawn into the vacuum wells, piping, and process equipment. This vapor, as it condensed, began to corrode the piping, wells and other process equipment. The first corrosion failures detected were in uninsulated areas of the well field.

The ISTD subcontractor identified extremely cold weather as a contributing factor to failure due to greater than anticipated heat losses in uninsulated piping. These conditions should have been foreseen, and the uninsulated piping design probably was a contributing factor to failure, since during the design of the project, the remediation system was always scheduled to occur during the winter months to avoid high groundwater and high summer electrical demand.

There was speculation if the majority of clogging in the vapor tees and hoses occurred prior to or after the heaters were shut down. There were several documented occurrences when vacuum loss occurred prior to heater shutdown. The increasingly difficult to achieve vacuum on the well field prior to shutdown indicates that clogging was occurring during heating. Clogging may have been exacerbated once heaters were shut down due to continued condensation caused by cooling.

There was also speculation if corrosion occurred primarily before or after shutdown of the heaters. It would seem obvious that corrosion occurred before shutdown due to the fact that the heaters were shut off after corrosion had already caused two different pieces of aboveground wellfield equipment to fail. At that point, with further investigation, the corrosion was discovered to be widespread. No definitive conclusion can be made as to whether most of the corrosion occurred pre- or post-shutdown.

Another concern was if there were any potential impacts from horizontal well installation to the heater well field. During well installation, drilling mud frac out (loss of drilling muds or fluids) occurred twice within the Hex Pit boundary. The ISTD subcontractor suggested there was potential that the frac out events may have caused hex to be forced into the heater wells, changing the underground conditions. This seems unlikely given the volume of drilling mud calculated to have been lost during the frac out events was minimal (800 gallons or less). The total estimated quantity of soil moisture in the Hex Pit is greater than 170,000 gallons, so suggesting that the addition of up to 800 gallons of frac-out liquid could move Hex contamination around or could increase the rate or quantity of HCl formed during heating seems unlikely. It is also unlikely that the very low pressure (8 psi) used to install the horizontal wells would have been sufficient to move a much higher density and viscous (tar-like) material such as hex. It was noted during the follow-up remediation that upon completion of the excavation to elevation 5250.0 (approximately. 8 feet above the horizontal wells) there was no evidence of drilling mud frac out on the excavation surface.

The ISTD technology has changed hands throughout the process of technology selection, design, and implementation. Although the company names have changed over this period of time, the same initially identified experts have remained. Concerns as to HCl generation during the treatment process were expressed to the ISTD experts as early as the Draft sampling and analysis plan for the technology selection in 1999. Per the experts' advice, samples were analyzed for chlorine, chlorinated COCs, and total chlorine in the airstream from the technology selection. This information was to be used by the ISTD subcontractor to design the system to account for HCl generation during treatment. The 100% design (Section 5.3, 5.4, Appendix A) included requirements for robustness of materials to withstand extreme temperatures and a corrosive atmosphere of HCl. Of potential impact to robustness was the decision by the ISTD designer to replace the previously used wells with Gen 2 Heater well designs. The original well design called for the use of expensive materials. The designer never metallurgically tested materials in order to select correct materials for the system in this environment.

Again, Section 6.1.2 of the design states that highly chlorinated vapors will be present in the subsurface during heating. (TerraTherm 2001) The design concluded that the corrosive environment necessitated the use of heater cans to protect the heater elements. In the field, the heater cans proved ineffective against the environment and in protecting the heater elements. Throughout the design, a highly corrosive atmosphere is acknowledged by the ISTD designer, yet the material specified for the equipment is consistently stainless steel (304L). This type of stainless steel is generally the least expensive and the least acid corrosion resistant stainless steel available.

In RVO's evaluation, the primary causes of failure of this system were due to an underestimation of volume of HCl generation during remediation, an inappropriate equipment material choice for the site conditions, and an overestimation of buffering capacity of surrounding soils. There were also contributing factors to the failure such as uninsulated piping where cold temperatures caused condensation of HCl vapor, and shutdown of the off gas treatment system exacerbating condensation.

REFERENCES

ENSR (ENSR Corporation)
2000 (Feb.) *Hex Pit Treatability Study Report (TSR), Part A – Treatability Test Results, Part B – Conceptual Design and Cost Estimate.*

HPWG (The Hex Pit Working Group)
1998 (Sept.) *Innovative Technology Evaluation Report for the Hex Pit Site at Rocky Mountain Arsenal.*

RVO (Remediation Venture Office)
2002 (Aug.) *Hex Pits Leachate Investigation Summary Report*

TerraTherm (TerraTherm, Inc.)
2001 (Mar.) *Hex Pit Remediation Final – 100% Design Package*

APPENDIX C

DATA VALIDATION SUMMARY REPORTS

MEMORANDUM

To:	ISTD File
From:	Harry Ellis
Date:	July 1, 2002 (revised February 11, 2003 by Neil Bingert)
Subject:	Data Validation for Pre-Demonstration Samples (VOC, SVOC, and Pesticide Analyses)

This memorandum documents a data validation of the analytical results from soil, waste, and groundwater samples collected during predemonstration sampling for the In Situ Thermal Destruction (ISTD) Technology Evaluation at the “Hex Pit” of the Rocky Mountain Arsenal, Adams County, Colorado. Tetra Tech EM Inc. (Tetra Tech) supported the U.S. Environmental Protection Agency (EPA) with the sampling effort as contracted under the Field Evaluation and Technical Support (FEATS) program.

Tetra Tech collected 30 soil samples (plus two field replicate samples), 15 waste samples (plus two field replicates), and four groundwater samples from July 12 to 30, 2001. The samples were accumulated at the site for 2 or more days, and sent by overnight courier to Accura Analytical Laboratory (AAL) of Norcross, Georgia. AAL analyzed each day’s shipment as a separate sample delivery group (SDG), Nos. 28376, 28404, 28443, 28451, 28467, 28502, and 28509. Some samples were analyzed by EPA Test Methods for Evaluating Solid Wastes (SW-846) Method 8270C for hexachlorocyclopentadiene only. Some samples were analyzed by EPA SW-846 Methods 8260B, 8270C, and 8081A for a full array of volatile organic compounds (VOC) , semivolatile organic compounds (SVOC), and organochlorine pesticides, respectively. Most samples received only one or two analyses.

The data were evaluated in general accordance with the EPA Contract Laboratory Program National Functional Guidelines (NFG) for organic data review, dated October 1999. The EPA test methods provide guidance on procedures and method acceptance criteria that, in some cases, differ from those in the NFG. When differences exist between the EPA test methods and the NFG, the data validation followed the acceptance criteria given in the methods. In addition, if the data package presented laboratory-specific acceptance criteria, these criteria were used to evaluate the data unless the criteria were considered inadequate. In cases where the criteria in Section 6.0 of the quality assurance project plan (QAPP) are different from the others, the QAPP criteria are used in the validation. The evaluation of the data was based on the following parameters:

- Data package completeness
- Holding times
- Gas chromatography/mass spectroscopy (GC/MS) instrument performance check

TABLE 1 (Continued)

SUMMARY OF PREDEMONSTRATION SAMPLES

- Initial and continuing calibrations
- Blanks
- Matrix spike/matrix spike duplicate (MS/MSD) analyses
- Laboratory control samples (LCS)
- Internal standards
- Surrogate recoveries
- Compound quantitation

Table 1 lists all samples, SDGs, and analyses performed.

TABLE 1

SUMMARY OF PREDEMONSTRATION SAMPLES

Sample	SDG No.	Analyses Performed[a]			
		Hex	**VOC**	**SVOC**	**OCP**
PRE-S-E1	28376	X			
PRE-S-E2	28376	X			
PRE-S-E3	28404	X			
PRE-S-E4	28404	X			
PRE-S-E5	28376	X			
PRE-S-E6	28376	X			
PRE-S-E7	28376	X			
PRE-S-E8	28404	X			
PRE-S-E9	28404	X			
PRE-S-E10	28404	X			
PRE-S-E11	28404	X			
PRE-S-E12	28404	X			
PRE-S-1 (VOC)	28443		X		
PRE-S-1 (0-2)	28443			X	X
PRE-S-1 (10-12)	28443			X	X
PRE-S-1 (12-13)	28443	X			X

TABLE 1 (Continued)

SUMMARY OF PREDEMONSTRATION SAMPLES

Sample	SDG No.	Analyses Performed[a]			
		Hex	VOC	SVOC	OCP
PRE-S-2 (0-2)	28467			X	X
PRE-S-2 (10-12)	28467			X	X
PRE-S-2 (12-13)	28467	X			X
PRE-S-3 (0-2)	28451			X	X
PRE-S-3 (10-12)	28451			X	X
PRE-S-3 (12-13)	28451	X			
PRE-S-6 (VOC)	28467		X		
PRE-S-14 (VOC)	28467		X		
PRE-S-15 (VOC)	28451		X		
PRE-S-16 (VOC)	28443		X		
PRE-S-23 (VOC)	28451		X		
PRE-S-31 (VOC)	28443		X		
PRE-S-33 (VOC)	28443		X		
PRE-S-36 (VOC)	28443		X		
PRE-S-301 (12-13)[b]	28451	X			
PRE-S-302 (12-13)[b]	28451	X			
PRE-W-1 (VOC)	28443		X		
PRE-W-1	28443			X	X
PRE-W-2	28467			X	X
PRE-W-3	28467			X	X
PRE-W-4	28451			X	X
PRE-W-5	28451			X	X
PRE-W-6	28443			X	X
PRE-W-6 (VOC)	28467		X		
PRE-W-14 (VOC)	28467		X		
PRE-W-15 (VOC)	28451		X		
PRE-W-16 (VOC)	28443		X		
PRE-W-23 (VOC)	28451		X		
PRE-W-31 (VOC)	28443		X		
PRE-W-33 (VOC)	28443		X		

TABLE 1 (Continued)

SUMMARY OF PREDEMONSTRATION SAMPLES

Sample	SDG No.	Hex	VOC	SVOC	OCP
		Analyses Performed[a]			
PRE-W-36 (VOC)	28443		X		
PRE-W-201[c]	28467			X	X
PRE-W-202[c]	28467			X	X
PRE-GW-01111	28502	X			
PRE-GW-01112	28502	X			
PRE-GW-01113	28509	X			
PRE-GW-01114	28509	X			

Notes:

a
HEX = Hexachlorocyclopentadiene only
VOC = Full volatile organic compounds list
SVOC = Full semivolatile organic compounds list
OCP = Organochlorine pesticides

b Field replicate of sample PRE-S-3 (12-13)

c Field replicate of sample PRE-W-2

1.0 HEXACHLOROCYCLOPENTADIENE ANALYSES

This section discusses the SVOC analyses performed for hexachlorocyclopentadiene. Table 2 includes validated results for that compound, including those that were derived during analyses for the full list of SVOCs that are discussed in Section 3.0. No problems were noted with data package completeness, GC/MS instrument performance check, initial and continuing calibrations, blanks, internal standards, or compound quantitation.

Due to a login error, sample PRE-GW-01112 was extracted 8 days after collection, just beyond the 7-day holding time. In addition, the LCS accompanying the initial full-list SVOC analyses was spiked only with hexachlorocyclopentadiene. As a result, these samples were re-extracted with new quality control (QC) samples as much as 2 weeks after the expiration of their holding times. However, hexachlorocyclopentadiene is a relatively stable compound and no qualifications will be applied for these holding time exceedances.

The MS/MSD analysis with SDG Nos. 28502 and 28509 was performed on sample PRE-GW-01112. Recoveries were 23 and 32 percent, respectively, and recovery from the accompanying LCS sample was 37 percent, versus QC requirements of 50 to 150 percent recovery for both MS and LCS analyses. The MS/MSD analysis also yielded an excessive relative percent difference (RPD) between the two recoveries. The results for hexachlorocyclopentadiene in the samples in that SDG are flagged "UJ" to indicate that the reporting limits are estimated, biased low.

Several sample extracts were diluted so much that surrogate recovery could not be determined. No qualifications are warranted for these data gaps.

Quantitative results were calculated correctly, with soil results corrected to dry weight. Most soil and waste samples were extracted by the medium-level procedure. Extracts were diluted as necessary to bring all positive results within calibration range, so no qualifications are required for quantitation problems.

TABLE 2

HEXACHLOROCYCLOPENTADIENE RESULTS

Sample	Concentration	Units
PRE-S-E1	360 U	µg/kg
PRE-S-E2	370 U	µg/kg
PRE-S-E3	370 U	µg/kg
PRE-S-E4	370 U	µg/kg
PRE-S-E5	370 U	µg/kg
PRE-S-E6	360 U	µg/kg
PRE-S-E7	370 U	µg/kg
PRE-S-E8	370 U	µg/kg
PRE-S-E9	370 U	µg/kg
PRE-S-E10	370 U	µg/kg
PRE-S-E11	360 U	µg/kg
PRE-S-E12	370 U	µg/kg
PRE-S-1 (0-2)	11,000 U	µg/kg
PRE-S-1 (10-12)	5,800,000	µg/kg
PRE-S-1 (12-13)	1,100,000	µg/kg

TABLE 2 (Continued)

HEXACHLOROCYCLOPENTADIENE RESULTS

Sample	Concentration	Units
PRE-S-2 (0-2)	2,800 J	µg/kg
PRE-S-2 (10-12)	1,800,000	µg/kg
PRE-S-2 (12-13)	1,300,000	µg/kg
PRE-S-3 (0-2)	63,000	µg/kg
PRE-S-3 (10-12)	4,400,000	µg/kg
PRE-S-3 (12-13)	920,000	µg/kg
PRE-S-301 (12-13)[a]	1,300,000	µg/kg
PRE-S-302 (12-13)[a]	1,300,000	µg/kg
PRE-W-1	5,500,000	µg/kg
PRE-W-2	8,600,000	µg/kg
PRE-W-3	7,800,000	µg/kg
PRE-W-4	6,000,000	µg/kg
PRE-W-5	11,000,000	µg/kg
PRE-W-6	9,500,000	µg/kg
PRE-W-201[b]	8,900,000	µg/kg
PRE-W-202[b]	9,800,000	µg/kg
PRE-GW-01111	10 UJ	µg/L
PRE-GW-01112	10 UJ	µg/L
PRE-GW-01113	10 UJ	µg/L
PRE-GW-01114	10 UJ	µg/L

Notes:

µg/kg = Micrograms per kilogram
µg/L = Micrograms per liter

U = Hexachlorocyclopentadiene was not detected. The reported numerical value is the sample quantitation limit.

J = Hexachlorocyclopentadiene was detected, but the result is considered to be estimated for quality control reasons.

UJ = Hexachlorocyclopentadiene was not detected. The sample quantitation limit is considered to be estimated for quality control reasons.

a = Field replicate of sample PRE-S-3 (12-13)

TABLE 2 (Continued)

HEXACHLOROCYCLOPENTADIENE RESULTS

b = Field replicate of sample PRE-W-2

2.0 VOLATILE ORGANIC COMPOUND ANALYSES

This section discusses the results for VOC analyses. Table 3 contains validated results for all samples; only the target compounds reported in at least one sample are listed. No problems were noted with data package completeness, holding times, GC/MS instrument performance checks, LCS analyses, or internal standards. No MS/MSD analyses were performed on samples collected for VOC analyses.

All initial calibration results on both instruments were within QC limits. In the first continuing calibration on the instrument used for the low-level analyses, dichlorodifluoromethane and isobutyl alcohol yielded percent differences (%D) above the QC limit of less than or equal to 25 percent. In the second continuing calibration on that instrument, acetone and methylene chloride yielded %Ds over the 25 percent QC limit. In the only continuing calibration on the instrument used for the medium-level analyses, dichlorodifluoromethane and pentachloroethane yielded excessive %Ds. Results for the named compounds are flagged “J” or “UJ,” as appropriate, in the associated samples to indicate that they are estimates.

The laboratory blanks contained trace levels of 1,2-dichlorobenzene and chloromethane. Similar concentrations of those compounds in some samples were flagged “U” to indicate that they may be laboratory artifacts.

Samples PRE-W-1, PRE-W-16, and PRE-W-33 had recoveries of the third (of three) surrogates, 4-bromofluorobenzene, above the QC limits during low-level analyses. This exceedance was caused by a matrix interference noted in the chromatograms that was confirmed by the absence of surrogate irregularities in the medium level analyses. All positive results for those samples that were derived from the low-level analyses are flagged “J” to indicate that they are estimates.

The VOCs in these samples displayed a wide range of concentrations, much wider than the calibration range. Most samples were analyzed twice, with the second time at a dilution or by the medium-level procedure, in an attempt to bring results within that calibration range. However, the available quantity of sample limited the reanalyses, especially at the lower concentration end, which requires more sample mass. Despite the laboratory’s efforts, some results, such as carbon tetrachloride in sample PRE-S-1, are below the calibration range and others, such as chloroform in that same sample, are above the calibration range. All such extrapolations are flagged “J” to indicate that they are estimates. The laboratory calculated results correctly, including adjustment to dry weight for soil samples.

TABLE 3

VALIDATED RESULTS OF VOLATILE ORGANIC COMPOUND ANALYSES (µg/kg)

Sample:	PRE-S-1	PRE-S-6	PRE-S-14	PRE-S-15	PRE-S-16	PRE-S-23	PRE-S-31	PRE-S-33	PRE-S-36
1,1,1,2-Tetrachloroethane	3.0 U	2.8 U	2.9 U	3.7 U	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
1,1,1-Trichloroethane	3.0 U	2.8 U	2.9 U	3.7 U	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
1,1,2,2-Tetrachloroethane	3.0 U	2.8 U	2.9 U	3.7 U	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
1,1,2-Trichloroethane	3.0 U	2.8 U	2.9 U	3.7 U	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
1,1-Dichloroethane	3.0 U	2.8 U	2.4	4.1	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
1,1-Dichloroethene	3.0 U	2.8 U	1.3 U	3.7 U	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
1,2,3-Trichloropropane	3.0 U	2.8 U	2.9 U	3.7 U	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
1,2-Dichlorobenzene	3.0 U	2.8 U	2.9 U	7.3	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
1,2-Dichloroethane	3.0 U	2.8 U	2.9 U	3.7 U	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
1,2-Dichloropropane	3.0 U	2.8 U	0.41 J	3.7 U	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
1,3-Dichlorobenzene	3.0 U	2.8 U	2.9 U	3.5 J	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
1,4-Dichlorobenzene	3.0 U	2.8 U	1.3 J	29	3.4 U	0.40 J	3.3 U	3.3 U	2.8 U
2-Butanone	30 U	1.8 J	1.3 J	17 J	5.4 J	2.0 J	2.2 J	1.5 J	1.9 J
2-Hexanone	30 U	28 U	29 U	37 U	34 U	28 U	33 U	33 U	28 U
4-Methyl-2-pentanone	30 U	28 U	29 U	0.99 J	34 U	28 U	33 U	33 U	28 U
Acetone	5.7 J	14 J	16 J	370 J	28 J	18 J	84 J	6.9 J	13 J
Acrolein	60 U	56 U	57 U	75 U	68 U	56 U	66 U	65 U	57 U
Benzene	0.75 J	0.33 J	26	42	0.67 J	2.8 U	3.3 U	0.35 J	2.8 U
Bromomethane	3.0 U	2.8 U	2.9 U	3.7 U	3.4 U	2.8 U	3.3 U	0.45 J	0.31 J
Carbon disulfide	3.0 U	2.8 U	2.9 U	0.78 J	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
Carbon tetrachloride	0.38 J	3.0	25	2.0 J	56	8.4	27	5.5	12
Chlorobenzene	3.0 U	2.8 U	1.1 J	7.7	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
Chloroethane	3.0 U	2.8 U	2.9 U	3.7 U	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
Chloroform	240 J	64	3,700	8.3	100	290	720 J	39	47

TABLE 3 (Continued)

VALIDATED RESULTS OF VOLATILE ORGANIC COMPOUND ANALYSES (µg/kg)

Sample:	PRE-S-1	PRE-S-6	PRE-S-14	PRE-S-15	PRE-S-16	PRE-S-23	PRE-S-31	PRE-S-33	PRE-S-36
Chloromethane	3.0 U	2.8 U	22	37	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
Dichlorodifluoromethane	1.6 J	1.0 J	1.1 J	2.1 J	7.1 J	1.5 J	1.8 J	2.1 J	1.6 J
Ethylbenzene	3.0 U	2.8 U	0.73 J	14	3.4 U	2.8 U	3.3 U	0.33 J	2.8 U
Isobutyl alcohol	0.62 J	28 UJ	29 UJ	37 UJ	34 UJ	28 UJ	33 UJ	33 UJ	0.34 J
Methylene chloride	6.0 UJ	5.6 UJ	6.2 J	50 J	1.5 J	5.6 UJ	0.51 J	6.5 UJ	5.7 UJ
Pentachloroethane	3.0 U	2.8 U	2.9 U	3.7 U	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
Styrene	3.0 U	2.8 U	2.9 U	3.7 U	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
Tetrachloroethene	13	21	330 J	500 J	67	18	60	20	38
Toluene	1.8 J	1.7 J	1.0 J	4.1	8.5	1.7 J	2.4 J	1.4 J	0.77 J
trans-1,2-Dichloroethene	3.0 U	2.8 U	0.70 J	3.7 U	3.4 U	2.8 U	3.3 U	3.3 U	2.8 U
Trichloroethene	1.3 J	1.9 J	58	10	1.8 J	1.0 J	2.9 J	0.48 J	1.0 J
Trichlorofluoromethane	3.0 U	2.8 U	2.9 U	3.7 U	0.50 J	2.8 U	3.3 U	0.34 J	2.8 U
Xylenes	1.3 J	1.2 J	2.5 J	48	0.69 J	0.32 J	0.61 J	1.6 J	0.64 J

Sample:	PRE-W-1	PRE-W-6	PRE-W-14	PRE-W-15	PRE-W-16	PRE-W-23	PRE-W-31	PRE-W-33	PRE-W-36
1,1,1,2-Tetrachloroethane	2.3 J	4.1 U	7.1 U	6.0 U	1.9 J	2.8 U	4,000 U	3.1 U	2.9 U
1,1,1-Trichloroethane	3.8 U	4.1 U	7.1 U	2.3 J	8.4 J	1.2 J	4,000 U	1.8 J	2.6 J
1,1,2,2-Tetrachloroethane	3.6 J	4.1 U	7.1 U	6.0 U	3.4 U	1.5 J	4,000 U	2.3 J	3.2
1,1,2-Trichloroethane	1.6 J	4.1 U	7.1 U	6.0 U	3.2 J	1.7 J	4,000 U	3.1 U	2.9 U
1,1-Dichloroethane	3.8 U	0.76 J	4.3 J	5.2 J	3.4 U	1.9 J	4,000 U	3.1 U	0.94 J
1,1-Dichloroethene	3.8 U	4.1 U	7.1 U	1.2 J	3.4 U	0.52 J	4,000 U	3.1 U	2.9 U
1,2,3-Trichloropropane	3.8 U	4.1 U	7.1 U	6.0 U	3.4 U	2.8 U	4,000 U	4.4 J	2.9 U
1,2-Dichlorobenzene	9.9 J	4.1 U	7.1 U	6.0 U	550	2.9 U	4,000 U	3.1 U	36 J

TABLE 3 (Continued)

VALIDATED RESULTS OF VOLATILE ORGANIC COMPOUND ANALYSES (µg/kg)

Sample:	PRE-W-1	PRE-W-6	PRE-W-14	PRE-W-15	PRE-W-16	PRE-W-23	PRE-W-31	PRE-W-33	PRE-W-36
1,2-Dichloroethane	3.8 U	0.68 J	7.1 U	6.0 U	3.4 U	2.8 U	4,000 U	3.1 U	2.9 U
1,2-Dichloropropane	1.0 J	4.1 U	7.1 U	1.2 J	3.4 U	2.8 U	4,000 U	0.81 J	2.9 U
1,3-Dichlorobenzene	13 J	4.1 U	7.1 U	0.65 J	240 J	2.1 J	4,000 U	2.0 J	46 J
1,4-Dichlorobenzene	50 J	2.0 J	12	7.0	1,000	15	840 J	12 J	110 J
2-Butanone	9.6 J	22 J	39 J	15 J	7.7 J	5.5 J	40,000 U	9.7 J	4.1 J
2-Hexanone	38 U	0.48 J	1.5 J	60 U	34 U	28 U	40,000 U	31 U	29 U
4-Methyl-2-pentanone	38 U	0.72 J	2.6 J	60 U	34 U	28 U	40,000 U	0.87 J	1.6 J
Acetone	81 J	280 J	850 J	200 J	1,100 J	54 J	2,500 J	140 J	52 J
Acrolein	76 U	82 U	140 U	120 U	1.2 J	56 U	81,000 U	63 U	59 U
Benzene	5.5 J	30	23	8.0	0.72 J	6.3	4,000 U	4.4 J	3.6 J
Bromomethane	0.61 J	4.1 U	7.1 U	6.0 U	3.4 U	2.8 U	4,000 U	3.1 U	2.9 U
Carbon disulfide	3.8 U	2.1 J	6.2 J	6.0 U	3.4 U	2.8 U	4,000 U	3.1 U	2.9 U
Carbon tetrachloride	8,600	9.9	35	490 J	3,800	580 J	13,000	4,600	5,600
Chlorobenzene	3.8 U	4.1 U	0.84 J	36	3.4 U	0.82 J	4,000 U	4.3 J	16 J
Chloroethane	3.8 U	4.1 U	7.1 U	6.0 U	9.5 J	9.1	4,000 U	3.1 U	2.9 U
Chloroform	22,000	170	150	2,300 J	2,400	1,100 J	4,600	580 J	470 J
Chloromethane	4.0 U	47	150	19	18 J	9.0	15,000	24 J	19 J
Dichlorodifluoromethane	2.4 J	1.8 J	3.5 J	1.2 J	1.4 J	1.3 J	4,000 UJ	2.0 J	1.8 J
Ethylbenzene	1.3 J	1.9 J	2.2 J	6.0 U	11 J	0.91 J	4,000 U	3.8 J	6.5 J
Isobutyl alcohol	38 UJ	41 UJ	71 UJ	60 UJ	34 UJ	28 UJ	40,000 U	31 UJ	29 UJ
Methylene chloride	7.6 UJ	17 J	52 J	12 UJ	24 J	4.7 J	1,600 J	50 J	19 J
Pentachloroethane	61 J	4.1 U	7.1 U	6.0 U	3.4 U	0.58 J	4,000 UJ	30 J	57 J
Styrene	3.8 U	4.1 U	2.4 J	6.0 U	3.4 U	2.8 U	4,000 U	3.1 U	2.9 U
Tetrachloroethene	4,800	84	200	1,200 J	6,700	480 J	3,700 J	350 J	4,300

TABLE 3 (Continued)

VALIDATED RESULTS OF VOLATILE ORGANIC COMPOUND ANALYSES (µg/kg)

Sample:	**PRE-W-1**	**PRE-W-6**	**PRE-W-14**	**PRE-W-15**	**PRE-W-16**	**PRE-W-23**	**PRE-W-31**	**PRE-W-33**	**PRE-W-36**
Toluene	5.8 J	1.9 J	11	2.8 J	280 J	1.7 J	4,000 U	9.2 J	3.4 J
trans-1,2-Dichloroethene	3.8 U	4.1 U	7.1 U	6.0 U	3.4 U	0.62 J	4,000 U	3.1 U	2.9 U
Trichloroethene	67 J	9.2	31	73	53 J	61	540 J	24 J	29 J
Trichlorofluoromethane	3.8 U	4.1 U	7.1 U	6.0 U	3.4 U	2.8 U	4,000 U	3.1 U	2.9 U
Xylenes	4.0 J	6.6	11	1.2 J	210 J	2.8	720 J	8.7 J	20 J

Notes:

µg/kg = Micrograms per kilogram

U = The compound was not detected. The reported numerical value is the sample quantitation limit.

J = The compound was detected, but the result is considered to be estimated for quality control reasons.

UJ = The compound was not detected. The sample quantitation limit is considered to be estimated for quality control reasons.

3.0 SEMIVOLATILE ORGANIC COMPOUND ANALYSES

This section discusses the results for the full-list SVOC analyses. Table 4 contains validated results for all samples; only compounds reported in at least one sample are listed. No problems were noted with data package completeness, GC/MS instrument performance checks, initial and continuing calibrations, blanks, MS/MSD analyses, LCS analyses, or internal standards.

The LCS accompanying the initial analyses was spiked with hexachlorocyclopentadiene only, and the analyses showed that the samples were generally complex mixtures with high concentration of SVOCs. Several extracts could not be concentrated to 1.0 milliliter, and the analyst described these extracts as "thick, dark, and nasty." The laboratory discarded these initial results and reextracted all samples 3 to 4 weeks after collection, beyond the holding time limit of 14 days. However, all of the detected compounds are relatively stable and very persistent in the environment. Since the samples were kept well cooled (below their original, in situ temperature) from collection until extraction, no qualifications are warranted for these delays.

A few extracts exhibited low recoveries for one acidic surrogate, 2,4,6-tribromophenol. No qualifications are warranted for such minor irregularities with only one surrogate. Many extracts were so diluted (up to 500-fold) that surrogate recoveries could not be determined. No qualifications are warranted for these data gaps.

Calculations were performed correctly, with soil results adjusted to dry weight. Most sample extracts were diluted (and some diluted more than once) to bring the more concentrated contaminants into calibration range. However, some results were below the calibration range in the least diluted analytical run. These extrapolations are flagged "J" to indicate that they are estimates.

TABLE 4

VALIDATED RESULTS FOR SEMIVOLATILE ORGANIC COMPOUNDS (µg/kg)

Sample:	**PRE-S-1 (0-2)**	**PRE-S-1 (10-12)**	**PRE-S-2 (0-2)**	**PRE-S-2 (10-12)**	**PRE-S-3 (0-2)**	**PRE-S-3 (10-12)**	**PRE-W-1**
1,2,4-Trichlorobenzene	11,000 U	530,000 U	13,000 U	11,000 U	11,000 U	13,000 U	490,000 U
2-Chloronaphthalene	11,000 U	530,000 U	13,000 U	11,000 U	11,000 U	13,000 U	490,000 U
4-Chlorophenyl phenyl ether	11,000 U	530,000 U	13,000 U	11,000 U	11,000 U	13,000 U	490,000 U
Fluoranthene	11,000 U	530,000 U	4,900 J	11,000 U	11,000 U	13,000 U	490,000 U
Hexachlorobenzene	29,000	410,000 J	45,000	130,000	44,000	520,000	1,300,000
Hexachlorobutadiene	11,000 U	530,000 U	4,700 J	11,000 U	11,000 U	89,000	380,000 J
Hexachlorocyclopentadiene	11,000 U	5,800,000	2,800 J	1,800,000	63,000	4,400,000	5,500,000
Hexachloroethane	11,000 U	530,000 U	13,000 U	10,000 J	11,000 U	40,000	490,000 U
Naphthalene	11,000 U	530,000 U	13,000 U	11,000 U	11,000 U	13,000 U	490,000 U
Phenanthrene	11,000 U	530,000 U	3,300 J	11,000 U	11,000 U	13,000 U	490,000 U
Pyrene	11,000 U	530,000 U	3,800 J	11,000 U	11,000 U	13,000 U	490,000 U

Sample:	**PRE-W-2**	**PRE-W-3**	**PRE-W-4**	**PRE-W-5**	**PRE-W-6**	**PRE-W-201[a]**	**PRE-W-202[a]**
1,2,4-Trichlorobenzene	570,000 U	630,000 U	5,200 J	600,000 U	580,000 U	560,000 U	600,000 U
2-Chloronaphthalene	570,000 U	630,000 U	10,000 J	600,000 U	580,000 U	560,000 U	600,000 U
4-Chlorophenyl phenyl ether	570,000 U	630,000 U	11,000 J	600,000 U	580,000 U	560,000 U	600,000 U
Fluoranthene	570,000 U	630,000 U	14,000 U	600,000 U	580,000 U	560,000 U	600,000 U
Hexachlorobenzene	4,100,000	3,600,000	2,100,000	3,000,000	2,600,000	5,300,000	5,700,000
Hexachlorobutadiene	240,000 J	200,000 J	180,000	290,000 J	250,000 J	270,000 J	310,000 J
Hexachlorocyclopentadiene	8,600,000	7,800,000	6,000,000	11,000,000	9,500,000	8,900,000	9,800,000
Hexachloroethane	570,000 U	630,000 U	92,000	130,000 J	120,000 J	560,000 U	600,000 U
Naphthalene	570,000 U	630,000 U	13,000 J	600,000 U	580,000 U	560,000 U	600,000 U
Phenanthrene	570,000 U	630,000 U	14,000 U	600,000 U	580,000 U	560,000 U	600,000 U
Pyrene	500,000 U	630,000 U	14,000 U	600,000 U	580,000 U	560,000 U	600,000 U

Notes:

µg/kg = Micrograms per kilogram
U = The compound was not detected. The reported numerical value is the sample quantitation limit.
J = The compound was detected, but the result is considered to be estimated for quality control reasons.
a = Field replicate of sample PRE-W-2

4.0 ORGANOCHLORINE PESTICIDE ANALYSES

This section discusses the results for organochlorine pesticide analyses. Table 5 contains validated results for all samples; only compounds reported in at least one sample are listed. No problems were noted with data package completeness, holding times, or initial calibrations. (GC/MS instrument performance check and internal standards are not relevant to organochlorine pesticide analyses.)

During continuing calibrations, an occasional result in one column was outside QC limits. Since the other column results were acceptable, no qualifications are warranted.

The laboratory blank contained low-level concentrations of aldrin, dieldrin, endrin, and endrin ketone. The samples contained such high concentrations of pesticides (including these four) however, that no qualifications are warranted.

MS/MSD analyses were performed on sample PRE-W-1, but results were not usable because the parent sample contained much higher concentrations of pesticides than the spikes. No qualifications are warranted for this data gap.

The LCS analysis reported a recovery of 160 percent for dieldrin, above QC limits of 57 to 123 percent. All dieldrin results are flagged “J” to indicate that they are estimates biased high.

In most analyses, surrogate recoveries could not be determined due to the high dilutions. No qualifications are warranted for these data gaps.

As noted above, sample extracts were diluted for analysis due to the high concentrations of pesticides. The results in Table 5 are derived from dilutions ranging from 200-fold to 200,000-fold. Two or three dilutions were used for each sample, so no results exceeded the calibration range. However, some results were below the calibration range in the least diluted analysis. These extrapolations are flagged “J” to indicate that they are estimates.

TABLE 5

VALIDATED RESULTS FOR ORGANOCHLORINE PESTICIDE ANALYSES (µg/kg)

Sample:	PRE-S-1 (0-2)	PRE-S-1 (10-12)	PRE-S-1 (12-13)	PRE-S-2 (0-2)	PRE-S-2 (10-12)	PRE-S-2 (12-13)	PRE-S-3 (0-2)	PRE-S-3-(10-12)
4,4’-DDD	3,600 U	3,700 U	940 U	21,000 U	8,200	4,900	360 U	1,100 U
4,4’-DDD	3,600 U	3,700 U	940 U	21,000 U	940 U	940 U	360 U	1,100 U
Aldrin	7,400	26,000	7,000	140,000	15,000	9,900	1,300	3,200
alpha-BHC	3,600 U	4,700	940 U	21,000 U	940 U	940 U	360 U	1,100 U
beta-BHC	3,600 U	3,700 U	940 U	21,000 U	940 U	940 U	360 U	1,100 U
Dieldrin	85,000 J	150,000 J	59,000 J	4,500,000 J	63,000 J	34,000 J	13,000 J	21,000 J
Endrin	3,700	3,700 U	940 U	53,000	940 U	940 U	1,200	1,100 U
Endrin ketone	3,900	3,700 U	940 U	6,500 J	8,300	2,700	2,500	1,100 U
Heptachlor	3,600 U	3,700 U	940 U	21,000 U	940 U	940 U	360 U	1,100 U

Sample:	PRE-W-1	PRE-W-2	PRE-W-3	PRE-W-4	PRE-W-5	PRE-W-6	PRE-W-201[a]	PRE-W-202[a]
4,4’-DDD	3,900 U	52,000	51,000	1,300 U	4,000 U	3,900 U	23,000	29,000
4,4’-DDD	3,900 U	4,000 U	11,000 U	1,300 U	14,000	3,900 U	4,000 U	10,000
Aldrin	110,000 J	700,000	110,000	40,000 J	1,400,000	3,800 J	490,000	570,000
alpha-BHC	3,900 U	4,000 U	11,000 U	1,300 U	4,000 U	3,900 U	4,000 U	4,000 U
beta-BHC	3,900 U	11,000	11,000 U	1,300 U	4,000 U	3,900 U	4,000 U	4,000 U
Dieldrin	1,300,000 J	1,700,000 J	360,000 J	280,000 J	1,500,000 J	23,000 J	1,200,000 J	1,200,000 J
Endrin	25,000	62,000	11,000 U	9,400	63,000	3,900 U	47,000	53,000
Endrin ketone	14,000	14,000	11,000 U	4,500	47,000	3,900 U	8,900	11,000
Heptachlor	3,900 U	15,000	4,400 J	1,300 U	20,000	3,900 U	11,000	11,000

Notes:

µg/kg = Micrograms per kilogram
U = The compound was not detected. The reported numerical value is the sample quantitation limit.
J = The compound was detected, but the result is considered to be estimated for quality control reasons.
a = Field replicate of sample PRE-W-2

5.0 OVERALL EVALUATION

Given the nature of the samples, analytical results and laboratory analyses appear to be acceptable, as qualified. Some laboratory errors (such as an apparent miscommunication that led to misspiking the first SVOC LCS) made little difference in the results. The samples contain many organic compounds, and many of the samples exhibit high concentrations of these contaminants. This complexity tends to produce significant matrix interferences, seen as irregularities in MS/MSD analyses, surrogate recoveries, and internal standard results. Some such problems were seen, but they were not severe enough to render the results unusable. Highly contaminated samples like these often have irregular distributions of the contaminants because the samples are a physical mixture of organic particles (containing most of the contaminants) within the bulk matrix of soil or water.

February 10, 2003

Memo to: ISTD File
From: Harry Ellis
Re: Data Validation for Pre-Demonstration Samples (Dioxin Analyses)

This memorandum documents a data validation of the analytical results from soil samples collected during the pre-demonstration sampling for the In Situ Thermal Destruction (ISTD) Technology carried out at the "Hex Pit" of the Rocky Mountain Arsenal, Adams County, Colorado, under the auspices of the U.S. Environmental Protection Agency (EPA) Field Evaluation and Technical Support (FEATS) program by Tetra Tech EM Inc. (Tetra Tech) and its subcontractor, Kemron Environmental Services (Kemron). A total of 12 composite soil samples and two replicate soil samples were collected by Tetra Tech on July 18 through 25, 2001, and sent in three shipments by overnight courier to Triangle Laboratories, Inc. (Triangle), of Durham, North Carolina. Triangle analyzed the samples for polychlorinated dibenzo(p)dioxins and polychlorinated dibenzofurans (dioxins) by EPA Test Methods for Evaluating Solid Wastes (SW-846) Method 8290. Each shipment was analyzed as a separate sample delivery group (SDG), Nos. 54747, 54763, and 54787. Additional samples were sent to another laboratory for other analyses; those analyses have been discussed in a separate memorandum.

The data were evaluated in general accordance with the EPA Contract Laboratory Program National Functional Guidelines (NFG) for dioxin review, dated August 2002. When differences exist between the SW-846 method and the NFG, the data validation followed the acceptance criteria given in the method. In addition, when Triangle gave laboratory-specific acceptance criteria, then these criteria were used to evaluate the data. The evaluation of the data was based on the following quality control (QC) parameters.

- Data package completeness
- Holding times
- Instrument performance check
- Initial and continuing calibrations
- Blanks
- Matrix spike/matrix spike duplicate (MS/MSD) analyses
- Laboratory control samples (LCS)
- Internal standards
- Surrogate recoveries
- Compound quantitation

The following sections discuss, in turn, the three SDGs. A final section provides an overall evaluation of the analyses and is followed by tables summarizing the validated analytical results.

1.0 SDG No. 54747

SDG No. 54747 included four soil samples collected July 18 and 19. There were no problems with data package completeness, holding times, instrument performance checks, LCS results, and surrogate recoveries. Validated analytical results are summarized in Table 1.

The closing continuing calibration performed after the analysis of the undiluted extracts had some unacceptable results due to carryover from the samples. Since the affected analytes were quantitated from diluted reanalyses, no qualifications are required.

Some of the laboratory blanks contained low-level concentrations of analytes. The samples contained much higher concentrations of the analytes (or of interfering nontargets), so no qualifications are required.

This SDG included no MS/MSD analyses. Duplicate LCS analyses provided adequate checks of accuracy and precision, so no qualifications are warranted for this data gap.

In a few cases, such as hexachlorodibenzofurans (HxCDF) and heptachlorodibenzofurans (HpCDF) in the undiluted analysis of sample PRE-S-1 (0-2), co-eluting nontarget compounds gave the internal standards an ion ratio outside QC limits. No such results were used for quantitation, so no qualifications are required for this problem. In addition, some internal standards had recoveries outside their QC limits, usually above the limits due to the presence of nontarget compounds. In most cases, the sample was reanalyzed at a different dilution with acceptable recoveries so no qualifications are required. The exception was sample PRE-S-1 (10-12) where three internal standards were outside their QC limits in the undiluted analysis. For instance, the recovery for $^{13}C_{12}$-2,3,7,8-tetrachlorodibenzo(p)dioxin (TCDD) was 197 percent, versus QC limits of 25 to 164 percent. Therefore, the results for 2,3,7,8-TCDD and other similarly affected analytes are flagged “J” to indicate that they are estimated, biased low.

These samples produced numerous problems with quantitation, which Triangle worked diligently to minimize. First, all samples were analyzed undiluted. Many analytes exceeded their calibration range and most of those saturated the detector. Therefore, Triangle reextracted the samples (using a smaller portion of soil) and diluted those extracts to reach 1,000-fold dilutions. One sample was analyzed a third time at a 12,000-fold dilution and one at a 25-fold dilution. Due to these repeated attempts, almost all of the results in Table 1 are within the calibration range of one dilution, so they are not qualified. A few results are above the calibration range from a less diluted sample but below the range for a more diluted one (calibration standards cover a 200-fold range), so these extrapolations are flagged "J" to indicate that they are estimated.

In this analysis, the detection limits are generally calculated from the definition of a peak, namely that it has a signal-to-noise ratio of 2.5 or more. This applies to the nondetect result for 2,3,4,7,8-pentachlorodibenzofuran (PeCDF) in sample PRE-S-1 (0-2). But in a number of cases, such as 2,3,7,8-tetrachlorodibenzofuran (TCDF) in that same sample, a peak was present in the window for the analyte but it was outside the acceptable range of isotope ratios. Therefore, the peak was partially or completely nontarget compounds. When this occurs, the detection limit is calculated from the interfering peak and is called in the laboratory report the "estimated maximum possible concentration" or EMPC. Table 1 does not distinguish between these two types of detection limits.

Finally, in a few cases, such as total TCDF in sample PRE-S-1 (0-2), polychlorinated diphenyl ethers (PCDPE) are contributing to the apparent mass of analytes. The laboratory sorted out the PCDPE from the dioxins as much as possible, but the results are flagged "J" to indicate that they are estimated.

2.0 SDG No. 54763

SDG No. 54763 includes four soil samples collected on 20 and 23 July. There were no problems with data package completeness, holding times, instrument performance check, LCS results, and surrogate recoveries. Validated analytical results are summarized in Table 2.

Almost all calibration results were acceptable. The initial analyses of these samples were performed in the same analytical run as the samples in SDG No. 54747. The closing continuing calibration had results outside QC limits due to carryover from some of the samples. No qualifications are applied for this irregularity.

Some of the laboratory blanks contained low-level concentrations of a few analytes. The samples contained much higher concentrations, so no qualifications are warranted.

No MS/MSD analyses were included in this SDG. Duplicate LCS analyses provided adequate evidence of acceptable accuracy and precision, so no qualifications are warranted for this data gap.

A few of the internal standard recoveries exceeded QC limits. For instance, in the original analysis of sample PRE-S-3 (10-12), the recovery of $^{13}C_{12}$-1,2,3,6,7,8-HxCDF was 170 percent versus QC limits of 26 to 123 percent. The HxCDF analytes were quantitated from a more diluted analysis (with acceptable internal standard recoveries), so no qualifications were warranted. However, $^{13}C_{12}$-1,2,3,6,7,8-hexachlorodibenzo(p)dioxin (HxCDD) had a 198 percent recovery, versus QC limits of 28 to 130 percent. Since all three HxCDD isomers were quantitated against this internal standard, they are flagged "J" to indicate that they are estimated, biased low. Similar considerations apply to other internal standards in this and other samples.

These samples contained many target analytes and even more nontarget compounds, which interfered with the analyses. All samples were reextracted and reanalyzed at a dilution. Sample PRE-S-3 (10-12) was also analyzed at a third, intermediate dilution. Despite this, a few results were above the calibration range at one dilution and below it in the next higher dilution. These extrapolations are flagged "J" to indicate that they are estimated. In some cases, peaks appeared in the windows for analytes, but the isotope ratios were outside the acceptable range. Therefore, the peaks were partially or completely nontarget compounds. These results are flagged "U" to indicate that the analyte was not detected and the size of the nontarget peak was used to calculate the sample quantitation limit (called an EMPC by the laboratory).

Finally, it is well known that 2,3,7,8-TCDF cannot be separated from some (relatively nontoxic) isomers, especially 2,3,4,7-TCDF and 1,2,3,9-TCDF, on the primary chromatography column. Therefore, the extract is reanalyzed on a second column to confirm the identity. With sample PRE-S-3 (10-12), the second column did not confirm the presence of 2,3,7,8-TCDF. Therefore, the result is flagged "U" to indicate that it is a false positive.

3.0 SDG No. 54787

SDG No. 54787 includes four soil samples and two replicate samples (a field triplicate) collected on 24 and 25 July. There were no problems with data package completeness, holding times, instrument performance checks, initial and continuing calibrations, LCS results, internal standards, and surrogate recoveries. Validated analytical results are summarized in Table 3.

Some of the laboratory blanks contained low-level concentrations of some analytes. However, all samples contained much higher concentrations of analytes, interferents, or both, so no qualifications are warranted.

MS/MSD analyses were performed on two samples, PRE-S-2 (10-12) and PRE-W-3. In both cases, accuracy could not be determined from the percent recovery data since the field sample concentrations were much more (generally orders of magnitude more) than the amounts spiked. Since all LCS results were acceptable, no qualifications are warranted for this data gap. The precision results (determined from the relative percent difference data) were quite good for the MS/MSD analyses on sample PRE-S-2 (10-12). In contrast, precision was poor for the MS/MSD analyses on sample PRE-W-3, with all MSD results about twice the MS results. This same sort of irregularity was seen with the field triplicate samples, since the primary sample (PRE-W-2) contained considerably more than the first replicate sample (PRE-W-201), which contained somewhat more than the second replicate sample (PRE-W-202). These results show that in many places there may be considerable local variations in the dioxin content of the soil, giving different quantitative results for different 12 to 13 gram portions from the field sample.

As with earlier SDGs, Triangle worked to get usable results. The initial analyses were performed at 1,000- or 2,000-fold dilutions. Some samples were reanalyzed at a greater dilution to bring higher concentrations within calibration range and some were reanalyzed at a 50-fold dilution to bring lower concentration results within calibration range. Despite all this work, some positive results [such as 1,2,3,7,8-pentachlorodibenzo-p-dioxin in sample PRE-S-2 (0-2)] were still below the calibration range. These extrapolations are flagged “J” to indicate that they are estimated. As defined in the method, there are two types of sample quantitation limits shown in the results. When there is no peak in the analyte window that has a signal-to-noise level of 2.5 or more, the listed value is the “detection level” of 2.5 times the noise. This applies to results such as 2,3,7,8-TCDD in sample PRE-S-2 (0-2). When there is a peak in the window but it fails the mass ratio test (indicating that it is, at least in part, a nontarget compound) the peak size is used to calculate an EMPC, as for 1,2,3,4,7,8-HxCDD in the same sample.

4.0 OVERALL EVALUATION

On the whole, the laboratory did as well as could be expected from the characteristics of the samples (highly contaminated, heterogenous) and the need to produce some usable numbers without delaying to carry out a research project on each sample. The results are usable as qualified for any purpose.

As summarized in Tables 1 through 3, about half the samples contained measurable concentrations of all 17 individual 2,3,7,8-substituted analytes. The others contained most of the target analytes. To provide a measure of the total adverse effects of these analytes, one uses the procedures in the method to calculate the "toxicity equivalent" for each sample. This is essentially the concentration of 2,3,7,8-TCDD that would have the same adverse effects as the entire mixture of contaminants because 2,3,7,8-TCDD has a toxicity equivalent factor of 1.00. These toxicity equivalents are generally used in risk assessments and other risk-based decision making. Table 4 summarizes the results of the toxicity equivalent calculation for these samples. For samples with one or more nondetect results, three calculations are presented. The first (labeled "maximum") calculation assumes that nondetected analytes are actually present at their quantitation limits, whether that is an actual detection limit or an estimated maximum possible concentration, as discussed for this SDG. The second calculation (labeled "minimum") assumes the nondetected analytes are completely absent. The third calculation (labeled "median") assumes that the true concentrations of nondetected analytes are half their quantitation limits. This "median" estimation is routinely used in risk assessment and is probably the most realistic. These samples have such high concentrations that the differences in the toxicity equivalent calculations produce negligible differences in biological effect estimates.

The primary technical problem with these analyses was interference from high concentrations of both target analytes and other compounds. The nontarget compounds are apparently closely related to the target ones since they respond readily to the detectors. The source of these samples is the disposal site for wastes from the manufacture of hexachlorocyclopentadiene. The manufacturing processes include heating various compounds in the presence of some oxygen sources, which may result in the generation of target compounds, especially highly chlorinated dibenzofurans. As discussed above for the MS/MSD analyses, there is good evidence of local heterogeneity in the dioxin concentrations. However, the relative concentrations of the various analytes within different portions of the same sample are essentially consistent. The simplest explanation for this is that the waste composition, in terms of dioxin compounds and their proportions, was relatively consistent over the years of production. One would expect this from a single manufacturing process and highly stable products. Therefore, the inconsistencies are practically limited to the total concentrations (expressed as toxicity equivalents) over space.

There is one significant consequence of this spatial heterogeneity. No single sample can be considered fully "representative" of its source area. Many samples, more than those discussed here, are needed to define an "average" concentration of dioxins in the pit. Therefore, it will be difficult to compare the post-demonstration results to these pre-demonstration results. Even if post-demonstration samples are taken within a few centimeters of the locations used here, differences between the results may be due to heterogeneity. To minimize the probability of error, it would be reasonable to consider a change of less than 10-fold in the toxicity equivalent to be a “no effect” response.

TABLE 1

SUMMARY OF VALIDATED DIOXIN RESULTS FROM SDG NO. 54747
(nanograms per kilogram)

Sample Location:	**PRE-S-1 (0-2)**	**PRE-S-1 (10-12)**	**PRE-W-1**	**PRE-W-6**
2,3,7,8-Tetrachlorodibenzo(p)dioxin	11.2	600 J	940	500 U
1,2,3,7,8-Pentachlorodibenzo(p)dioxin	83	4,900 J	7,600	4,600
1,2,3,4,7,8-Hexachlorodibenzo(p)dioxin	180	11,100	21,000	10,600
1,2,3,6,7,8-Hexachlorodibenzo(p)dioxin	200	10,700 J	22,000	11,600
1,2,3,7,8,9-Hexachlorodibenzo(p)dioxin	220	11,800 J	19,000	12,300
1,2,3,4,6,7,8-Heptachlorodibenzo(p)dioxin	1,150	68,000 J	171,000	70,000
Octachlorodibenzo(p)dioxin	2,400 J	75,000 J	330,000	105,000
2,3,7,8-Tetrachlorodibenzofuran	880 U	76,200	91,000 U	128,000
1,2,3,7,8-Pentachlorodibenzofuran	7,500 J	420,000	670,000	660,000
2,3,4,7,8-Pentachlorodibenzofuran	133 U	94,000	156,000	94,000
1,2,3,4,7,8-Hexachlorodibenzofuran	14,600 J	950,000	1,840,000	1,240,000
1,2,3,6,7,8-Hexachlorodibenzofuran	5,000	600,000	1,130,000	740,000
2,3,4,6,7,8-Hexachlorodibenzofuran	1,750	170,000	300,000	250,000
1,2,3,7,8,9-Hexachlorodibenzofuran	2,700	145,000	250,000	210,000
1,2,3,4,6,7,8-Heptachlorodibenzofuran	26,000 J	2,000,000	4,500,000	2,200,000
1,2,3,4,7,8,9-Heptachlorodibenzofuran	14,800 U	1,140,000	2,500,000	1,300,000
Octachlorodibenzofuran	280,000	12,500,000	30,000,000	52,000,000
Total tetrachlorodibenzo(p)dioxins	500	27,000	55,000	34,000
Total pentachlorodibenzo(p)dioxins	1,110	39,000	71,000	50,000
Total hexachlorodibenzo(p)dioxins	2,300	146,000	230,000	137,000
Total heptachlorodibenzo(p)dioxins	2,000	142,000	320,000	139,000
Total tetrachlorodibenzofurans	7,000 J	750,000	610,000	1,400,000
Total pentachlorodibenzofurans	17,000	1,360,000	1,900,000	2,400,000
Total hexachlorodibenzofurans	29,000	2,900,000	5,200,000	3,900,000
Total heptachlorodibenzofurans	37,000	3,900,000	8,600,000	4,500,000

Notes:

J = The analyte was detected. The reported numerical value is considered to be estimated for quality control reasons.
U = The analyte was not detected. The reported numerical value is the sample quantitation limit.

TABLE 2

SUMMARY OF VALIDATED DIOXIN RESULTS FROM SDG NO. 54763

(nanograms per kilogram)

Sample Location:	**PRE-S-3 (0-2)**	**PRE-S-3 (10-12)**	**PRE-W-4**	**PRE-W-5**
2,3,7,8-Tetrachlorodibenzo(p)dioxin	560	60	290	670 U
1,2,3,7,8-Pentachlorodibenzo(p)dioxin	3,700	40	2,000	4,500 U
1,2,3,4,7,8-Hexachlorodibenzo(p)dioxin	7,700	70 J	4,100	6,400
1,2,3,6,7,8-Hexachlorodibenzo(p)dioxin	9,400	80 J	4,800	10,600
1,2,3,7,8,9-Hexachlorodibenzo(p)dioxin	9,400	80 J	5,000	11,000
1,2,3,4,6,7,8-Heptachlorodibenzo(p)dioxin	60,000	840 J	31,000	66,000
Octachlorodibenzo(p)dioxin	75,000	2,500 J	39,000	78,000
2,3,7,8-Tetrachlorodibenzofuran	36,000	2,500 U	82,000	81,000
1,2,3,7,8-Pentachlorodibenzofuran	148,000	16,200	300,000	500,000
2,3,4,7,8-Pentachlorodibenzofuran	48,000	1,100	24,000	57,000
1,2,3,4,7,8-Hexachlorodibenzofuran	200,000	16,100	490,000	440,000 J
1,2,3,6,7,8-Hexachlorodibenzofuran	104,000	11,400	280,000	270,000 J
2,3,4,6,7,8-Hexachlorodibenzofuran	80,000	3,100	43,000	69,000 J
1,2,3,7,8,9-Hexachlorodibenzofuran	84,000	3,200	47,000	86,000 J
1,2,3,4,6,7,8-Heptachlorodibenzofuran	340,000	27,000 U	860,000	780,000
1,2,3,4,7,8,9-Heptachlorodibenzofuran	180,000	19,400	560,000	390,000
Octachlorodibenzofuran	2,800,000	245,000	8,500,000	13,700,000
Total tetrachlorodibenzo(p)dioxins	43,000	610	25,000	46,000
Total pentachlorodibenzo(p)dioxins	51,000	770	24,000	53,000
Total hexachlorodibenzo(p)dioxins	117,000	880	60,000	139,000
Total heptachlorodibenzo(p)dioxins	109,000	840	61,000	132,000
Total tetrachlorodibenzofurans	270,000	30,000	870,000	1,180,000
Total pentachlorodibenzofurans	380,000	61,000	1,220,000	1,810,000
Total hexachlorodibenzofurans	540,000	56,000	1,520,000	1,390,000
Total heptachlorodibenzofurans	680,000	27,000	1,830,000	1,530,000

Notes:

J = The analyte was detected. The reported numerical value is considered to be estimated for quality control reasons.
U = The analyte was not detected. The reported numerical value is the sample quantitation limit.

TABLE 3

SUMMARY OF VALIDATED ANALYTICAL RESULTS FROM SDG NO. 54787

(nanograms per kilogram)

Sample Location:	**PRE-S-2 (0-2)**	**PRE-S-2 (10-12)**	**PRE-W-2**	**PRE-W-201[a]**	**PRE-W-202[a]**	**PRE-W-3**
2,3,7,8-Tetrachlorodibenzo(p)dioxin	18.9 U	190	1,200 U	600 U	1,800 U	2,000 J
1,2,3,7,8-Pentachlorodibenzo(p)dioxin	119 J	1,350	8,300 J	5,200 J	2,100 U	14,100
1,2,3,4,7,8-Hexachlorodibenzo(p)dioxin	198 U	2,300	13,900	9,800 J	8,400 J	71,000
1,2,3,6,7,8-Hexachlorodibenzo(p)dioxin	270	3,500	21,000	12,500	10,100	45,000
1,2,3,7,8,9-Hexachlorodibenzo(p)dioxin	240	3,300	19,100 U	10,200	6,300 J	33,000
1,2,3,4,6,7,8-Heptachlorodibenzo(p)dioxin	1,900	23,000	106,000	65,000	51,600 U	420,000
Octachlorodibenzo(p)dioxin	4,200	43,000	257,000	146,000	156,000	910,000
2,3,7,8-Tetrachlorodibenzofuran	4,400	27,000	73,000	32,000	32,000	94,000
1,2,3,7,8-Pentachlorodibenzofuran	14,700	146,000	720,000	480,000	390,000	1,550,000
2,3,4,7,8-Pentachlorodibenzofuran	1,420	16,100	57,000	37,000	30,000	73,000
1,2,3,4,7,8-Hexachlorodibenzofuran	20,000	250,000	1,340,000	900,000	860,000	1,330,000
1,2,3,6,7,8-Hexachlorodibenzofuran	10,000	176,000	650,000	480,000	430,000	1,620,000
2,3,4,6,7,8-Hexachlorodibenzofuran	3,900	32,210	195,000	142,000	109,000	290,000
1,2,3,7,8,9-Hexachlorodibenzofuran	3,100	33,000	164,000	115,000	59,000	330,000
1,2,3,4,6,7,8-Heptachlorodibenzofuran	36,000	490,000	2,200,000	1,550,000	1,480,000	2,400,000
1,2,3,4,7,8,9-Heptachlorodibenzofuran	26,000	183,000	1,240,000	880,000	690,000	3,900,000
Octachlorodibenzofuran	480,000	4,500,000	24,000,000	19,600,000	14,200,000	24,000,000
Total tetrachlorodibenzo(p)dioxins	290	16,700	31,000	48,000	36,000	109,000
Total pentachlorodibenzo(p)dioxins	730	28,000	133,000	73,000	60,000	240,000
Total hexachlorodibenzo(p)dioxins	2,300	41,000	210,000	140,000	128,000	720,000
Total heptachlorodibenzo(p)dioxins	3,200	41,000	191,000	119,000	51,000	680,000
Total tetrachlorodibenzofurans	26,000	500,000	1,890,000	1,160,000	1,070,000	2,300,000
Total pentachlorodibenzofurans	50,000	730,000	2,700,000	1,880,000	1,700,000	5,700,000

TABLE 3 (Continued)

SUMMARY OF VALIDATED ANALYTICAL RESULTS FROM SDG NO. 54787

(nanograms per kilogram)

Sample Location:	**PRE-S-2 (0-2)**	**PRE-S-2 (10-12)**	**PRE-W-2**	**PRE-W-201[a]**	**PRE-W-202[a]**	**PRE-W-3**
Total hexachlorodibenzofurans	63,000	770,000	3,600,000	2,700,000	2,500,000	4,100,000
Total heptachlorodibenzofurans	79,000	910,000	4,600,000	3,200,000	2,800,000	5,000,000

Notes:

a Field replicate of sample PRE-W-2
J = The analyte was detected. The reported numerical value is considered to be estimated for quality control reasons.
U = The analyte was not detected. The reported numerical value is the sample quantitation limit.

TABLE 4

SUMMARY OF TOXICITY EQUIVALENTS
(nanograms per kilogram)

Sample	Toxicity Equivalents		
	Maximum[a]	**Minimum[b]**	**Median[c]**
PRE-S-1 (0-2)	3,750	3,450	3,600
PRE-S-1 (10-12)	313,000	313,000	313,000
PRE-W-1	586,000	577,000	581,000
PRE-W-6	430,000	430,000	430,000
PRE-S-3 (0-2)	95,700	95,700	95,700
PRE-S-3 (10-12)	5,890	5,370	5,630
PRE-W-4	147,400	147,400	147,400
PRE-W-5	179,900	177,000	178,400
PRE-S-2 (0-2)	6,890	6,850	6,870
PRE-S-2 (10-12)	80,200	80,200	80,200
PRE-W-2	378,000	374,000	376,000
PRE-W-201[d]	260,000	260,000	260,000
PRE-W-202[d]	226,000	222,000	224,000
PRE-W-3	596,000	596,000	596,000

Notes:

a	"Maximum" calculated with nondetect results assumed to be equal to the sample reporting limits
b	"Minimum" calculated with nondetect results assumed to be zero
c	"Median" calculated with nondetect results assumed to be half the sample reporting limits
d	Field replicates of sample PRE-W-2

January 15, 2003

Memo to:	ISTD File
From:	Harry Ellis
Re:	Data Validation for Post-Demonstration Samples (All Analyses)

This memorandum documents a data validation of the analytical results from soil samples collected during the post-demonstration sampling for the In Situ Thermal Destruction (ISTD) Technology carried out at the "Hex Pit" of the Rocky Mountain Arsenal, Adams County, Colorado, under the auspices of the U.S. Environmental Protection Agency (EPA) Field Evaluation and Technical Support (FEATS) program by Tetra Tech EM Inc. (Tetra Tech) and its subcontractor, Kemron Environmental Services (Kemron). A total of 14 soil samples were collected by Tetra Tech on October 15 through 17, 2002. These were sent by overnight courier to Accura Analytical Laboratory (AAL) of Norcross, Georgia. AAL analyzed the samples as sample delivery group (SDG) No. 2846. The seven grab samples were analyzed by EPA Test Methods for Evaluating Solid Wastes (SW-846) Method 8260B for volatile organic compounds (VOC). AAL analyzed the seven composite samples for semivolatile organic compounds (SVOC) by SW-846 Method 8270C and for organochlorine pesticides by SW-846 Method 8081A. About a week after sample collection, AAL also analyzed the composite samples for pH by SW-846 Method 9045C. Tetra Tech also sent portions of the composite samples to Triangle Laboratories, Inc. (Triangle), of Durham, North Carolina. Triangle analyzed the samples for polychlorinated dibenzo(p)dioxins and polychlorinated dibenzofurans (dioxins) by SW-846 Method 8290, under SDG No. 58676.

The data were evaluated in general accordance with the EPA Contract Laboratory Program National Functional Guidelines (NFG) for organic data review, dated October 1999, and the draft NFG for dioxin data review, dated August 2002. The various methods provide guidance on procedures and method acceptance criteria that, in some cases, differ from those in the NFG. When differences exist between the methods and the NFG, the data validation followed the acceptance criteria given in the methods. In addition, if the data package presented laboratory-specific acceptance criteria, then these criteria were used to evaluate the data unless the criteria were considered inadequate. Finally, in cases where the criteria in Section 6.0 of the quality assurance project plan (QAPP) are different from the others, the QAPP criteria are used in the validation. The evaluation of the data was based on the following parameters:

- Data package completeness
- Holding times
- Instrument performance check

- Initial and continuing calibrations
- Blanks
- Matrix spike/matrix spike duplicate (MS/MSD) analyses
- Laboratory control samples (LCS)
- Internal standards
- Surrogate recoveries
- Compound quantitation

The following sections discuss, in turn, the analyses for VOCs, SVOCs, organochlorine pesticides, pH, and dioxins. A final section provides an overall evaluation of the analyses and is followed by an attachment containing a series of tables summarizing the validated analytical results

1.0 VOLATILE ORGANIC COMPOUND ANALYSES

The VOC analyses had no problems with data package completeness, holding times, instrument performance check, LCS results, internal standards, and surrogate recoveries. Validated results are on Table 1 of the attachment.

In the VOC initial calibrations, some analytes had an average relative response factor (RRF) less than the usual data validation minimum of 0.05. Accura compensated for this by using appropriately higher quantitation limits for these compounds, so no qualifications are warranted. In the continuing calibration performed before most of the sample analytical runs, the RRF for 1,2,3-trichlorobenzene, 1,2,4-trichlorobenzene, 1,4-dioxane, and acetone had an excessive percent difference (over 25 percent) from the average RRF from the initial calibration. Therefore, all results for those compounds from the associated runs are flagged “J” or “UJ,” as appropriate, to indicate that they are estimated. In the last continuing calibration, acrolein had an excessive percent difference. Since all acrolein results are derived from earlier analyses, no qualifications are warranted.

VOC blanks contained traces of chloromethane and xylenes. Similar low concentrations in some samples are flagged “U” to indicate that they are considered to be artifacts.

The MS/MSD analyses were performed using sample POST-HVJ6. That sample was diluted so much to bring the major contaminants within calibration range in the parent sample that spike recoveries could not be reliably determined. However, the precision results (relative percent differences between the two spiked sample results) were acceptable. No qualifications are warranted for the missing data.

Accura found it difficult to bring all positive results within the calibration range, despite the use of multiple dilutions and both low-level and medium-level analytical procedures. Table 1 (in the attachment) reflects the best available results. When a concentration from the least diluted chromatographic run is below the calibration range (such as 1,1-dichloroethane, 1,2,3-trichlorobenzene, and other compounds in sample POST-HVH4), that extrapolation is flagged “J” to indicate that it is estimated.

Carbon tetrachloride and chloroform in sample POST-HVJ6 are illustrative examples of inconsistent results. Although the upper end of the calibration range is 20 times the lower end, the results for those compounds exceed the range in the undiluted run but are below it in the 5-fold diluted run. This may be a consequence of a highly variable distribution of contaminants within the sample. The tabulated results are those from the undiluted run and are flagged “J” to indicate that they are estimated.

2.0 SEMIVOLATILE ORGANIC COMPOUND ANALYSES

The SVOC analyses had no problems with data package completeness, holding times, instrument performance check, LCS results, and internal standards. Validated results are summarized in Table 2 of the attachment.

All initial calibration results were within QC limits. One continuing calibration had an excessive percent difference for 2,4-dinitrophenol. The sample quantitation limits for that compound are flagged “UJ” to indicate that they are estimated. The other continuing calibration had an excessive percent difference for pentachlorophenol. Since all results for that compound were associated with the first continuing calibration, no further qualifications are warranted.

The laboratory blank contained traces of hexachlorocyclopentadiene and several polynuclear aromatic hydrocarbons (PAH). The samples contained much more hexachlorocyclopentadiene but none of the PAHs, so no qualifications are required.

As with the VOC analyses, sample POST-HVJ6 was used for MS/MSD analyses and recoveries could not be calculated due to the excessive dilution of the sample required to bring contaminants within calibration range. The precision results were all acceptable. No qualifications will be applied for the data gaps.

Surrogate recoveries could not be determined in many analytical runs because of the high dilution factors. In the less diluted runs, most surrogate recoveries were within Accura's limits. However, two of the three acidic surrogates in the less diluted analytical run of sample POST-HVH8 were below their limits. Therefore, the results for all acidic analytes in that sample are flagged "UJ" to indicate that the quantitation limits are estimated, biased low.

As with the VOC analyses, samples were analyzed at multiple dilutions. The positive results below the calibration range in the least diluted run are flagged "J" to indicate that they are estimated.

3.0 ORGANOCHLORINE PESTICIDE ANALYSES

The organochlorine pesticide analyses had no problems with data package completeness, holding times, instrument performance check, blanks, and LCS results. The method uses no internal standard. Validated results are summarized in Table 3 in the attachment.

All initial calibration results met QC requirements. A number of compounds had an excessive percent difference on the primary column or the secondary column, but not both, during the continuing calibrations. No qualifications are warranted for these irregularities. However, delta-BHC had differences above the QC limit of 15 percent on both columns during the closing continuing calibration. The results for that compound are flagged "UJ" to indicate that they are estimated.

No MS/MSD analyses were performed. In view of the results from the SVOC analyses, it is probable that such analyses would have provided little, if any, useful information. No qualifications will be applied for this data gap.

Due to the high dilution factor required by the presence of large amounts of various organochlorine compounds in the samples, surrogate recoveries could not be determined. No qualifications are warranted for these data gaps.

As with other analyses, some positive results, such as endrin ketone in sample POST-HVH8, were below the calibration range in the least diluted analysis. These extrapolations are flagged "J" to indicate that they are estimated. A number of other results, such as aldrin and endrin in that same sample, had relatively high differences between the results on the primary and secondary columns. These irregularities may be a result of varying amounts of nontarget compounds eluting with the analytes. All such results are flagged "J" to indicate that they are estimated.

4.0 pH ANALYSES

The pH analyses had no problems with data package completeness, calibration, and sample duplicate results. The only other QC parameter relevant to these analyses is sample quantitation. The instrument was calibrated with standard buffers over the range of 4 to 10. However, all sample results were at least 2 standard units outside this range. Therefore, the validated results, listed on Table 3 in the attachment, are flagged "J" to indicate that these extrapolations are estimated.

5.0 POLYCHLORINATED DIBENZO(P)DIOXIN AND POLYCHLORINATED DIBENZOFURAN ANALYSES

The dioxin analyses had no problems with holding times, instrument performance checks, initial and continuing calibrations, LCS and LCS duplicate analyses, internal standards, and surrogate recoveries. Validated analytical results are summarized in Table 4.

As received, the data package was missing two pages, the results summary for one sample. The data were available elsewhere, in both the raw data and the introductory data summary. Triangle furnished copies of the pages when requested.

The laboratory (method) blank and the cleanup blank contained low-level concentrations of several of the more chlorinated analytes. The samples contained much higher concentrations, so no qualifications are warranted.

MS/MSD analyses were performed on sample POST-HVJ6. For most analytes, the sample contained so much more compound than the spike that recoveries could not be reliably measured. Even for 2,3,7,8-tetrachlorodibenzo(p)dioxin (TCDD), which was not reported in the unspiked sample, the interfering material dominated analytical results. Therefore, there is no sample-specific information on accuracy. In addition, precision results were not satisfactory since the MSD sample contained more of every analyte than the MS sample. These results are probably due to a heterogenous distribution of the analytes within the material collected for the sample. All results for the parent sample are flagged "J" or "UJ" to indicate that they are estimated due to sample heterogeneity.

The initial analyses of these samples used the undiluted extracts. Most, if not all, of the analytes in every sample were above the calibration range, with many being high enough to saturate the detector. Triangle then reanalyzed all samples at a 100-fold dilution. In six of the seven sample extracts, one or more analytes still exceeded the calibration range, so these were reanalyzed at a 1000-fold dilution. Even then, the octachlorodibenzofuran (OCDF) concentration in four samples still exceeded calibration range. Further dilutions are not practical, since the internal standards would be difficult to separate cleanly from other material. Most tabulated results (Table 4) are derived from the 100-fold dilution. Some low concentration results (primarily TCDD) come from the original, undiluted analyses. The 1000-fold dilution results are used for the highest concentrations. The OCDF results that were extrapolated beyond the calibration range are flagged "J" to indicate that they are estimated.

The few nondetected results have rather high quantitation limits. All samples contained compounds that eluted in the same range as some target analytes. These peaks failed the ion abundance ratio criteria (for number of chlorine atoms per molecule), had the characteristics of polychlorinated diphenyl ethers, or both, and were deemed to be nondetected results. However, the presence of these extraneous peaks means that the sample quantitation limits, what the method calls "estimated maximum possible concentrations" which are calculated from the interferent concentrations, are therefore relatively high.

Table 5 summarizes the total toxicity equivalents of the samples. A sample containing 2,3,7,8-TCDD at a listed concentration on the table and none of the other target analytes would have the same toxic effects as a sample with several positives because 2,3,7,8-TCDD has a toxicity equivalent factor of 1.00. When one or more analytes has nondetected results, there are many possible assumptions one could make about the actual concentration, and therefore many possible toxicity equivalent estimates. The table shows the results of the three most common assumptions. The "maximum" values are based on the assumption that the nondetected results are equal to the sample reporting limits. The "minimum" values are based on the assumption that the nondetected results are actually zero. The "median" values are based on the assumption that the nondetected results are half the sample reporting limits. Risk assessment usually uses the "median" values. When there are no nondetected results, as is the case for most samples, the three toxicity equivalent values are identical. When there are few nondetected results, as in the other samples, the differences are small.

6.0 OVERALL EVALUATION

These analyses went as well as could be expected, given the nature of the analytical methods and the samples. The methods (except for the pH method) are designed to identify and quantitate extremely low concentrations of organic compounds in relatively uncontaminated matrices of soil minerals. The samples, accurately labeled “nasty” by Accura’s preparation chemist, have low to high concentrations of many organic compounds, mostly chlorinated compounds. The collision between those characteristics produced many failures of QC measures. The matrix interferences seen in these samples can produce both false positives and false negatives and did produce extremely high sample quantitation limits in many cases. As a result, all of the quantitative results are somewhat uncertain, although not all have been formally qualified in the tables in the attachment.

All the samples have similar sorts of matrix interference, so the relative degrees of contamination are probably accurate. With these caveats, the validated results can be used, as qualified, for any purpose.

One notable aspect of these analyses is evidence of heterogeneity within samples, seen especially in the VOC and dioxin analyses. This adds to the uncertainty caused by the matrix interferences. Therefore, it would be difficult to compare these analytical results to the pre-demonstration results. A 10-fold difference in a parameter would represent a definite change. However, a lesser difference may only represent sample heterogeneity and analytical variation.

Since all samples were taken from borings in a single disposal unit, it is anticipated that all pH results would be either acidic or basic. Therefore the observed situation, with five highly acidic samples and two highly basic samples, is rather surprising. However, a review of the post-demonstration sampling borehole logs indicates that thick layers of probable lime material occurred in the borings producing the highly basic samples. In addition, there are differences in the organic chemistry of the two sets of samples. As shown in Tables 2, 4, and 5, the basic samples have much lower concentrations (usually one or more orders of magnitude) of SVOCs and dioxins than the acidic samples. The extreme differences in pH should be considered real.

The most unexpected part of this demonstration was finding that the stainless steel tubing and well points installed in the contaminated soil were practically destroyed. In chemical terms, at least one component of the iron-chromium-minor metals alloy was oxidized and then dissolved. All of the soil samples exhibited extreme pH values, either acidic or basic. Most commonly used oxidizing agents, including nitrate, sulfate, and perchlorate, are active in acidic conditions. A few, such as peroxide, are active in basic conditions. And a few, including both hypochlorite and elemental chlorine, are active at both pH extremes. The presence of suitable inorganic oxidants, of which hypochlorite is the one most likely to be associated with the wastes in the Hex Pit, plus the observed pH conditions, would be adequate to explain the dissolution of the metal.

TABLE 1

SUMMARY OF VALIDATED VOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS

(micrograms per kilogram)

Sample Location:	**POST-HVH4**		**POST-HVP4**		**POST-HVL4**		**POST-HVL401[a]**		**POSTHVJ6**		**POST-HVH8**		**POST-HVP8**	
Depth (feet):	**12.6**		**7.8**		**8.5**		**8.5**		**8.7**		**8.8**		**7.5**	
1,1,1,2-Tetrachloroethane	3.7	U	300	U	270	U	3.9	U	8.9	U	7.6	U	3.6	U
1,1,1-Trichloroethane	3.7	U	300	U	270	U	3.9	U	8.9	U	7.6	U	3.6	U
1,1,2,2-Tetrachloroethane	3.7	U	300	U	160	J	3.9	U	8.9	U	7.6	U	3.6	U
1,1,2-Trichloroethane	3.7	U	300	U	110	J	3.9	U	3.1	J	7.6	U	2.4	J
1,1-Dichloroethane	0.54	J	300	U	270	U	3.9	U	1.9	J	7.6	U	3.6	U
1,1-Dichloroethene	3.7	U	300	U	270	U	3.9	U	8.9	U	7.6	U	3.6	U
1,1-Dichloropropene	3.7	U	300	U	270	U	3.9	U	8.9	U	7.6	U	3.6	U
1,2,3-Trichlorobenzene	3.3	J	230	J	260	J	3.9	UJ	13	J	3.1	J	3.6	UJ
1,2,3-Trichloropropane	3.7	U	300	U	270	U	3.9	U	8.9	U	7.6	U	3.6	U
1,2,4-Trichlorobenzene	11	J	780		1,600		1.7	J	25	J	4.1	J	3.6	UJ
1,2,4-Trimethylbenzene	7.5		170	J	270	U	3.6	J	5.7	J	5.3	J	2.7	J
1,2-Dibromo-3-chloropropane	3.7	U	300	U	110	J	3.9	U	8.9	U	7.6	U	3.6	U
1,2-Dichlorobenzene	1.8	J	190	J	200	J	3.9	U	11		4.8	J	3.6	U
1,2-Dichloroethane	3.7	U	300	U	74	J	3.9	U	1.1	J	7.6	U	3.6	U
1,2-Dichloropropane	3.7	U	300	U	270	U	3.9	U	8.9	U	7.6	U	3.6	U
1,3,5-Trimethylbenzene	2.5	J	300	U	270	U	1.1	J	1.9	J	1.6	J	0.83	J
1,3-Dichlorobenzene	1.2	J	110	J	79	J	3.9	U	5.8	J	7.6	U	3.6	U
1,3-Dichloropropane	3.7	U	300	U	94	J	3.9	U	8.9	U	7.6	U	3.6	U
1,4-Dichlorobenzene	3.7	U	300	U	600		1.0	J	13		7.6	U	3.6	U
1,4-Dioxane	73	UJ	6,000	U	5,300	U	79	UJ	180	UJ	150	UJ	71	UJ
2,2-Dichloropropane	3.7	U	300	U	270	U	3.9	U	8.9	U	7.6	U	3.6	U
2-Butanone	25	J	3,000	U	2,700	U	2.9	U	47	J	19	J	4.7	J

TABLE 1 (Continued)

SUMMARY OF VALIDATED VOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS

(micrograms per kilogram)

Sample Location:	**POST-HVH4**	**POST-HVP4**	**POST-HVL4**	**POST-HVL401[a]**	**POSTHVJ6**	**POST-HVH8**	**POST-HVP8**
Depth (feet):	**12.6**	**7.8**	**8.5**	**8.5**	**8.7**	**8.8**	**7.5**
2-Chlorotoluene	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
2-Hexanone	37 U	3,000 U	2,700 U	39 U	89 U	76 U	36 U
4-Chlorotoluene	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
4-Methyl-2-pentanone	37 U	3,000 U	2,700 U	39 U	89 U	76 U	36 U
Acetone	1,200	1,700 J	2,700 U	780	1,200	560 J	69 J
Acetonitrile	37 U	3,000 U	2,700 U	39 U	89 U	76 U	3.6 U
Acrolein	7.3 U	600 U	530 U	7.9 U	18 U	15 U	7.1 U
Acrylonitrile	7.3 U	600 U	270 J	7.9 U	18 U	15 U	7.1 U
Allyl chloride	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
Benzene	45	150 J	65 J	5.4	27	23	4.3
Bromobenzene	3.7 U	300 U	33 J	3.9 U	8.9 U	7.6 U	3.6 U
Bromochloromethane	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
Bromodichloromethane	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
Bromoform	3.7 U	300 U	110 J	3.9 U	8.9 U	7.6 U	3.6 U
Bromomethane	11	600 U	530 U	16	18 U	15 U	7.1 U
Carbon Disulfide	3.7 U	300 U	270 U	3.9 U	7.4 J	8.8	3.6 U
Carbon Tetrachloride	5,200	3,800	870	54	830 J	63	100
Chlorobenzene	5.3	170 J	57 J	3.9 U	9.4	2.2 J	0.73 J
Chloroethane	12	600 U	530 U	15	29	15 U	9.4
Chloroform	4,400	2,300	1,100	2,600	670 J	180	4,400
Chloromethane	24	200 J	410 J	60	47	15 U	7.1 U

TABLE 1 (Continued)

SUMMARY OF VALIDATED VOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS
(micrograms per kilogram)

Sample Location:	**POST-HVH4**	**POST-HVP4**	**POST-HVL4**	**POST-HVL401[a]**	**POSTHVJ6**	**POST-HVH8**	**POST-HVP8**
Depth (feet):	**12.6**	**7.8**	**8.5**	**8.5**	**8.7**	**8.8**	**7.5**
cis-1,2-Dichloroethene	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
cis-1,3-Dichloropropene	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
Dibromochloromethane	3.7 U	300 U	71 J	3.9 U	8.9 U	7.6 U	3.6 U
Dibromomethane	3.7 U	300 U	90 J	3.9 U	8.9 U	7.6 U	3.6 U
Ethyl Methacrylate	3.7 U	300 U	140 J	3.9 U	8.9 U	7.6 U	3.6 U
Ethylbenzene	11	300 U	270 U	3.9 U	2.2 J	2.9 J	0.68 J
Hexachlorobutadiene	68	7,500	8,600	5.7	120	21	23
Iodomethane	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
Isobutanol	73 U	6,000 U	5,300 U	79 U	180 U	150 U	71 U
Isopropylbenzene	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
Isopropyltoluene	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
Methyl Methacrylate	3.7 U	300 U	150 J	3.9 U	8.9 U	7.6 U	3.6 U
Methyl tert-butyl ether	3.7 U	300 U	130 J	3.9 U	8.9 U	7.6 U	3.6 U
Methylacrylonitrile	37 U	3,000 U	1,500 J	39 U	89 U	76 U	36 U
Methylene chloride	15	78 J	110 J	30	130	100	9.6
Naphthalene	4.1	300 J	190 J	3.9 U	1.6 J	7.6 U	3.6 U
n-Butylbenzene	1.2 J	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
Pentachloroethane	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
Propionitrile	37 U	3,000 U	2,700 U	39 U	89 U	76 U	36 U
sec-Butylbenzene	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
Styrene	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U

TABLE 1 (Continued)

SUMMARY OF VALIDATED VOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS
(micrograms per kilogram)

Sample Location:	**POST-HVH4**	**POST-HVP4**	**POST-HVL4**	**POST-HVL401[a]**	**POSTHVJ6**	**POST-HVH8**	**POST-HVP8**
Depth (feet):	**12.6**	**7.8**	**8.5**	**8.5**	**8.7**	**8.8**	**7.5**
tert-Butylbenzene	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
Tetrachloroethene	3,700	2,500	1,400	28	100	55	90
Toluene	3.9	300 U	270 U	1.2 J	4.2 J	2.9 J	11
trans-1,2-Dichloroethene	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
trans-1,3-Dichloropropene	3.7 U	300 U	63 J	3.9 U	8.9 U	7.6 U	3.6 U
Trichloroethene	9.9	68 J	270 U	2.4 J	11	7.1 J	8.2
Trichlorofluoromethane	3.7 U	300 U	270 U	3.9 U	8.9 U	7.6 U	3.6 U
Vinyl acetate	73 U	300 U	270 U	79 U	8.9 U	7.6 U	3.6 U
Vinyl chloride	3.7 U	300 U	270 U	2.5 J	8.9 U	7.6 U	3.6 U
Xylenes (total)	47	130 J	270 U	3.9 U	11	15	3.6 U

Notes:

J = The analyte was detected. The reported numerical value is considered to be estimated for quality control reasons.
U = The analyte was not detected. The reported numerical value is the sample quantitation limit.
UJ = The analyte was not detected. The reported sample quantitation limit is considered estimated for quality control reasons.
a Field duplicate sample

TABLE 2

SUMMARY OF VALIDATED SEMIVOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS

(micrograms per kilogram)

Sample Location:	**POST-HVH4**	**POST-HVP4**	**POST-HVL4**	**POST-HVL401[a]**	**POSTHVJ6**	**POST-HVH8**	**POST-HVP8**
Depth (feet):	**7.6 - 15.6**	**4.8 - 12.8**	**5.5 - 13.5**	**5.5 - 13.5**	**5.7 - 13.7**	**5.8 - 13.8**	**6 - 14**
1,1'-Biphenyl	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	390 J	2,700,000 U
1,2,4-Trichlorobenzene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	1,400 J	2,700,000 U
1,2-Dichlorobenzene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
1,3-Dichlorobenzene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
1,4-Dichlorobenzene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
1-Methylnaphthalene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
2,3,4,6-Tetrachlorophenol	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 UJ	2,700,000 U
2,4,5-Trichlorophenol	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 UJ	2,700,000 U
2,4,6-Trichlorophenol	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 UJ	2,700,000 U
2,4-Dichlorophenol	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 UJ	2,700,000 U
2,4-Dimethylphenol	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 UJ	2,700,000 U
2,4-Dinitrophenol	1,300,000 UJ	5,500,000 UJ	5,300,000 UJ	5,200,000 UJ	600,000 UJ	30,000 UJ	13,000,000 UJ
2,4-Dinitrotoluene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
2,6-Dinitrotoluene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
2-Chloronaphthalene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
2-Chlorophenol	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 UJ	2,700,000 U
2-Methylnaphthalene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
2-Methylphenol	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 UJ	2,700,000 U
2-Nitroaniline	530,000 U	2,200,000 U	2,100,000 U	2,100,000 U	240,000 U	12,000 U	5,300,000 U
2-Nitrophenol	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 UJ	2,700,000 U
3,3'-Dichlorobenzidine	530,000 U	2,200,000 U	2,100,000 U	2,100,000 U	240,000 U	12,000 U	5,300,000 U
3,4-Dimethylphenol	530,000 U	2,200,000 U	2,100,000 U	2,100,000 U	240,000 U	12,000 UJ	5,300,000 U
3-Nitroaniline	530,000 U	2,200,000 U	2,100,000 U	2,100,000 U	240,000 U	12,000 U	5,300,000 U

TABLE 2 (Continued)

SUMMARY OF VALIDATED SEMIVOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS

(micrograms per kilogram)

Sample Location:	**POST-HVH4**	**POST-HVP4**	**POST-HVL4**	**POST-HVL401[a]**	**POSTHVJ6**	**POST-HVH8**	**POST-HVP8**
Depth (feet):	**7.6 - 15.6**	**4.8 - 12.8**	**5.5 - 13.5**	**5.5 - 13.5**	**5.7 - 13.7**	**5.8 - 13.8**	**6 - 14**
4,6-Dinitro-2-methylphenol	1,300,000 U	5,500,000 U	5,300,000 U	5,200,000 U	600,000 U	30,000 UJ	13,000,000 U
4-Bromophenyl-phenyl ether	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
4-Chloro-3-methylphenol	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 UJ	2,700,000 U
4-Chloroaniline	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
4-Chlorophenyl-phenylether	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
4-Nitroaniline	530,000 U	2,200,000 U	2,100,000 U	2,100,000 U	240,000 U	12,000 U	5,300,000 U
4-Nitrophenol	530,000 U	2,200,000 U	2,100,000 U	2,100,000 U	240,000 U	12,000 UJ	5,300,000 U
Acenaphthene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Acenaphthylene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Acetophenone	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Anthracene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Atrazine	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Benzo(a)anthracene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Benzo(a)pyrene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Benzo(b)fluoranthene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Benzo(g,h,i)perylene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Benzo(k)fluoranthene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Benzoic acid	1,300,000 U	5,500,000 U	5,300,000 U	5,200,000 U	600,000 U	30,000 UJ	13,000,000 U
Benzyl alcohol	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Benzylbutylphthalate	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
bis(2-Chloroethoxy)methane	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
bis(2-Chloroethyl)ether	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U

TABLE 2 (Continued)

SUMMARY OF VALIDATED SEMIVOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS

(micrograms per kilogram)

Sample Location:	**POST-HVH4**	**POST-HVP4**	**POST-HVL4**	**POST-HVL401[a]**	**POSTHVJ6**	**POST-HVH8**	**POST-HVP8**
Depth (feet):	**7.6 - 15.6**	**4.8 - 12.8**	**5.5 - 13.5**	**5.5 - 13.5**	**5.7 - 13.7**	**5.8 - 13.8**	**6 - 14**
bis(2-Chloroisopropyl)ether	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
bis(2-Ethylhexyl)phthalate	270,000 U	1,100,000 U	88,000 J	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Caprolacram	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Chrysene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Dibenz(a,h)anthracene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Dibenzofuran	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Diethylphthalate	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Dimethylphthalate	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Di-n-butylphthalate	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Di-n-octylphthalate	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Fluoranthene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Fluorene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Hexachlorobenzene	2,300,000	2,400,000	7,400,000	6,400,000	740,000	42,000	4,300,000
Hexachlorobutadiene	56,000 J	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	3,400 J	2,700,000 U
Hexachlorocyclopentadiene	4,700,000	5,000,000	190,000 J	93,000 J	1,500,000	4,100 J	7,300,000
Hexachloroethane	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Indeno(1,2,3-cd)pyrene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Isodrin	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Isophorone	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Methyl methanesulfonate	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Naphthalene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U
Nitrobenzene	270,000 U	1,100,000 U	1,100,000 U	1,000,000 U	120,000 U	6,100 U	2,700,000 U

TABLE 2 (Continued)

SUMMARY OF VALIDATED SEMIVOLATILE ORGANIC COMPOUND ANALYTICAL RESULTS

(micrograms per kilogram)

Sample Location:	**POST-HVH4**		**POST-HVP4**		**POST-HVL4**		**POST-HVL401[a]**		**POSTHVJ6**		**POST-HVH8**		**POST-HVP8**	
Depth (feet):	**7.6 - 15.6**		**4.8 - 12.8**		**5.5 - 13.5**		**5.5 - 13.5**		**5.7 - 13.7**		**5.8 - 13.8**		**6 - 14**	
N-Nitrosodi-n-propylamine	270,000	U	1,100,000	U	1,100,000	U	1,000,000	U	120,000	U	6,100	U	2,700,000	U
N-Nitrosodiphenylamine	270,000	U	1,100,000	U	1,100,000	U	1,000,000	U	120,000	U	6,100	U	2,700,000	U
Pentachlorophenol	530,000	U	2,200,000	U	2,100,000	U	2,100,000	U	240,000	U	12,000	UJ	5,300,000	U
Phenanthrene	270,000	U	1,100,000	U	1,100,000	U	1,000,000	U	120,000	U	6,100	U	2,700,000	U
Phenol	270,000	U	1,100,000	U	1,100,000	U	1,000,000	U	120,000	U	6,100	UJ	2,700,000	U
Pyrene	270,000	U	1,100,000	U	100,000	J	1,000,000	U	120,000	U	6,100	U	2,700,000	U

Notes:

J = The analyte was detected. The reported numerical value is considered to be estimated for quality control reasons.
U = The analyte was not detected. The reported numerical value is the sample quantitation limit.
UJ = The analyte was not detected. The reported sample quantitation limit is considered estimated for quality control reasons.
a Field duplicate sample

TABLE 3

SUMMARY OF VALIDATED ORGANOCHLORINE PESTICIDE AND pH ANALYTICAL RESULTS
(microgram per kilogram)

Sample Location:	**POST-HVH4**	**POST-HVP4**	**POST-HVL4**	**POST-HVL401[a]**	**POSTHVJ6**	**POST-HVH8**	**POST-HVP8**
Depth (feet):	**7.6 - 15.6**	**4.8 - 12.8**	**5.5 - 13.5**	**5.5 - 13.5**	**5.7 - 13.7**	**5.8 - 13.8**	**6 - 14**
4,4'-DDD	14,000 U	14,000 U	14,000 U	14,000 U	16,000 U	16,000 U	14,000 U
4,4'-DDE	35,000 J	110,000	14,000 U	14,000 U	180,000 J	16,000 U	14,000 U
4,4'-DDT	14,000 U	14,000 U	14,000 U	14,000 U	16,000 U	16,000 U	14,000 U
Aldrin	21,000	14,000 U	14,000 U	14,000 U	16,000 U	68,000 J	14,000 U
alpha-BHC	14,000 U	14,000 U	14,000 U	14,000 U	16,000 U	16,000 U	14,000 U
alpha-Chlordane	14,000 U	14,000 U	14,000 U	14,000 U	16,000 U	16,000 U	14,000 U
beta-BHC	14,000 U	14,000 U	14,000 U	14,000 U	16,000 U	16,000 U	14,000 U
Chlordane (technical)	140,000 U	140,000 U	140,000 U	140,000 U	160,000 U	160,000 U	140,000 U
delta-BHC	14,000 UJ	14,000 UJ	14,000 UJ	14,000 UJ	16,000 UJ	16,000 UJ	14,000 UJ
Dieldrin	190,000	14,000 U	14,000 U	14,000 U	40,000	480,000	14,000 U
Endosulfan I	14,000 U	14,000 U	160,000	150,000	16,000 U	16,000 U	14,000 U
Endosulfan II	120,000	190,000	14,000 U	14,000 U	16,000 U	16,000 U	14,000 U
Endosulfan sulfate	14,000 U	14,000 U	14,000 U	14,000 U	16,000 U	16,000 U	14,000 U
Endrin	14,000 U	14,000 U	14,000 U	14,000 U	16,000 U	19,000 J	14,000 U
Endrin aldehyde	14,000 U	14,000 U	14,000 U	14,000 U	16,000 U	16,000 U	14,000 U
Endrin ketone	14,000 U	14,000 U	200,000 J	210,000 J	16,000 U	4,500 J	14,000 U
gamma-BHC (Lindane)	19,000	14,000 U	14,000 U	14,000 U	16,000 U	16,000 U	14,000 U
gamma-Chlordane	14,000 U	14,000 U	14,000 U	14,000 U	9,200 J	16,000 U	14,000 U
Heptachlor	14,000 U	14,000 U	14,000 U	14,000 U	7,400 J	16,000 U	14,000 U
Heptachlor epoxide	14,000 U	14,000 U	14,000 U	14,000 U	16,000 U	16,000 U	14,000 U
Methoxychlor	72,000 U	72,000 U	70,000 U	69,000 U	81,000 U	81,000 U	72,000 U
Toxaphene	720,000 U	720,000 U	700,000 U	690,000 U	810,000 U	810,000 U	720,000 U

TABLE 3 (Continued)

SUMMARY OF VALIDATED ORGANOCHLORINE PESTICIDE AND pH ANALYTICAL RESULTS
(microgram per kilogram)

Sample Location:	**POST-HVH4**	**POST-HVP4**	**POST-HVL4**	**POST-HVL401[a]**	**POSTHVJ6**	**POST-HVH8**	**POST-HVP8**
Depth (feet):	**7.6 - 15.6**	**4.8 - 12.8**	**5.5 - 13.5**	**5.5 - 13.5**	**5.7 - 13.7**	**5.8 - 13.8**	**6 - 14**
pH (standard units)	2.0 J	2.0 J	2.0 J	1.0 J	12 J	12 J	2.0 J

Notes:

J = The analyte was detected. The reported numerical value is considered to be estimated for quality control reasons.
U = The analyte was not detected. The reported numerical value is the sample quantitation limit.
UJ = The analyte was not detected. The reported sample quantitation limit is considered estimated for quality control reasons.
a Field duplicate sample

TABLE 4

SUMMARY OF VALIDATED DIOXIN RESULTS

(nanograms per kilogram)

Sample Location:	**POST-HVH4**	**POST-HVP4**	**POST-HVL4**	**POST-HVL401[a]**	**POSTHVJ6**	**POST-HVH8**	**POST-HVP8**
Depth (feet):	**7.6 - 15.6**	**4.8 - 12.8**	**5.5 - 13.5**	**5.5 - 13.5**	**5.7 - 13.7**	**5.8 - 13.8**	**6 - 14**
2,3,7,8-Tetrachlorodibenzo(p)dioxin	1,190	825 U	1,340	1,830	471 UJ	430	970
1,2,3,7,8-Pentachlorodibenzo(p)dioxin	9,500	11,200	23,000	28,000	11,400 J	3,700	5,400 U
1,2,3,4,7,8-Hexachlorodibenzo(p)dioxin	21,000	24,000	48,000	59,000	31,000 J	3,200	14,800
1,2,3,6,7,8-Hexachlorodibenzo(p)dioxin	25,000	23,000	58,000	73,000	74,000 J	5,900	16,000
1,2,3,7,8,9-Hexachlorodibenzo(p)dioxin	24,000	17,400	42,000	58,000	55,000 J	6,200	14,400
1,2,3,4,6,7,8-Heptachlorodibenzo(p)dioxin	197,000	167,000	380,000	490,000	540,000 J	18,700	140,000
Octachlorodibenzo(p)dioxin	440,000	340,000	710,000	880,000	740,000 J	11,000	280,000
2,3,7,8-Tetrachlorodibenzofuran	55,000	88,130	194,000	240,000	5,500 J	13,700	68,000
1,2,3,7,8-Pentachlorodibenzofuran	351,000	700,000	1,370,000	1,610,000	25,000 J	24,200	1,150,000
2,3,4,7,8-Pentachlorodibenzofuran	38,000	64,000	143,000	200,000	12,300 J	7,300	62,000
1,2,3,4,7,8-Hexachlorodibenzofuran	1,120,000	1,600,000	3,000,000	3,200,000	250,000 J	58,000	2,100,000
1,2,3,6,7,8-Hexachlorodibenzofuran	380,000	620,000	1,140,000	1,300,000	106,000 J	32,000	1,350,000
2,3,4,6,7,8-Hexachlorodibenzofuran	149,000	250,000	480,000	570,000	45,000 J	10,600	360,000
1,2,3,7,8,9-Hexachlorodibenzofuran	86,000	200,000	290,000	350,000	4,800 J	4,500 J	280,000
1,2,3,4,6,7,8-Heptachlorodibenzofuran	1,800,000	2,060,000	3,300,000	3,500,000	940,000 J	154,000	5,200,000
1,2,3,4,7,8,9-Heptachlorodibenzofuran	1,110,000	1,460,000	2,500,000	2,900,000	86,000 J	32,000	2,900,000
Octachlorodibenzofuran	46,500,000 J	38,100,000	57,000,000 J	64,000,000 J	4,100,000 J	270,000	79,000,000 J
Total tetrachlorodibenzo(p)dioxins	58,000	55,000	37,000	46,000	23,000 J	17,100	18,400
Total pentachlorodibenzo(p)dioxins	130,000	144,000	197,000	188,000	130,000 J	40,000	50,000
Total hexachlorodibenzo(p)dioxins	240,000	230,000	450,000	600,000	530,000 J	48,000	155,000
Total heptachlorodibenzo(p)dioxins	330,000	270,000	620,000	760,000	950,000 J	33,000	240,000
Total tetrachlorodibenzofurans	860,000	1,710,000	1,740,000	2,000,000	71,000 J	106,000	1,310,000

TABLE 4 (Continued)

SUMMARY OF VALIDATED DIOXIN RESULTS
(nanograms per kilogram)

Sample Location:	**POST-HVH4**	**POST-HVP4**	**POST-HVL4**	**POST-HVL401[a]**	**POSTHVJ6**	**POST-HVH8**	**POST-HVP8**
Depth (feet):	**7.6 - 15.6**	**4.8 - 12.8**	**5.5 - 13.5**	**5.5 - 13.5**	**5.7 - 13.7**	**5.8 - 13.8**	**6 - 14**
Total pentachlorodibenzofurans	1,330,000	2,700,000	4,300,000	5,000,000	290,000 J	148,000	3,600,000
Total hexachlorodibenzofurans	2,600,000	4,200,000	7,400,000	7,800,000	810,000 J	210,000	6,600,000
Total heptachlorodibenzofurans	3,940,000	4,800,000	7,900,000	8,700,000	1,180,000 J	230,000	10,000,000

Notes:

J = The analyte was detected. The reported numerical value is considered to be estimated for quality control reasons.
U = The analyte was not detected. The reported numerical value is the sample quantitation limit.
ng/kg = nanograms per kilogram
[a] Field duplicate sample

TABLE 5

SUMMARY OF TOXICITY EQUIVALENTS
(nanograms per kilogram)

Sample	Toxicity Equivalents		
	Maximum[b]	**Minimum[c]**	**Median[d]**
POST-HVH4	305,000	305,000	305,000
POST-HVP4	432,000	431,000	432,000
POST-HVL4	798,000	798,000	798,000
POSTHVL401[a]	910,000	910,000	910,000
POST-HVJ6	62,000	62,000	62,000
POST-HVH8	18,600	18,600	18,600
POST-HVP8	675,000	673,000	674,000

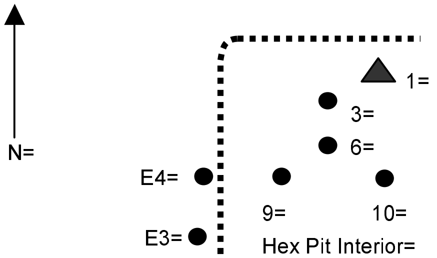
Notes:

[a] Field Duplicate Sample
[b] "Maximum" calculated with nondetected results assumed to be equal to the sample reporting limit
[c] "Minimum" calculated with nondetected results assumed to be zero
[d] "Median" calculated with nondetected results assumed to be half the sample reporting limits

APPENDIX D

SITE SOIL BOREHOLE LOGS

Tetra Tech EM Inc.



Borehole ID: **1**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain; Jason Lauer and Zack Beck=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7-18-01=
Logged By: Erika Herreria=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	1.35=	737=	0.05=	▨		SW=	0 to 1: Sand with silt and gravel; med. grained; brown; poorly sorted; loose; soft; = moist; VOC sample collected from 1 ft. interval at 0738.=
					▨	1=		
				2.26=	▨			1 to 2: Same as above with black staining throughout; moist. Note: offset ~6 inches to the NW. After moving the drillers encounter apparent void spaces from 2 to 6 ft., incomplete recovery.=
2=	6=	?=	802=		▨	2=		
				4=	▨		ML=	2 to 6: Sandy silt; rust color patches and black color patches throughout (Hex); soft; = loose; moist; slightly plastic. Note: VOC sample collected at 5 ft at 0802.=
					▨	3=		
					▨			
					▨	4=		
					▨			
					▨	5=		
					▨			
6=	10=	4=	804=		▨	6=		
					▨		SM=	6 to 7.4: Silty sand; brown; fine grained; loose; soft=
				2.5=	▨	7=		
					▨			
				0.7=	▨	8=	ML=	7.4 to 8.2: Silt; loose; soft; slightly plastic; light brown=
					▨		SP=	8.2 to 10: Sand; trace fines; fine grained; subrounded; well sorted; very soft; very = loose; "clean".=
				9.5=	▨	9=		
					▨			
10=	13=	3=	810=		▨	10=		
					▨		SM=	10 to 11: Silty sand; brown; med. grained; moderately firm; moderately dense; = moist; slightly plastic=
				0.1=	▨	11=		
				1.4=	▨		ML=	11 to 13: Sandy silt with some clay; brown; moderately dense; moderately firm; = some black staining at ~13 ft. (the staining seems wet).=
					▨	12=		
					▨			
					▨	13=		
							TD=	TD = 13 ft.=
						14=		
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		

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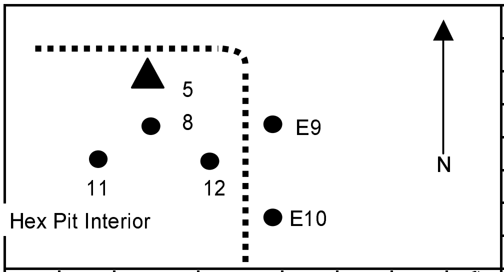

Borehole ID: 5
Job Number: G1093-240
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Jason Lauer and Zack Beck
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 7-17-01
Logged By: Erika Herreria

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0					▨			<u>0 to 0.6:</u> Sand with some fines; light brown; medium sand; well sorted; loose; soft; "clean fill"; subrounded to rounded.
		2	1125	0.1	▨	1		
		2		5	▨			<u>0.6 to 1:</u> Gravel sand mix; poorly sorted; fine gravel; loose; soft; dark brown; gravel is subrounded to subangular; "clean".
2	2			6	▨	2		
				0.3	▨			<u>1 to 2:</u> Sandy silt; brown; fine to med. sand; moderately sorted; med. dense; slightly plastic; "clean".
					▨	3		
				0.5	▨			<u>2 to 4.5:</u> Sandy silt; brown; fine sand; well sorted; loose; soft; slightly plastic; with coal like material throughout.
			1128		▨	4		
		3		1.4	▨			
		7			▨	5		<u>4.5 to 6.8:</u> Sandy silt; with lots of rust and black hex/tar material throughout the whole interval.
				1.5	▨			
6	6			1	▨	6		
				7	▨			<u>6.8 to 7.5:</u> Silty sand; dark brown; fine sand; well sorted; very loose; very soft; "clean".
					▨	7		
				11.2	▨			<u>7.5 to 8.5:</u> Sandy silt; brown; fine sand; well sorted; loose; soft; slightly plastic; "clean".
		3	1135		▨	8		
		4		3.1	▨			
					▨	9		
				1.4	▨			<u>8.5 to 11.2:</u> Sand with fines; light brown; fine sand; well sorted; very loose; very soft; "clean".
	10				▨	10		
				3	▨			
					▨	11		<u>11.2 to 11.8:</u> Silty sand; light brown; med. sand; well sorted; loose; soft; subrounded; slightly plastic; "clean".
		3.15		3.4	▨			
		3	1145		▨	12		
				0.4	▨			<u>11.8 to 13:</u> Clay silt with fines; light brown; plastic; med. dense; moderately firm; with white sand pockets throughout; "clean".
					▨	13		
						14		
						15		
						16		
						17		
						18		
						19		
						20		

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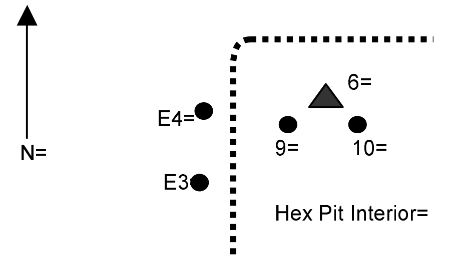

Borehole ID: **6**

Job Number: G1093-240=

Site: Rocky Mountain Arsenal - Hex Pit=

Drilling Company: ESN - Rocky Mountain; Steve Mitchell & Zack Beck=

Drilling Method: Direct push=

Continuous core in 4 ft. X 1.125 in. PETG plastic liners=

Drilling Date(s): 7/25/01=

Logged By: David West=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	2=	808=				SP=	0.0 to 1.1: Sand; moderately sorted fine to medium grained: yellowish brown, dry = loose; abundant rock fragments to 1/3" to 1/2" at 0.8 ft; new surfical fill; sharp = contact below. =
				0.4=		1=		
								1.1 to 3.8: Silty sand; fine grained moderately sorted; silt to 25%; slightly moist; stiff; = dark yellowsih brown to dark grayish brown.
2=	6=	2.5=	815=	0.35=		2=		
								Collected VOC sample at 1 ft. @ 0814 PRE-S-6(VOC)=
						3=	SM=	Collected VOC sample at 5 ft. @ 0819 PRE-W-6(VOC)=
								Moderate recovery in 2 to 6 ft. run (2.5/4.0), depths are approx. 3 to 3.8 silty sand = becomes strongly mixed with black (hex) staining; sharp contact at 3.8 with obvious = color change in waste.=
				2.5=		4=		
							Waste (SM)	
						5=		3.8 to 6.2: waste; light bluish gray silty waste with greasy (graphite-like) texture to = about 4.5 ft. (lime?); silty sand matrix in poorly sorted mixed waste below 4.5, = reddish brown to dark yellowish brown; tar-like laminated fiber layer; orange wet = fibrous material; black liquid hex at 5.9 to 6.1 ft.=
				3.2=				
6=	10=	3.6=	820=			6		
				76=			Hex=	
						7=		
				97=			ML=	6.2 to 8.4: Silt; strongly stained very dark brown to dark reddish brown from hex = waste above; uniform soft texture; moist to slightly moist; becomes sandy below 7.5 = ft; relatively sharp contact with sand below; streaked with hex.=
						8=		
				91=				
						9=	SP=	8.4 to 10.0: Sand; well sorted fine to medium fine grained; dark brown to dark yellowish brown; moderately loose; streaked/stained with hex (hex sheen); slightly = moist to moist.=
10=	13=	3.2=	830=			10=		
				20=				10.0 to 13.0: Silty sand and sandy silt; uniform yellowish brown to dark yellowish brown with some tan mattles; sparse hex staining throughout; moderately stiff; very = fine to fine grained sand, slightly moist.
						11=		
				35=			SM/ML	
						12=		* sparse hex staining and "micro stringers" throughout 10-13=
				30=				
						13=		
							TD=	TD = 13 ft=
						14=		
								Collect 3-point composite at 2-10 for sample PRE-W-2=
						15=		Collected 6-point composite at 0-2, 10-12, 12-13 for sample PRE-S-2=
						16=		
						17=		
						18=		
						19=		
						20=		

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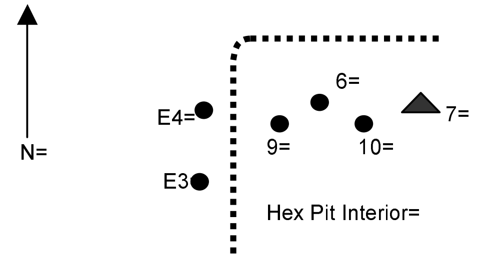

Borehole ID: **7**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain; Steve Mitchell & Zack Beck=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7/25/01=
Logged By: David West=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	2=	850=		▨		SW=	0.0 to 1.0: Surficial fill; poorly sorted sand with gravel/rock fragments to 3/4" = (granite); dry; loose.=
				0.12=	▨	1=		
					▨		SM=	1.0 to 2.0: Silty sand; poorly sorted very fine to medium sand and abundant (> 25%) = silt; stiff but "plastic"; dark reddish brown to orange-brown; slightly moist; reddish = brown (oxidized) clasts but no hex is visible.=
2=	6=	1.1=	855=	1.9=	▨	2=	WASTE (SM)	2.0 to 6.0: Poor recovery (1.1/4.0); some poorly sorted silty sand yellowish brown = followed by distinct light bluish gray waste, dry and indunted clasts (cemented = sands?) with typical light bluish gray greesy textured silt below (lime?); some dark = brown silty sand with strong hex staining at bottom of interval.=
					▨			
					▨	3=		
					▨			
					▨	4=		
					▨			
					▨	5=		
				1.8=	▨			
6=	10=	2.8=	900=		▨	6=		
					▨		ML	6.0 to 7.4: Silt; dark grayish brown to dark reddish brown stained from waste above, = (similar to borehole 6, but no visible flowing hex); soft texture; sharp contact with = sand.=
					▨	7=		
					▨			
				27=	▨	8=	SP=	7.4 to 10.0: Sand; well sorted very fine to fine grained, very moist; dark reddish = brown to dark brown like above; some black hex-like sheen thoughout; minor silt = content.=
				97=	▨			
					▨	9=		
				52=	▨			
10=	13=				▨	10=		
					▨		ML/SM	10.0 to 13.0: Silt and Silty Sand; uniform pale brown to yellowish brown with light = yellow to tan mottles/partings in silt; stiff to moderately stiff; very slightly moist; minor sand but grades to very fine to fine grained silty sand below 12 ft: less stiff than = above; very slightly moist; very spurse black (hex) staining throughout interval (not = obvious).=
				13=	▨	11=		
				16=	▨			
					▨	12=		
				32=	▨			
					▨	13=		
							TD=	TD = 13 ft=
						14=		
								Collect 3-point composite at 2-10 for sample PRE-W-2=
						15=		Collect 6-point composite at 0-2, 10-12, 12-13 for sample PRE-S-2=
						16=		
						17=		
						18=		
						19=		
						20=		

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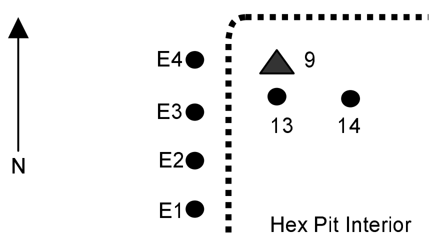

Borehole ID: 9
Job Number: G1093-240
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Steve Mitchell & Zack Beck
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 7/24/01
Logged By: David West

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0							GM	0.0 to 1.2: Surface fill; sand, silty sand, gravel; and rock fragments; dry to very slightly moist; yellowish brown; rock fragments to 1 1/2 inch; poorly sorted.
		2.0/2.0	1047	0.7		1		
							SM	1.2 to 2.0: Silty sand; well sorted fine grained sand, yellowish brown; moist; stiff; grades to silt below.
2	2			0.2		2		
							ML	2.0 to 3.8: Silt; grayish brown; very slightly moist; stiff; some greenish brown to pale yellow mottles;
				1.5		3		
		2.7/4.0	1051				SM	
				3.1		4		3.8 to 4.6: Silty sand; dark yellowish brown with abundant dark gray to black hex patches/streaks, also black (hex) granules; moderate sorting fine to medium grains.
				4.5		5		
								4.6 to 8.0: Waste material; concrete rubble and rock/fibroes fragments with litlle fine grained matrix 4.6 to 5.5 ft; dry to very slightly moist; sharp contact at 5.5 ft with rusted metalic band (drum) with distinct bright orange to ruby red crystalline hex waste material (drum contents) to about 7 ft. (poor recovery at top of 6 to 10 run), 7.7 to 8 ft. is black liquid hex within clayey silt matrix; running liquid is black, matrix is dark gray to blak becoming less stained at 8 to 8.5 ft.
6	6					6		
				59		7		
		2.4/4.0	1055					
				167		8		
						9		8.0 to 9.1: Silt; no sand; dark brown with dark gray to black hex smears throughout; very slightly moist; moderately stiff; moderately sharp contact with sand below.
								9.1 to 10.5: sand; uniform sorting very fine to medium fine grained; yellowish brown to dark yellowish brown, very slightly moist; moderately stiff; moderately sharp contact with silt below.
10	10					10		
				25				
						11		10.5 to 13.0: silt; grading to silty sand at 12.5; uniform pale yellowish brown to dark yellowsih brown; slightly moist; yellowish white mottles; no obvoius hex staining; very stiff.
		3.3/3.0	1058	22.4				
						12		
				14.8				Collect 3-Point composite at 2-10 ft. for sample PRE-W-2
	13					13		Collect 6-Point composite at 0-2, 10-12, and 12-13 for sample PRE-S-2
						14		
						15		
						16		
						17		
						18		
						19		
						20		

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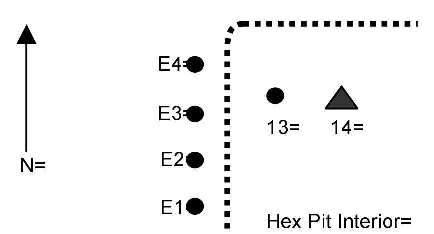

Borehole ID: **14**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain; Steve Mitchell & Zack Beck
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7/24/01=
Logged By: David West=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	2=	808=	0.2=	▨		GM=	0.0 to 0.8: surface fill; dry silty sand and gravel/ rock fragments; loose; yellowish = brown; quartz rock fragments to 3/4 inc.; sharp contact below.=
					▨	1=		
				3.9	▨		waste	0.8 to 1.4: waste material; wood fragments/chunks; dark brown silty sand matrix; no = obvious contamination; slightly moist to moist; sharp contact and obvious color = change to light gray (lime?) below; collect sample PRE-S-14(VOC) at 1 ft at 0809.=
2=	6=	2.3=	820=		▨	2=		
					▨			
					▨	3=		
					▨		SM=	1.4 to 5.6: silty sand with some clay; obvious light bluish gray; indurated (cemented) = clasts at 1.8 ft; grasy texture increases below 2 ft. where materials turns to more = uniform silt with minor clay; collect sample PRE-W-14(voc) at 5 ft (0823); very sharp = contact with wood fragments/waste at 5.6 ft.=
					▨	4=		
				4.9=	▨			
					▨	5=		
				4.3=	▨			Photo: 4-22, 4-23.=
6=	10=	3.1=	827=		▨	6=	waste	5.6 to 7.3: wood fragments and mixed granular hex waste to 6 ft.; wet; dark reddish = brown becoming dark brownish gray below 6 ft.; clayey silt with some wood fragments from 6 to 7.3, also wet; 40 ppm FID signature; typical hex sheen throughout, but no = "flowing" hex; grades into less stained silt below; hex creates sheen on water.=
					▨			
					▨	7=		
				40=	▨			
					▨	8=	ML/ SM=	7.3 to 8.2: silt/silty sand; mostly "clean" dark yellowish brown silt, grading to silty = sand; slightly moist, moderately dense; uniform sorting; native material.=
				48=	▨			
					▨	9=		
				23=	▨		SP=	8.2 to 10.0: sand; well sorted fine to medium fine grained; uniform yellowish brown; = slightly moist; loose to slightly dense, native.=
10=	13=	3=	835=	35=	▨	10=		
				36=	▨		ML/SM/SP	10.0 to 13.0: silt, silty sand, and sand interbedded; uniform (light) yellowish brown; = stiff throughout; predominantly silt and silty sand with some 0.2 to 0.3 ft. thick sandy = interbeds; slightly moist; sands are well sorted fine to medium fine grained; native = material; some light yellow to tan mottle with silt; some 1/4-in. dark gray patches at = 12.5 to 13.0 may be minor hex contamination. =
					▨	11=		
				42=	▨			
					▨	12=		
				24=	▨			
					▨	13=		
							TD=	TD = 13 ft=
						14=		Note: 3 point composite collected at 2-10 for sample PRE-W-3 and a 6-point = compsites collected at 0-2, 10-12, 12-13 for sample PRE-S-2=
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		

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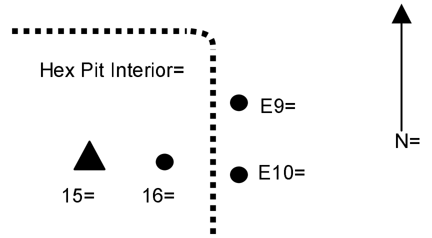
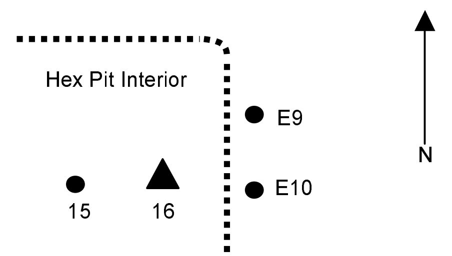


Borehole ID: **15**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain; Steve Mitchell & Zack Beck=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7/23/01=
Logged By: David West=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0=	2=	1.8=	1100=		▨		SM/ GM	<u>0.0 to 0.8</u>: silty sand and gravel/rock fragments; surface fill; dry; loose; grayish brown; sharp contact with silty sand below.=
				0.2=	▨	1=		<u>0.8 to 2.0</u>: silty sand; moderate sorting, fine to medium fine grained; yellowish brown, = moist; moderately loose; sharp color change at 1.6 ft to dark brown poorly sorted silty = sand; 1 1/2 inch wood fragments at 2 ft.; collected VOC sample PRE-S-15 (VOC) at = 1.0 ft. at 1107.=
					▨		SM =	
2=	5=	2.6=	1105=	2.1=	▨	2=		
					▨		WASTE (CL)	
				4=	▨	3=		<u>2.0 to 6.0</u>: clay; cemented sands and waste material; distinct light gray color = throughout (lime?); upper 0.2 ft. is indurated cemented sands, sharp contact with clay of identical color; uniform; distinct greasy/graphite texture; dark brown silty sand and = rock fragment interbed at 4.1 to 4.2 ft.; wood fragment at 4.5; at 6.0 ft. becomes = mottled light gray to gray, also distinct at 5.0 ft.; collected VOC sample PRE-W-= 15(VOC) at 5 ft. at 1111.=
					▨			
				1.4=	▨	4=		
					▨			
5=	6=	1=	1106=	4.1=	▨	5=		
					▨			
6=	10=	3.4=	1120=	4.5=	▨	6=		
					▨			<u>6.0 to 7.8</u> : clay as above; very strong mottling light gray to dark gray, wet at 7.6 to = 7.7 ft.; fid reading to 41 ppm; sharp contact at 7.8 with orange granular hex below; = wood fragments at 7.7 to 7.8.=
					▨	7=		
				41=	▨			
					▨	8=	HEX=	<u>7.8 to 8.2</u>: hex waste; granules of industrial hex and obvious orange to reddish = orange staining in clayey silt matrix; moist; some tar-like hex in fine grained matrix; = graded to "clean" silt below.=
				8.5=	▨		ML=	<u>8.2 to 9.1</u>: silt; yellowish brown; moderately stiff; "clean"; slightly moist to moist; = grades to silty sand below.=
					▨	9=	SP/ = SM=	
				4.9=	▨			
10=	13=	3=	1125=		▨	10=	SM=	
				6.9=	▨			<u>9.1 to 13.0</u>: silty sand to sand with minor silt; well sorted fine to medium fine grained; uniform pale brown to light yellowish brown; overall maintains silty sand; slightly moist throughout; stiff to moderately stiff; native material.
					▨	11=		
				8.1=	▨			
					▨	12=		
				9.4=	▨			
					▨	13=		
							TD=	TD = 13 ft=
						14=		
								6 pt. Composite collected at 0-2, 10-12, 12-13 feet.=
						15=		3 pt. Composite collected at 2-10 feet.=
								Several photos of Kevin & Neil Collecting VOC samples.=
						16=		
								Note: obvious reddish-orange hex coloration below 8.0 ft. (to 8.2 ft) was a "smearing" = of waste along liner.=
						17=		
						18=		
						19=		
						20=		



Borehole ID: **16**
Job Number: G1093-240
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Jason Lauer and Zack Beck
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 7-18-01
Logged By: Erika Herreria

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type
0	2	2.2	930	0.3	▨		SP
					▨	1	GW
				0.05	▨		
2	6	4	936		▨	2	ML
				0.15	▨		
					▨	3	SM
				0.25	▨		
					▨	4	
				0.65	▨		ML
					▨	5	
					▨		
6	10	3.75	940		▨	6	
					▨		
				51.2	▨	7	
					▨		
				24.8	▨	8	
					▨		
				63.4	▨	9	
					▨		SP
10	13		946		▨	10	
					▨		
				10.3	▨	11	
					▨		SM
				8.8	▨	12	ML
					▨		
					▨	13	
							TD
						14	
						15	
						16	
						17	
						18	
						19	
						20	

Soil Description

Take VOC sample at the 1 ft. interval at 0933

0 to 0.5: Sand with fines; med. grained; brown; well sorted; loose; soft; subrounded; "clean".

0.5 to 1.6: Sand with gravel; med. grained sand with coarse gravel; poorly sorted; loose; soft; subrounded gravel.

1.6 to 2: Sandy silt with some clay; brown; moderately dense; moderately firm; moderately plastic; "clean".

2 to 4.2: Silty sand; brown; fine to med. grained; moderately soft; moderately dense with black nodules of coal-like material throughout; at the 4.1 to 4.2 ft interval the color changes to a rust color and at 4.2 ft to a black color.

4.2 to 6: Sandy silt; black; moderately dense; moderately soft; slightly plastic; wet (no visible liquid product). Note: Take VOC sample at the 5 ft interval at 0938.

6 to 9: Sandy silt; dark brown; soft; moderately dense; slightly plastic; wet (no visible liquid product); with black staining throughout.

9 to 10: Sand with fines; fine grained; well sorted; very loose; very soft; subrounded; brown color.

10 to 11.2: Same as above; color change toward to bottom at 11.1 ft. to a lighter brown.

11.2 to 11.8: Silty sand; med. grained; light brown; well sorted; loose; soft; moist.

11.8 to 13: Sandy silt; light brown; loose; soft; slightly plastic; with white sand pockets; "clean".

Sample 2-10 taken at 1015 from a composite of borings 1, 16, 4.

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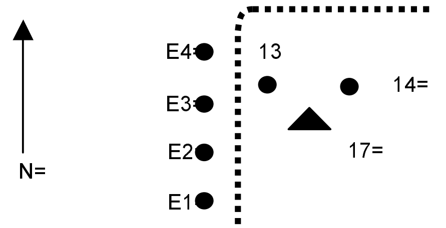

Borehole ID: **17**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7/24/01=
Logged By: David West=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0=	2=	2=	900=		▨		SM/ GM=	0 to 1.1: surface fill: silty sand and gravel/rock fragments to 1/2 inch; dark yellowish = brown; loose; dry.=
				0.5=	▨	1=		
				0.25=	▨		SM =	1.1 ro 1.8: silty sand; well sorted find to very fine sand; dark yellowish brown; slightly moist; stiff; appears "clean", sharp contact below.=
2=	6=	1.8=	907=		▨	2=		1.8 to 4.4: (?) (poor recovery at 2 to 6 ft.); silty sand, poorly sorted sand, fine to = medium grained; dark yellowish brown with dark gray patches of possible hex; = slightly moist; sharp contact below.=
					▨			
					▨	3=		
					▨			
					▨	4=		
				9.6=	▨			
					▨	5=	HEX WASTE	4.4 to 7.3: waste material; bright reddish orange industrial sand 0.6 ft. thick at about = 4.4 to 5.0 ft.; mixed silty sand and distinct light grayish white silt (lime?); slightly = moist; poorly sorted, rock fragments to 1 inch; minor wood fragments; wet at 6 ft. = and sharp contact with dark grayish brown clayey silt with obvious hex sheen/smear; slippery; texture; grades to less stained silt below.
				7.3=	▨			
6=	10=	2.9=	912=		▨	6=		
				20.9=	▨			
					▨	7=		
				48=	▨		ML	7.3 to 8.5: silt; very dark yellowish brown; uniform texture; slightly moist; no sand = content; moderately stiff; grades to silty sand/sand below.=
					▨	8=		
				24=	▨		SP=	
					▨	9=		
				27=	▨			8.5 to 10.3: sand with minor silt; well sorted fine to medium grained; dark yellowish = brown becoming yellowish brown at 10 ft.; slightly moist; moderately loose.=
10=	13=	3.3=	918=		▨	10=		
				22=	▨		SM/ML	
					▨	11=		10.3 to 13: silty sand/sandy silt interbedded; light yellowish brown to pale brown with = some dark gray patches/streaks of possible hex contamination; slightly moist; stiff = throughout; some pale yellow/white mottles in silt.=
				10.1=	▨			
					▨	12=		
				17=	▨			9:36 completed sampling;
					▨	13=		Note: several photos of sample collection/drilling=
							TD=	TD = 13 ft=
						14=		
								3-point composite collected at 2-10 for sample PRE-W-3 and 6-point composite = collected at 0-2, 10-12, 12-13 for sample PRE-S-2=
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		

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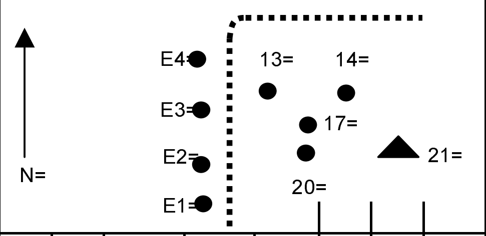

Borehole ID: **21**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain; Steve Mitchell & Zack Beck=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7/23/01=
Logged By: David West=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	1.9=	802=		▨		SW/GM	0.0 to 1.2: Sand with rock/gravel fragments; grayish brown; dry; loose; rock/gravel = abundment at 0.8 to 1.0 feet; poorly sorted fine to medium grained sand; 5-10% silt; = sharp contact with silty sand below.=
				0.9=	▨	1=		
				1.3=	▨			1.2 to 2: silty sand; well sorted fine to medium fine grained; silt to 10%; slight moist; = moderately dense; strong brown to dark yellowish brown.=
2=	6=	1.7=	808=		▨	2=	SM =	
					▨			2.0 to 6.0: upper 0.3 ft is silty sand, similar to above lithology but grayish brown with = strong black (hex) mottling; some black granular (hex?) coal-like fragments: some = rock fragments to 1 inch at middle of interval. ~3.0 to 4.0: sandy silt; moist; soft; = dark yellowish brown to orange brown, minor hex mottling; moist; one piece of black rubber 3/4 inch round; fibrous dark grayish brown material (0.1 ft. thick); waste = material; sharp contact and obvious color change to light gray to pale white (lime?), = silty sand below waste layer. approximately 5 to 6 ft (?); moderately sorting fine to = medium grained; strongly mottled light gray/pale white/medium to dark gray: moist; = grades to pure silt in next interval. =
				8.2=	▨	3=		
					▨		ML (GM)=	
					▨	4=		
					▨			
					▨	5=		
					▨			
6=	10=	3.2=	812=		▨	6=		6.0 to 7.8: Silt/clayey silt; mottled dark gray to light gray with distinct band of pale = white clay at 7.2 to 7.5 with slippery, graphite texture (lime?); very dark gray silty = clay/clayey silt below 7.5; sharp contact with "clean" material below 7.8 ft.=
				3.8=	▨		ML=	
					▨	7=		
				55.3=	▨		white=	
					▨	8=	ML/ CL	7.8 to 9.0: Silty sand with minor clay; well sorted fine to very fine grained sand; dark = yellowish brown; moist; moderately dense; grades into sand with minor silt at 9 to = 10 ft; "clean" yellowish brown, slightly moist, well sorted, fine to medium fine = grained; minor silt (< 5%).=
				26=	▨		SM=	
					▨	9=		
					▨			
10=	13=	2.9=	819=		▨	10=	SP=	9.0 to 10.8: sand, as described above; moderately sharp contact with silt below.=
				23.4=	▨			
					▨	11=		
				9.3=	▨		ML=	10.8 to 13.0: silt and sandy silt; "clean" light yellowish brown; slightly moist; stiff; = native material: intervedded silt and sand content up to 25-35% with increased = moisture; pale brown to light yellowish color is uniform throughout.=
					▨	12=		
					▨			
					▨	13=		
							TD=	TD = 13 ft.=
						14=		
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		

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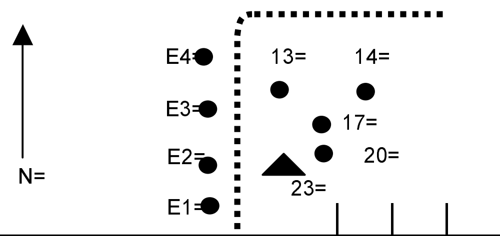

Borehole ID: **23**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 07/20/01=
Logged By: Erika Herreria=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	2=	1038=	0.8=	▨		GM=	<u>0 to 0.2</u>: silty gravel; fine, poorly sorted, loose, soft, "clean".=
					▨	1=	ML=	<u>0.2 to 2.0</u>: Sandy silt; brown; loose; soft; with black coal-like material throughout = interval.=
				1.0=	▨			Note: Sample PRE-S-23 (VOC) was collected at the 1 foot interval at 1040=
2=	6=	1.6=	1042=		▨	2=		<u>2.0 to 5.0</u>: same as above. At approximately 5.0' feet hit a rock.=
				0.8=	▨			Note: Sample PRE-W-23 (VOC) was collected at the 5 foot interval at 1044=
					▨	3=		
					▨			
					▨	4=		
					▨			
					▨	5=		<u>5.0 to 6.0</u>: Silt; white grey blue color; very fine; soft; dense; moist (lime?)=
					▨			
6=	10=	2.2=	1048=	4.0=	▨	6=		
				45.5=	▨		SM=	
					▨	7=		
				94.5=	▨			
					▨	8=		<u>6.0 to 10.0</u>: Silty sand; very dark brown; fine grained; well sorted; loose; soft; at 6.0" = feet there was about 2" inches of liquid hex.=
					▨			
					▨	9=		
					▨			
10=	13=	3.5=	1054=		▨	10=		
				8.5=	▨		ML=	<u>10.0 to 11.0</u>: Clayey silt; brown; moderately stiff; moderately dense; plastic; moist; = with black staining throughout interval.=
					▨	11=		
				105.0=	▨			
					▨	12=		
				83.0=	▨			<u>11.0 to 13.0</u>: Sandy silt; brown; loose; soft; moist; with black staining and very moist = spots throughout interval.=
					▨	13=		
							TD=	TD = 13 ft.=
						14=		
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		

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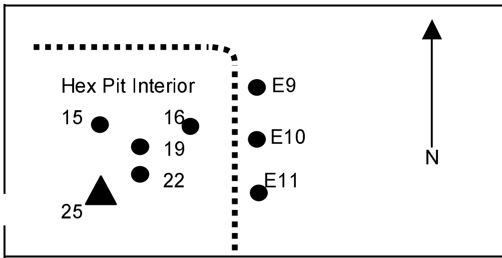

Borehole ID: 25
Job Number: G1093-240
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Steve Mitchell & Zack Beck
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 7/23/01
Logged By: David West

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0					▨		SM/ GM	0 to 1.2: silty sand and gravel/rock fragments; dry surface fill; grayish brown; loose; possible concrete rabble; rock fragments to 1 inch; sharp contact with silty sand below.
		2.0/2.0	8:40	0.9	▨	1		
				1.6	▨		SM	1.2 to 2.0: silty sand; poorly sorted very fine to medium grained but uniform otherwise; silt from 10 to 15%; dark yellowish brown; slightly moist; moderately dense.
2	2				▨	2		
				2.4	▨			
					▨	3		2.0 to 5.3: silty sand (as above); mostly clean to 3.5 ft, becomes variable mottled with black hex 3.5 to 5.3 with black granular coal-like band at 4.3 to 4.5 ft; moderately sorted fine to medium fine sand below 4.5 ft; increased moisture at 4.5 to 5.3 to mearly wet; sharp contact at 5.3 to gray stained waste material.
		3.3/4.0	8:45	3.0	▨			
					▨	4		
				2.4	▨			
					▨	5		
				5.9	▨		▨	5.3 to 5.6: waste material; silty sand matrix; fiboroous and wood fragments; strong gray to dark gray staining with no significant FID signature; grades to light gray clay below.
6	6				▨	6	CL	5.6 to 6.0: clay; obvious light gray to pale white mottles, very greasy graphite-like texture, moist.
				14.3	▨			6.0 to 7.6: clay; as describe above, mostly black and very dark gray with distinct pale white to light gray. Band at 7.1 to 7.3 ft; moist; greasy/graphite texture remains throughout; grades to silt below.
					▨	7		
				102.0	▨		white	
		3.4/4.0	8:50		▨	8	ML	7.6 to 8.5: silt; stained dark gray from above, becoming dark yellowish brown; uniform texture; moderately stiff; slightly moist; grades to silty sand.
				75.4	▨			8.5 to 9.0: silty sand; uniform dark yellowish brown, "clean" native material; slightly moist; graades to sand with minor silt.
					▨	9	SM	
					▨		SP	9.0 to 11.1: sand; well sorted fine to medium fine grained; slightly moist; loose; yellowish brown, uniform "clean" native material; sharp contact.
10	10				▨	10		
				31.1	▨			
					▨	11		11.1 to 13.0: silty sand and silt interbedded; light yellowish brown to pale brown; slightly moist; moderately stiff, uniform "clean" native material.
		2.5/3.0	8:55	14.8	▨		SM/ ML	
					▨	12		Photo 4-24 taken of kevin P. sampling.
				11.5	▨		ML	Note: Sample collected from entire borehole used in 6-point composite sample PRE-S-3
	13				▨	13		
							TD	
						14		
						15		
						16		
						17		
						18		
						19		
						20		

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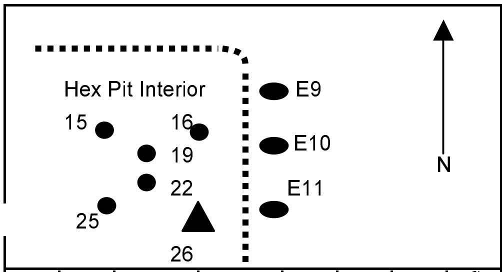

Borehole ID: 26
Job Number: G1093-240
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Jason Lauer and Zack Beck
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 7-18-01
Logged By: Erika Herreria

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0					▨		SP	0 to 0.4: Sand; light brown; med. sand; well sorted; very loose; very soft; rounded; "clean"; dry.
		2	1104	1.5	▨	1	GW	
		2			▨		ML	0.4 to 1.5: Sand with gravel; med. sand; coarse gravel; poorly sorted; loose; soft; subrounded to subangular gravel; dry; "clean".
2	2			6	▨	2		
				0.3	▨			1.5 to 2: Sandy silt; light brown; fine sand; well sorted; moderately firm; moderately dense; dry; "clean".
					▨	3		
				0.45	▨			
					▨	4		2 to 6: Sandy silt; fine to med. sand; moderately sorted; loose; soft; with black coal like material throughout; From 2 to 5 ft interval was a brown color at 5 ft the color changed to a rust color.
		2.5	1108	2.1	▨			
		4			▨	5		
					▨			
6	6				▨	6		6 to 6.3: Black liquid Hex; sticky; high viscosity.
					▨		SM	6.3 to 7: Silty sand; fine sand; very loose; very soft; well sorted; moist; color change at 6.5 ft from black to dark brown.
				23	▨	7		
		2.6			▨		ML	
		4	1111		▨	8		7 to 9: Sandy silt; brown; fine sand; well sorted; loose; soft; slightly plastic; moist.
				9.7	▨			
					▨	9		9 to 10: Sand with some fines; very fine sand; well sorted; very loose; very soft; moist; brown; "clean".
					▨		SP	
10	10				▨	10		10 to 11.3: Same as above; with some spots more moist and dark brown in color.
		3.1		9.4	▨			
		3	1117		▨	11		
				12.9	▨		ML	11.3 to 12.3: Sandy silt with clay; brown; fine sand; well sotred; moderately dense; moderately firm; plastic; with white sand color pocket throughout; moist.
					▨	12		
	13			5.1	▨			12.3 to 13: Sandy silt; brown; fine sand; well sorted; soft; moderately dense; slightly plastic; moist.
					▨	13		
						14		
						15		
						16		
						17		
						18		
						19		
						20		

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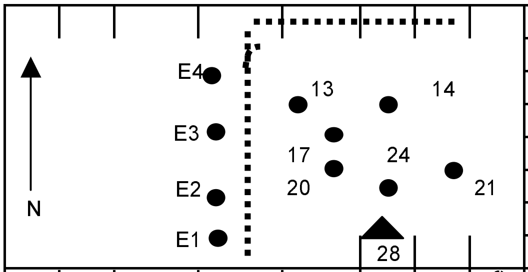
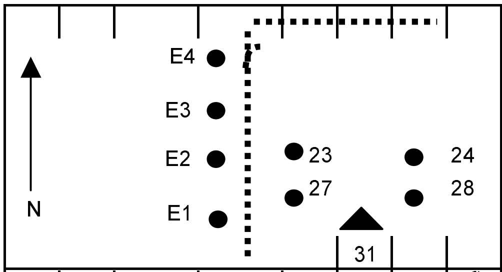


Borehole ID: 28
Job Number: G1093-240
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Jason & Zack
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 07/20/01
Logged By: Erika Herreria

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0				0.3	▨		GM	0.0 to 1.0: silty sand with gravel; brown color; fine sand; poorly sorted; coarse gravel; loose; soft; "clean".
		2.0/2.0	7:42		▨	1		
				0.8	▨		ML	1.0 ro 2.0: sandy silt; brown color; fine sand; well sorted; medium stiff; medium dense; with some coal like materials throughout interval.
2	2				▨	2		
					▨			
				0.7	▨	3		2.0 to 4.0: same as above; at 3.5' to 4.0' feet the color changes to a rust color.
		2.0/4.0			▨			
				2.5	▨	4		
					▨			
			7:47		▨	5		4.0 to 6.0: silt; white grey blue color; very fine, well sorted, soft, dense, moist, sligtly plastic.
					▨			
6	6				▨	6		6.0 to 7.0: silt with fines; black color (hex), very fine, well sorted, soft, dense, moist to wet.
					▨			
				29.7	▨	7		
		2.15/4.0			▨			7.0 to 8.5: silt; very dark brown, very fine, well sorted, soft, dense, moist, hex shim throughout interval.
				97	▨	8		
					▨			
					▨	9	SP	
			7:52		▨			8.5 to 10.0: sand with fines; dark brown, fine sand, well sorted, soft, loose, moist.
10	10				▨	10		
					▨		SM	
				11.3	▨	11		
		3.2/3.0			▨			10.0 to 13.0: silty sand; light brown, medium sand, well sorted, soft, loose, moist, with black staining throughout.
				16.8	▨	12		
			8:00		▨			
	13				▨	13		
						14		
						15		
						16		
						17		
						18		
						19		
						20		



Borehole ID: 31
Job Number: G1093-240
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Jason Lauer and Zack Beck
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 7-18-01
Logged By: Erika Herreria

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0					▨		GW	Note: took sample PRE-S-31 (VOC) from 1 ft. at 1045
					▨	1		<u>0 to 1:</u> Sand with gravel; some fines; poorly sorted; loose; soft; fine to coarse gravel; brown sand.
		2	1040	2.3	▨		ML	
2	2	2			▨	2		<u>1 to 2.7:</u> Sandy silt; brown; fine sand; well sorted; soft; med. dense; slightyly plastic; with coal like material throughout.
				3	▨			
					▨	3		<u>2.7 to 4.5:</u> Sandy silt with gravel; fine gravel; poorly sorted; dense; firm; range in color at firm dark gray 2.7 to 3.5 ft.; white gray with fibers from 3.5 to 3.9 ft.; rust color from 3.9 to 4.5 ft; moist.
		2.7		3.8	▨			
		4	1044		▨	4		
					▨			
					▨	5		<u>4.5 to 6.2:</u> Black liquid Hex. Note: took sample PRE-W-31 (VOC) from 5 foot interval at 1050.
					▨			
6	6				▨	6		
					▨			
		2.3		44.5	▨	7		<u>6.2 to 7.6:</u> Clayey silt; very dark brown; moderately dense; moderately firm; slightly plastic; moist.
		4	1052		▨			
					▨	8	SM	
				96.5	▨			<u>7.6 to 10.2:</u> Silty sand; brown; well sorted; loose; soft; fine sand; moist.
					▨	9		
					▨			
10	10				▨	10	ML	
					▨			
		3.1		8.4	▨	11		<u>10.2 to 12:</u> Sandy silt; light brown; med. To fine sand; moderately sorted; moderately dense; moderately firm; moist; with some coal like material throughout.
		3			▨			
				12.7	▨	12		
	13		1102		▨			<u>12 to 13:</u> Clayey silt; light brown; dense; firm; plastic; some black staining; with fines; moist.
					▨	13		
						14		
						15		
						16		
						17		
						18		
						19		
						20		

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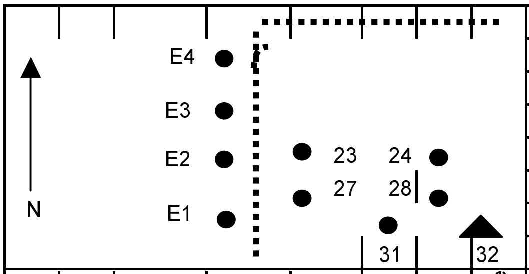
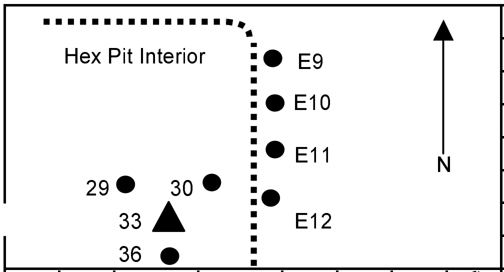


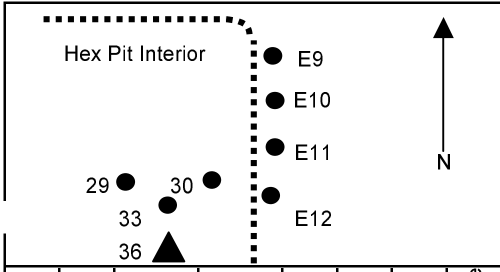
Borehole ID: 32
Job Number: G1093-240
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 07/20/01
Logged By: Erika Herreria

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0				-0.2	▨		GM	0 to 1: silty sand with gravel; poorly sorted; fine to medium sand; fine to coarse gravel; loose; soft; with coal like material in the center of the interval.
		2.0/2.0	8:12		▨	1		
				3.9	▨		ML	1 to 2: sandy silt; light brown; fine sand; well sorted; loose; soft; moist; with lots of coal like material (a 10 mm size coal like material found at the bottom of the interval).
2	2				▨	2		
					▨			
			8:17	2.4	▨	3		2 to 3.5: sandy silt; light brown; fine sand; well sorted; loose; soft; moist; with lots of coal like material throughout.
		2.45/4.0			▨			
				28.2	▨	4		3.5 to 6.0: sandy silt; fine to medium sand, moderately sorted, soft, dense, moist, range in color at the top of interval is a rust color then it trasitions to a very dark brown with black staining. Note: lost the shoe at 6 feet so the drillers offset 6 in to northeast of the original location.
					▨			
					▨	5		
					▨			
6	6				▨	6		6.0 to 6.7: silt; black color (hex shim); very fine; well sorted; soft; dense; moist; with a few coarse gravels throughout.
				87.6	▨			6.7 to 7.2: sandy silt; very dark brown (with some hex shim); fine; well sorted; soft; moderately dense; moist; with some black staining.
				56	▨	7		
		2.5/4.0			▨			7.2 to 9.0: no recovery (the drillers hit a void space)
			8:48		▨	8		
					▨			
					▨	9		9.0 to 11.0: sandy silt; dark brown; fine sand; well sorted; soft; dense; moist; with some coal like material and black staining throughout.
					▨			
10	10			38.4	▨	10		
					▨			
				34.4	▨	11		11.0 to 13.0: sandy silt; brown; medium sand; well sorted; soft; moderately dense; moist; with some black staining throughout.
		3.0/3.0			▨			
				19.1	▨	12		
			8:52		▨			
	13				▨	13		
						14		
						15		
						16		
						17		
						18		
						19		
						20		



Borehole ID: 33
Job Number: G1093-240
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Jason Lauer and Zack Beck
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 7-18-01
Logged By: Erika Herreria

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0				0.1	▨		GW	Note: sample PRE-S-33 (VOC) collected from the 1 ft. interval at 0753.
		2	0745		▨	1		0 to 1: Sand with fravel; med. sand; poorly sorted; loose; soft; coarse;gravel; with coal like material spots throughout.
		2		0.1	▨		ML	
2	2				▨	2		1 to 2: Sandy silt; med. to fine sand; dark brown; well sorted; soft; moderately dense; slightyly plastic; with coal like material modules throughout.
				0.2	▨			
					▨	3		2 to 3.2: Same as above.
		3.2		0.57	▨			
		4			▨	4		3.2 to 5.8: Sandy silt; fine sand; well sorted; loose; soft; slightly plastic; rust color from 3.2 to 4 ft then transition to a brown color from 4 to 5.8 ft; with coal like material throughout.
			0750	0.3	▨			
					▨	5		
				9.5	▨			
6	6				▨	6		5.8 to 6.9: Sandy silt; same as above; change color to very dark brown with black staining throughout.
					▨			
					▨	7		
		2.65			▨			6.9 to 8.5: Silt; reddish brown; well sorted; soft; moderately dense; slightly plastic; moist.
		4	0755		▨	8		
					▨			
					▨	9		8.5 to 10.2: Clayey silt; brown; med. stiff; dense; slightly plastic; moist.
					▨			
10	10				▨	10		
					▨		SM	10.2 to 13: Silty sand; light brown; med. sand; loose; soft; moist.
					▨	11		
		2.6	0903		▨			
		3			▨	12		
	13				▨			
					▨	13		
						14		
						15		
						16		
						17		
						18		
						19		
						20		



Borehole ID: 36
Job Number: G1093-240
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Jason Lauer and Zack Beck
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 7-18-01
Logged By: Erika Herreria

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0					▨		GW	Note: Sample PRE-S-36 (VOC) from 1 ft. at 0838
		2	0813		▨	1		0 to 1: Sand with gravel; med. sand; fine to coarse gravel; poorly sorted; loose; soft; brown color sand.
		2			▨			
2	2				▨	2		1 to 2: Sandy silt; brown color; fine sand; well sorted; med. stiff; medium dense; slightly plastic; with coal like material throughout.
					▨			
		2.7			▨	3		2 t o 4.5: Sandy silt; fine sand; well sorted; moderately dense; soft; brown color from 2 to 4 ft. then change to redish brown from 4 to 4.5; moist.
		4			▨		ML	
			0818		▨	4		
					▨			
					▨	5		4.5 to 6: Sandy silt; fine sand; well sorted; moderately dense; soft; very dark brown with black staining throughout; also 2 in. of liquid Hex. Note: sample PRE-W-36 (VOC) taken at 5 feet at 0855 and FID stopped working.
					▨			
6	6				▨	6		
		0.4			▨			
		4			▨	7		
			0825		▨			
					▨	8	NR	6 to 9.8: No recovery; drillers noted possible water.
					▨			
					▨	9		
					▨			
10	10				▨	10	ML	9.8 to 10: Silt; brown; moderately dense; moderately stiff; with fines; moist slightly plastic.
					▨			
		1			▨	11		
		3	0834		▨			
					▨	12	SM	10 to 13: Note rock in drill shoe, very poor recovery. Silty sand; med.sand; well sorted; loose; soft; moist; "clean looking".
	13				▨			
					▨	13		
						14		
						15		
						16		
						17		
						18		
						19		
						20		

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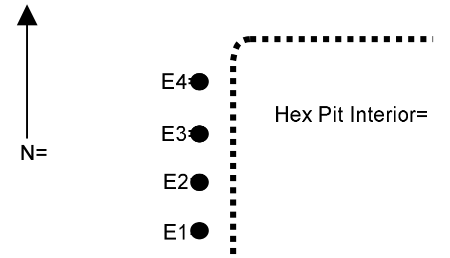

Borehole ID: **E1**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain Steve Mitchell and Zack Beck=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7-12-01=
Logged By: David West, Erica Herreria assisting=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type
0=	2=	1.5=	1133=	0=			SP=
				0=		1=	
				0=			SM=
2=	7=	3.6=	1206=	0=	▨	2=	
				0=	▨		SP=
				0=	▨	3=	
				0=	▨		
				0=	▨	4=	
				1=	▨		
				1=	▨	5=	
				0=	▨		
				0=	▨	6=	SM=
				0=	▨		
7=	10=			0=	▨	7=	SP=
				0=	▨		SM=
				0=	▨	8=	
				0=	▨		SP=
				0=	▨	9=	
				0=	▨		
				0=	▨	10=	
							TD=
						11=	
						12=	
						13=	
						14=	
						15=	
						16=	
						17=	
						18=	
						19=	
						20=	

Soil Description

0 to 2 Poor recovery in loose surficial sands. Fill material: sand with minor silt= with fine to medium gravel; moderate sorting; moist; dark brown to brown; loose; "clean"; offset < 1 ft. west and redrive with good recovery (1.5/2.0); sand, as= decribed above; sharp contact at 1 ft. to dark brown very fine silty sand; slighty moist to wet; minor silt at 2 ft; silty sand is stiff/dense; no FID detection= throughout; wet at 1 ft contact.=

2 to 6 (no recovery on 1st and 2nd attempt; offset to 3rd location) Obvious= surficial saturation "silty" on sharp contact at 1 ft with dense silty sand.

2 to 7 (3rd attempt); sand with minor silt; fine to medium grained moderately = well sorted (SP); loose; slightly to very little moisture; yellowish brown; grades= to dark brown silty sand at 5.5 to 6.5 ft.; sand with minor silt =

6.5 to 7 Sand; loose; no moisture; well sorted; yellowish brown and "clean" =

7 to 10 Silty sand; very fine grained 7 to 8 ft; slightly moist well sorted sand= with abundant silt; dark yellowish brown; grades to very well-sorted= fine grained sand with minor silt at 8 to 10 ft; loose; yellowish brown, "clean" (as above), very slightly to slightly moist.=

TD = 10 ft=

Collect 2 to 10 ft composite and split for agent screening at 1220; composite= mixed in disposable aluminum pan; sanple ID = PRE-S-E2=

Background FID readings = -.0.68

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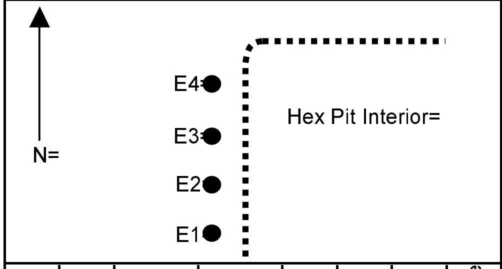
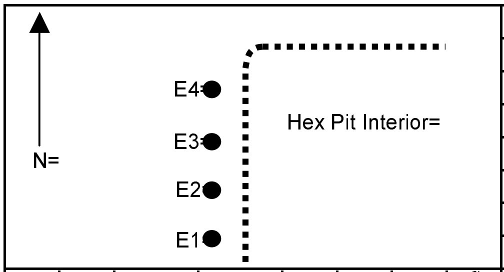


Borehole ID: **E2**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain Steve Mitchell and Zack Beck=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7-13-01=
Logged By: David West; Erica Herreria assisting=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	1.7=	817=	0=			SW=	0 to 0.5 Surficial gravel and sand, loose, dry, light brown=
				0=		1=		
				0=			SM	0.5 to 2 Silty sand; fine to medium grained dark brown, slightly moist=
2=	6=	3.6=	824=	0=		2=		
				0=	▨			
				0=	▨	3=		
				0=	▨			2 to 5.8 Sand with minor silt, uniform, well sorted fine to medium fine grained,=
				0=	▨	4=	SP=	moderately loose, slightly moist, yellowish brown, "clean," grades to silty sand=
				0=	▨			below.=
				0=	▨	5=		
				0=	▨			
6=	10=	3.3=	826=	0=	▨	6=		5.8 to 6.5 Silty sand, very fine to fine-grained, dark yellowish brown=
					▨		SM=	moderately stiff, slightly moist, grades to sand below=
					▨	7=		6.5 to 10 Sand, minor silt, modertly well sorted, fine to medium grained,=
					▨			"clean," loose, yellowish brown, slightly moist, silt content increases to 5 - 10=
					▨	8=		% at 10 ft; overall very uniform native material.=
					▨		SP=	
					▨	9=		
					▨			
					▨	10=		
							TD=	TD = 10 ft=
						11=		
								Background FID = -0.66 ppm =
						12=		0835 collect 2 to 10 ft composite and split sample for agent screening; sample=
								composited in disposable aluminum tray; sample ID = PRE-S-E2=
						13=		
						14=		
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		



Borehole ID: E3=
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain; Jason Lauer and Zack Beck=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7-13-01=
Logged By: Erica Herreria=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	1.9=	909=				GW=	0 to 0.7 Gravel-sand mixture, poorly sorted, med. Sand, loose, soft, with fines, = gravel size range fine to coarse=
						1=		
							ML=	0.7 to 1.5 Clayey silt with fines, moderately dense, dark brown, moderately firm, = slightly plastic, with black, coal-like material=
2=	7=	3.85=	914=		▨	2=		
					▨			1.5 to 2 Silty sand, light brown, fine sand, loose, soft, well sorted, "clean"=
					▨	3=		
					▨			
					▨	4=	SM=	
					▨			2 to 6.2: Silty sand; same as above=
					▨	5=		
					▨			
					▨	6=		6.2 to 7 Sandy silt, light brown, very fine sand, loose, soft, well sorted, "clean," = slightly plastic=
					▨			
7=	10=	2.6=	920=		▨	7=	ML=	7 to 7.5: Sandy silt; same as above=
					▨			
					▨	8=		
					▨			7.5 to 10 Silty sand, light brown, very loose, very soft, well sorted, fine sand, = rounded, "clean"=
					▨	9=	SM=	
					▨			
					▨	10=		
							TD=	TD = 10 ft=
						11=		
								Sample PRE-S-E3 taken from 2 to 10 ft at 0930=
						12=		
						13=		
						14=		
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		

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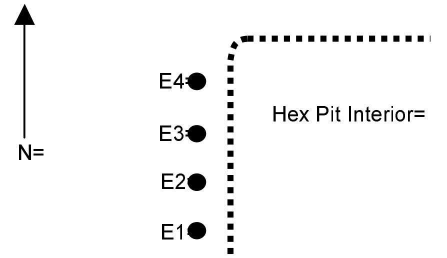

Borehole ID: **E4**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain; Jason Lauer and Zack Beck=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7-13-01=
Logged By: Erica Herreria=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	2=	933=				GW=	<u>0 to 1.3</u> Sand with fines; med. sand; light brown; soft; loose; well sorted; rounded to = subrounded; "clean"=
						1=		
							ML=	<u>1.3 to 2</u> Sandy silt; med. sand; light brown; soft loose; slightly plastic; "clean"; moist=
2=	7=	3.8=	937=		▨	2=		
					▨			
					▨	3=		
					▨			
					▨	4=	SM=	<u>2 to 6.2</u> Silty sand; light brown; fine sand; very loose; very soft; well sorted; "clean"=
					▨			
					▨	5=		
					▨			
					▨	6=		
					▨		ML	<u>6.2 to 7.5:</u> Sandy silt; light brown; fine sand; loose; soft; well sorted; slightly plastic; = "clean".=
7=	10=	3=	942=		▨	7=		
					▨			
					▨	8=		
					▨			
					▨	9=	SM=	<u>7.5 to 10</u> Silty sand; light brown; fine sand; very loose; very soft; well sorted; "clean"=
					▨			
					▨	10=		
							TD=	TD = 10 ft=
						11=		
								Sample PRE-S-E4 taken from 0 to 2 ft at 0950.=
						12=		
						13=		
						14=		
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		

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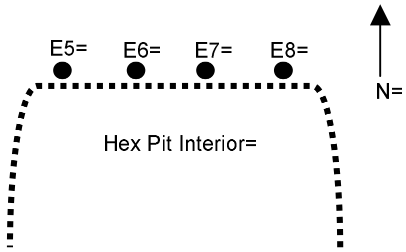

Borehole ID: **E5**

Job Number: G1093-240=

Site: Rocky Mountain Arsenal - Hex Pit=

Drilling Company: ESN - Rocky Mountain Steve Mitchell; Zack Beck=

Drilling Method: Direct push=

Continuous core in 4 ft. X 1.125 in. PETG plastic liners=

Drilling Date(s): 7-13-01=

Logged By: David West; Erica Herreria assisting=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	2.1=	935=	0.1=				0 to 2 Sand, little to no silt, poorly sorted, fine to medium grained,=
						1=	SW=	modertly loose; slightly moist; appears "clean" throughout; yellowish brown=
				0.4=				grades to well-sorted medium to fine silty sand at 1.9 ft.=
2=	7=	3.9=	941=		▨	2=		
				0.5=	▨			
					▨	3=		2 to 5.5 Sand with little silt; silt content 5-10 %; well-sorted fine to=
				0.4=	▨			medium grained, modertly compact; moist; yellowish brown; "clean,"=
					▨	4=	SP=	grades to more dense silty sand/sandy silt below=
				0.6=	▨			
					▨	5=		
					▨			5.5 to 7 Silty sand/sandy silt; very fine granied (well sorted) sand with =
				1.3=	▨	6=		abundant silt, becoming sandy silt at 6.5 to 7 ft.; more dense (stiff) but still=
					▨		SM=	crumbles easily; dark yellowish brown; moist to slightly moist; "clean" native =
7=	10=	2.7=	947=	0.6=	▨	7=		soil=
					▨			
				0.8=	▨	8=	ML=	7 to 9 Silt; uniform; soft; moist; dark yellowish brown to dark brown; "clean"=
					▨			native material; interbed of sandy silt 0.2 ft thick at 7.5 ft.=
				1.6=	▨	9=		
					▨		SP=	9 to 10 Sand; well sorted fine grained; loose; yellowish brown; "clean"=
				0.5=	▨	10=		
							TD=	T.D.= 10 ft.=
						11=		
								FID background = 1 to 0.3 ppm=
						12=		0955 Collect 2 to 10 ft. composite sample "PRE-S-E5" in 8 OZ jar; collect split=
								sample for agent screening.=
						13=		0955 Borehole E5 grouted; move rig to E6=
								0958 Start E6=
						14=		
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		

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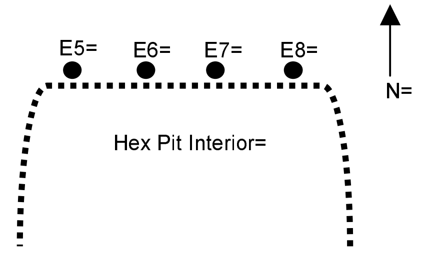
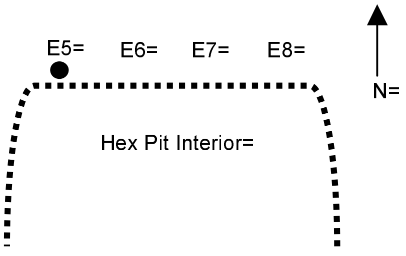


Borehole ID: **E6**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain Steve Mitchell; Zack Beck=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7-13-01=
Logged By: David West=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	1.8=	1000=	0.8=			SW=	0 to 1 Sand; moderately sorted; fine to medium grained; yellowish brown;=
						1=		loose "clean" cover material; slightly moist to moist; sharp contact at 1 ft.=
				0.8=			SP=	
2=	6=	3.4=	1009=		▨	2=		
				0.6=	▨			1 to 6 Sand; well sorted; fine grained; no silt, uniform yellowish =
					▨	3=		brown; modertly loose native soil; slightly moist; "clean;" grades to silty sand=
				0.5=	▨			below=
					▨	4=		
				1=	▨			
					▨	5=		
				0.2=	▨			
6=	10=	3.6=	1014=		▨	6=		6 to 8.4 Silty sand; very fine to fine grained; well sorted; silt to =
				0.8=	▨		SM=	approximately 10 %; loose; yellowish brown; slightly moist; 'clean"=
					▨	7=		native material; relatively sharp contact with silt below=
				1.8=	▨			
					▨	8=		
				1.6=	▨			8.4 to 9 Silt/sandy silt; sand is very fine grained; about equal percent sand and=
					▨	9=	ML=	silt; dark yellowish brown to dark brown; moist; sharp contact with sand below.=
				2=	▨		SP =	9 to 10 Sand; well sorted fine grained; loose; yellowish brown; "clean", no silt.=
					▨	10=		
							TD=	T.D. = 10 ft=
						11=		
								FID background = 0.10 ppm=
						12=		1026 Collect 2 to 10 ft composite sample "PRE-S-E6" and split sample for agent=
								screening=
						13=		Borehole E-6 grouted to surface.=
						14=		
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		



Borehole ID: **E7**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain Steve Mitchell; Zack Beck=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7-13-01=
Logged By: David West=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0=	2=	2=	1137=					0 to 1.6: Sand; minor silt (<5%); moderately sorted very fine to med. coarse = grained; loose; moist; uniform yellowish brown; "clean" surface fill; sharp contact to mostly dry well sorted fine grained sand 1.5 to 1.6 ft.; orange survey tape in sample = at 1.6 ft. (at contact).=
				1.8=		1=	SW=	
2=	7=	4=	1144=	1.4=	▨	2=		
				1.5=	▨	3=	SP=	1.6 to 5.1: Sand; well sorted fine to very fine grained; moderately dense; very = slightly moist; very uniform yellowish brown; "clean" native material; grades to silty = sand at 5.1 ft.=
				2=	▨	4=		
				1.3=	▨	5=		
				0.9=	▨	6=		5.1 to 8.5: Silty sand; uniform well sorted very fine to fine grained sand; slightly = moist; more dense than above; dark yellowish brown; remains clean native soil; = grades to silt at 8.5 ft.=
7=	10=	2.6=	1149=	0.7=	▨	7=	SM=	
				1=	▨	8=		8.5 to 9.1: Silt; uniform grayish brown; moist; moderately dense; remains "clean"; = very sharp contact at 9.1 ft. to sand.=
				1.8=	▨	9=	ML=	9.1 to 10: Sand; uniform grayish brown; moist; moderately dense; remains "clean"; very well sorted fine to very fine grined; yellowish brown; slightly moist; loose; = "clean" native (?)
				3.1=	▨	10=	SP=	
							TD=	TD = 10 ft=
						11=		
						12=		
						13=		
						14=		
						15=		
						16=		
						17=		1158: Collect 2 to 10 ft. composite sample "PRE-S-E7" (1, 8-oz. jar) for Hex = analysis. Sample composited in disposable aluminum tray. Borehole E7 grouted to = surface.=
						18=		
						19=		
						20=		

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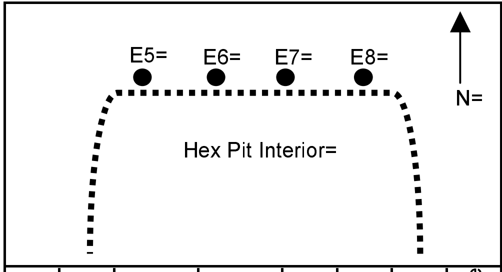

Borehole ID: **E8**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain; Jason Lauer & Zack Beck=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7-16-01=
Logged By: Erika Herreria=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	2=	850=				SW=	0 to 1.75 Sand; little fines; moderately sorted; med. grained; light brown; = subrounded; "clean;" dry; loose; soft.=
						1=		
2=	6=	3.7=	856=			2=	ML=	1.75 to 2 Sandy silt; brown; moderately dense; moderately firm; slightly plastic.=
					▨			
					▨	3=		
					▨			
					▨	4=		
					▨			
					▨	5=	SM=	2 to 7 Silty sand; light brown; loose; soft=
					▨			
6=	10=	3.45=	906=		▨	6=		
					▨			
					▨	7=		
					▨			
					▨	8=	ML	7 to 9.25 Sandy silt; brown; loose; soft; slightly plastic; moist.=
					▨			
					▨	9=		
					▨		SM=	
					▨	10=		9.25 to 10 Silty sand; light brown; rounded; well sorted; loose; soft=
							TD=	TD = 10 ft=
						11=		
								Sample PRE-S-E8 taken from 2 to 10 ft. at 0914=
						12=		
						13=		
						14=		
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		

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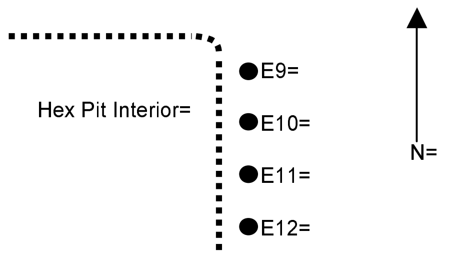

Borehole ID: **E9**	
Job Number: G1093-240=	
Site: Rocky Mountain Arsenal - Hex Pit=	
Drilling Company: ESN - Rocky Mountain; Jason Lauer & Zack Beck=	
Drilling Method: Direct push=	
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=	
Drilling Date(s): 7-16-01=	
Logged By: Erika Herreria=	

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	2=	1014=	0=				
				-0.15		1=	SP=	0 to 2 Sand; very little fines, med. grained; well sorted; loose; soft; subrounded; light brown; "clean".=
				-0.05				
2=	7=	2.7=	1021=	-0.1=	▨	2=		
				-0.21	▨			
					▨	3=		
					▨		NR=	2 to 4.5 No recovery.=
					▨	4=		
					▨			4.5 to 5 Sand; same as above with some organic matter (roots); "clean".=
					▨	5=	SP=	5 to 5.25 Sandy silt with black, charcoal-like material; moist; moderately dense; = slightly plastic; brown =
				0.05=	▨			
				0.08=	▨	6=		
				-0.2=	▨		SM=	5.25 to 7 Silty sand; light brown; loose; soft; medium to fine grain=
7=	10=	2.55=	1024=	-0.2=	▨	7=		
					▨			
				-0.05	▨	8=	ML=	7 to 9 Sandy silt; light brown; loose; soft=
					▨			
				0.21=	▨	9=		
					▨		SP=	9 to 10 Sand with some fines; light brown; loose; moist.=
				0.28=	▨	10=		
							TD=	TD = 10 ft=
						11=		
						12=		PRE-S-E9 taken from 2 to 10 ft at 1040.=
						13=		
						14=		
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		

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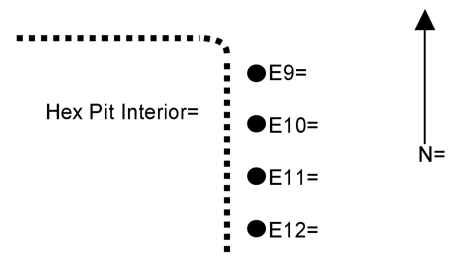

Borehole ID: **E10**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain; Jason Lauer & Zack Beck=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7-16-01=
Logged By: Erika Herreria=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	1.5=	1044=				SP=	0 to 0.25 Sand with some fines; med. grained; loose;l soft; brown; moist; some = roots and grass; well sorted.=
				0.05=		1=		
								0.25 to 2: Sand; light brown; little fines; med. grained; well sorted; loose; soft; = "clean"; subrounded.
2=	6=	2.6=	1050=	0.05=	▨	2=		
					▨			
					▨	3=	NR=	2 to 3.4: No recovery.=
					▨			
				0.3=	▨	4=	SP=	3.4 to 4: Sand; same as above.=
					▨		SM=	4 to 4.5: Silty sand; brown; loose; soft; fine sand; well sorted; moist; "clean".=
				0.2=	▨	5=		
					▨			
6=	10=	3=	1058=	0.1=	▨	6=	SP=	4.5 to 7.5 Sand; fine grained; some fines; loose; soft; light brown; well sorted; = increasing fines with depth=
					▨			
				0.1=	▨	7=		
					▨			
				0.2=	▨	8=		
					▨			
				0.2=	▨	9=	ML	7.5 to 10: Sandy silt; brown; slightly plastic; soft; moderately dense; moist=
					▨			
				0.15=	▨	10=		
							TD=	TD = 10 ft=
						11=		
						12=		
								Sample PRE-S-E10 collected from 2 to 10 ft at 1103.=
						13=		
						14=		
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		

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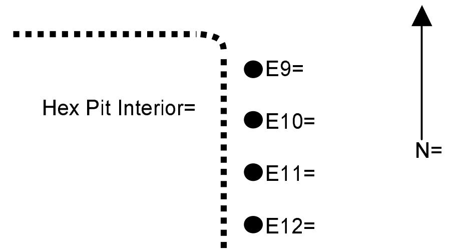

Borehole ID: **E11**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain; Jason Lauer & Zack Beck=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7-16-01=
Logged By: Erika Herreria=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	2=	1150=					
				0.05=		1=	SP=	<u>0 to 2</u> Sand, trace fines; med. grained; light brown; well sorted; subrounded; soft; loose; "clean".=
2=	7=	3.8=	1155=	0.05=	▨	2=		
					▨		NR=	<u>2 to 3.2</u> No recovery.=
					▨	3=		
					▨			
				0.3=	▨	4=		
					▨			
				0.2=	▨	5=		
					▨		SM=	<u>3.2 to 7</u> Silty sand; fine grained; light brown; subrounded; loose; soft=
				0.1=	▨	6=		
					▨			
7=	10=	2.5=	1201=	0.1=	▨	7=		
					▨		NR=	<u>7 to 7.5</u> No recovery.=
				0.2=	▨	8=	ML=	<u>7.5 to 8.5</u> Sandy silt; brown; med. density; moderately firm; moist=
					▨			
				0.2=	▨	9=	SM=	<u>8.5 to 9</u> Silty sand; light brown; loose; soft; moist=
					▨		ML	<u>9 to 10</u> Silt; brown; moderatly firm; soft; slightyly plastic; moist=
				0.15=	▨	10=		
							TD=	TD = 10 ft=
						11=		
						12=		
								Sample PRE-S-E11 collected from 2 to 10 ft at 1206.=
						13=		
						14=		
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		

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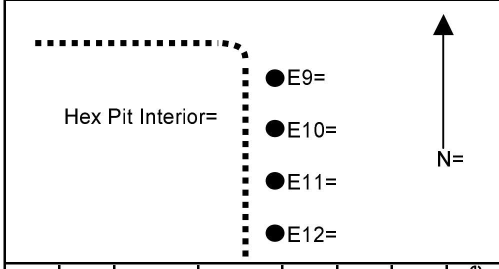

Borehole ID: **E12**
Job Number: G1093-240=
Site: Rocky Mountain Arsenal - Hex Pit=
Drilling Company: ESN - Rocky Mountain; Jason Lauel & Zack Beck=
Drilling Method: Direct push=
Continuous core in 4 ft. X 1.125 in. PETG plastic liners=
Drilling Date(s): 7-17-01=
Logged By: Erika Herreria=

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description=
0=	2=	2=	757=					
				0.1=		1=	SP=	<u>0 to 2</u> Sand; some fines; light brown; med. grained; moderately sorted; loose; med. = stiff; roots; subrounded; "clean" fill.=
2=	7=	3.8=		-0.3=	▨	2=		
					▨			
				0.1=	▨	3=	ML	<u>2 to 4</u> Sandy silt; light brown; soft; loose;=
					▨			
				0.1=	▨	4=		
					▨			
				-0.5=	▨	5=		<u>4 to 6.5:</u> Silty sand; light brown; fine grained; subrounded; very loose; very soft=
					▨			
					▨	6=	SM=	<u>6.5 to 7:</u> Silty sand; dark brown; fine to med. grained; moderately sorted; loose; soft; with rust color nodule and with black color nodules (coal like). Note: Took a picture = of a section of the internal.=
					▨			
7=	10=	2.6=	808=	0.1=	▨	7=		
					▨			
				0.08=	▨	8=		<u>7 to 8.4:</u> Sandy silt; light brown; loose; soft=
					▨			
				0.1=	▨	9=	ML=	
					▨			<u>8.4 to 10:</u> Silt; light brown; loose; soft; slightly plastic; moist=
					▨	10=		
							TD=	TD = 10 ft=
						11=		
						12=		Sample PRE-S-E12 taken at 0819 from 2 to 10 ft.=
						13=		
						14=		
						15=		
						16=		
						17=		
						18=		
						19=		
						20=		

Borehole ID: HVH4
Job Number: G9008-1900500
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Dustin McNeil & Zack Beck
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 10/15/02
Logged By: John Yerton

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0			10:32					0-2 No Recovery
		2/4				1		
				0.26		2		2-4 Fill Material-Silty sand gravel silt mixture, some cobbles, 3.8 ft insulation
								material (yellow), yellowish brown, moist, nonplastic, poorly sorted, loose,
				0.40		3		"clean"
	4			0.50		4		4-6.6 No Recovery
4			10:36					
		2.6/4		0.50		5		
				0.60		6		6.6 - 7.6 Dark fill material (Asphalt base) Brown/Black sand gravel mixture,
								some cobbles, loose coarse gravel
				0.50		7		7.6 - 8.0 Silty sand with gravel, brown color, fine sand mottled with black semi
								crystaline material @ 7-7.4 feet, poorly sorted, moist-dry
	8		10:42			8		8.0-10.0 No Recovery
8			X					
		VOID	X			9		
								10.0-10.6 Silty sand with gravel, brown color, fine sand mottled with black
		2/4		7.20		10		semi-crystalline material
								10.6-12.0 Silty sand with some gravel 10.6-10.10, red in color, 1 inch of
				1.90		11		crystalline "coal like" material, 10.10-11.0, Black in color, Tar material very soft
								11.0-12.0 "Coal-like" material, loose stretched with Tar globules, sand gravel
	12			1.50	VOC	12		mixtures, medium sand, loose, moist, change in color to yellow @ 11.4, sand
12			10:45		XX			gravel mixture, poorly sorted, loose, dry
				1.90		13		12.0-14.0 Sandy silt, black staining throughout, loose, moist, non-plastic
		3/4						
				7.50		14		14.0-15.0 Sandy silt, black staining throughout, loose, moist, non-plastic,
								yellowish brown mottled with black staining (14.6-15.0 wet) otherwise moist,
				12.70		15		soft, loose
								15.0-16.0 Sand gravel silt mixture with coarse gravel, medium to coarse
	16			20.50		16		gravel, medium to coarse sand, brown in color, no apparent staining, medium
TD								dense to dense
						17		
								Note: Composite sample taken 7.6-15.6 ft bgs. VOC sample taken 12.6 ft bgs
						18		total depth=16 ft bgs
						19		
						20		

Tetra Tech EM Inc.

Borehole ID: HVL4
Job Number: G9008-1900500
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Dustin McNeil & Zack Beck
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 10/16/02
Logged By: John DeAngelis

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0	4	3	1046					0-3.5 ft Fill, silty sand, light brown, medium grained with occasional course fragments, light moist, loose
				0.00		1		
				0.00		2		3.5-4.0 ft Insulation debris and traces of asphalt debris (top of waste material) with silty sand fill, grayish brown, miscellaneous flakes and iron oxide staining present.
				0.00		3		
4	8	3.5	1055	0.00		4		
								Slightly clayey (somewhat cohesive) from 4-5 ft bgs, gravel layer present from 5.5-6.0 ft bgs, ?angular fragments ranging from 1 to 10 mm diameter.
				0.00		5		
				0.00		6		6.0-9.0 ft Silty sand, light brown, loose, light moist
				0.00		7		
8	12	3	1105	0.60		8		
					X	VOC		
				0.00		9		9-12.0 ft Silty sand as above, except black stained, (apparent hex staining) dry, loose, fine grained, traces of metal debris, occasional fragments of waste material, tar-like, somewhat friable.
				0.00		10		
				0.00		11		
12	14	2	1111	0.00		12		12.2-14.0 ft Silty sand as above, black staining less prominent and changing to greenish-gray with depth, occasional coarse sand fragments in primarily well sorted fine grained matrix.
				0.00		13		
				0.00		14		TD=14 ft bgs
						15		Collected VOC sample at 8.5 ft bgs; Collected composite sample from 5.5 ft to 13.5 ft bgs, also collected extra volume for field duplicate.
						16		
						17		
						18		
						19		
						20		

Tetra Tech EM Inc.

Borehole ID: HVP4
Job Number: G9008-1900500
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Dustin McNeil & Zack Beck
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 10/15/02
Logged By: John Yerton

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0		3.3/4	1426					0-2.4 Sandy silt, gravel, silt mixture (fill material), Brown in color, loose,
				1.67		1		dry-moist, 2.4 ft insulation matt material
								2.4-2.8 Base asphalt fill material, sandy silt, "clean"
				1.75		2		2.8-3.3 Sandy silt, well sorted, poorly graded, brownish red
								3.3-4.0 No Recovery
				1.80		3		
	4					4		4.0-5.0 Sandy silt, gravel mixture, brown in color, fine-coarse sandy silt,
4		3.4/4	1430	19.80				coarse gravel, loose, dry-moist
				3.40		5		5.0-6.0 Sandy silt, well sorted, poorly graded, brownish in color, medium
								dense, moist 6.0-6.1 Black stained layer (?)
				6.90		6		6.0-6.8 Sandy silt, well sorted, poorly graded, brownish in color, medium
								dense, moist
				6.20		7		6.8-7.8 Sandy silt, well sorted, poorly graded, brownish in color, medium
								dense, moist, with several (Hex) Stained layers and intermittent color changes
	8			6.20		8		6.8-7.0 Red, 7.0-7.3 Dark brownish red, 7.3-7.8 Dark black layer
8		2/4	1434					7.8-8.0 No recovery
				2.50		9		8.0-8.6 Sandy silt, well sorted, poorly graded, brownish in color, medium
								dense, moist, with several (Hex) Stained layers and intermittent color changes
				6.20		10		dark red in color
								8.6-9.3 Sandy silt gravel mixture, "coal-like", Hex 50% substance
				23.30		11		9.3-9.7 "Tar-like" Hex substance, very soft, wet
								9.7-10.0 Sandy silt mottled with Black Tar-like Hex substance, well sorted,
	12		1436	24.50		12		fine sandy silt, loose to medium dense, red/brown in color
12								10-12.0 No Recovery
				27.90		13		12.0-13.0 Sandy silt mottled with black tar-like Hex substance, well sorted,
								fine sandy silt, loose to medium dense, with several color changes:
						14		12.0-12.4 Dark yellow, 12.4-12.8 Dark brown, 12.8-13.0 Redish brown
						15		Total depth 13 ft bgs, Composite sample 4.8-12.8 ft bgs, VOC sample 7.8 ft bgs
	16					16		Notes: Hole recored due to cobble plugged cutting shoe, First offset abandoned
								due to steel plate, Second offset logged.
						17		
						18		
						19		
						20		

Tetra Tech EM Inc.

Borehole ID: HVJ6
Job Number: G9008-1900500
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Dustin McNeil & Zack Beck
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 10/16/02
Logged By: John DeAngelis

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0	4	3	1408					0-3.7 ft Fill, silty sand, light brown, dry, loose, fine-medium grained, well
				X		1		sorted, minimal rock fragments
				BG		2		
				BG		3		3.7ft Insulation debris and traces asphalt (top of waste layer)
								3.7-4.7 ft Silty sand as above, except color is grayish brown and contours
4	8	4	1410	BG		4		medium to coars grained rock fragments, loose, dry
								4.7-7.2 ft Coarse sand, silty, light brown, loose, coarse fragments ranging
				0.26		5		from 2 mm to 5mm.
				BG		6		
				BG		7		7.2-10.6 ft Sharp contact (7.2 ft) silt, buff white, slightly cohesive, moist,
								uniform, traces of Fe Oxide luminations present
8	12	4	1415	BG		8		
				0.80		9		
				BG		10		10.6-11.5 ft Sharp contact @ 10.6-Black waste material (apparently hex)
								silty sand matrix, dry, somewhat consolidated
				BG		11		
								11.5-14.0 ft Silty sand, fine grained, reddish brown, loose, dry, uniform, well
12	14	2	1420	BG		12		sorted.
				0.45		13		
				1.30		14		TD=14 ft bgs
						15		Collected VOC sample at 8.7 ft bgs
								Collected composite sample from 5.7 to 13.7 ft bgs
						16		Collected extra volume for MS/MSD
						17		Note: BG = background level
						18		
						19		
						20		

Tetra Tech EM Inc.

Borehole ID: HVH8
Job Number: G9008-1900500
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Dustin McNeil & Zack Beck
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 10/16/02
Logged By: John DeAngelis

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0	4	1.8	1505					0-2.2 ft No recovery- Large rock fragments slough in top of sampler-1 inch diameter
				X		1		
				X		2		2.2-3.8 ft Fill, silty sand, light brown fine to medium grained, loose, dry
				BG		3		3.8-7.5 ft Silty sand (fill) as above, color is grayish brown, coarse sand present and some gravel up to 0.5 inches diameter; coarse sand lense present from 5.8 to 6.2 ft bgs, underlain by fine grained silty sand (light brown) to 7.5 ft. Distinct Fe Oxide staining and trace of black stained waste (apparent hex @ 7.0 ft bgs)
4	8	3	1507	BG		4		
				BG		5		
				BG		6		
				1.30		7		7.5 ft Abrupt contact
								7.5 - 11.0 ft Silt, buff-white, soft, very fine grained, uniform, trace of saturation (water) noted @ 9.4 ft bgs, traces of FeOxide staining (minor) in seams
8	12	3	1513	0.90		8		
				3.20		9		
				4.40		10		
				20.50		11		11.0 ft Abrupt contact
								11.0-14.0 ft Silty sand, loose, well sorted, uniform, rust-brown from 11 to 11.5 ft bgs, black stained (possibly hex) from 11.5 to 12.4 ft bgs, then rust-brown and reddish brown to 14 ft. Very fine grained, uniform throughout, loose, except slightly cohesive from 13.8 to 14.0 ft bgs.
12	14	2	1520	BG		12		
				BG		13		
				BG		14		TD=14 ft bgs
						15		Collected VOC sample at 8.8 ft bgs
								Collected composite sample from 5.8 to 13.8 ft bgs.
						16		
								Note: BG=Background level
						17		
						18		
						19		
						20		

Borehole ID: HVP8
Job Number: G9008-1900500
Site: Rocky Mountain Arsenal - Hex Pit
Drilling Company: ESN - Rocky Mountain; Dustin McNeil & Zack Beck
Drilling Method: Direct push
Continuous core in 4 ft. X 1.125 in. PETG plastic liners
Drilling Date(s): 10/17/02
Logged By: John Yerton

Sample Top	Sample Bottom	Recovered	Time	FID Reading	Lab Analysis	Depth in Feet	USCS Soil Type	Soil Description
0		3/4	842					0-2 ft Fill material, sand, gravel, silt, light brown mixture, medium dense, dry-
				BG		1		moist, insulation material tarp layer @ 2 ft bgs light?
				BG		2		2.0-2.5 ft Asphalt fill base material
								2.5-3.0 ft Fill base material, sand gravel silt mixture, dark brown, moist-dry
				BG		3		loose, medium dense
								3.0-4.0 ft No Recovery
	4			BG		4		4.0-5.0 ft Sand gravel silt mixture, coarse sand and gravel, medium dense,
4		3/4	846					loose, moist-dry, light brown in color
				BG		5		5.0-6.0 ft Sand with some silt, brown in color, medium dense, loose
				BG		6		6.0-7.0 ft Silty sand (mottled with coal like black hex material @ 6.6 ft), Brown
								in color, grades to reddish brown at 7 ft, medium dense, nonplastic, moist-dry
				2.10	VOC	7		7.0-8.0 ft No Recovery
					XX			
	8	3/4	852	BG		8		8.0-10.0 ft Sand (Hex material intermittant, colors brown, whitish gray, red
8								bands approximately 2 inches in length) Some gravel and coal like hex material
				BG		9		dry, loose, very hard hex pieces.
				BG		10		10.0-12.0 ft Coal like Hex material interbedded with tar-like Hex material, moist
								slightly plastic-plastic soft
				4.30		11		
	12			2.80		12		12.0-13.0 ft Sandy silt saturated with Hex material, moist/sticky, greenish
12		2/2	856					mottled with dark green in color, soft-very soft
				4.10		13		13.0-14.0 ft Sandy silt saturated with moist sticky Hex material, dark reddish
								brown in color, moist, soft-very soft
				3.10		14		
								TD=14 feet
						15		
								VOC samples collected at 7.5 feet
	16					16		Composite samples collected from 4.0-14.0
16								
						17		Notes: BG=background level
						18		
						19		
						20		