

Low Temperature Thermal Treatment (LT³®) Technology

Roy F. Weston, Inc.

Applications Analysis Report

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



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Notice

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Foreword

The Superfund Innovative Technology Evaluation (SITE) program was authorized by the 1986 Superfund Amendments and Reauthorization Act (SARA). The SITE program is a joint effort between the EPA Office of Research and Development (ORD) and the Office of Solid Waste and Emergency Response (OSWER). The purpose of the program is to accelerate the development and use of innovative cleanup technologies applicable to Superfund and other hazardous waste sites. This is accomplished through field technology demonstrations designed to provide performance and cost data on selected technologies.

A field demonstration was conducted under the SITE program to evaluate the Low Temperature Thermal Treatment (LT³) technology. The technology demonstration took place at the Anderson Development Company (ADC) site in Adrian, Michigan. The purpose of the demonstration effort was to obtain information on the performance and cost of the technology and to assess its use at this and other uncontrolled hazardous waste sites. Documentation of the demonstration consists of two reports: (1) a Technology Evaluation Report, which describes field activities and laboratory results, and (2) this Applications Analysis Report, which interprets the demonstration data and discusses the technology's potential applicability.

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E. Timothy Oppelt, Director

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Abstract

This report evaluates the Low Temperature Thermal Treatment (LT³®) system's ability to remove volatile organic compounds (VOC) and semivolatile organic compounds (SVOC) from solid wastes. This evaluation is based on treatment performance and cost data from the Superfund Innovative Technology Evaluation (SITE) demonstration and five other case studies.

The LT³® system thermally desorbs organic compounds from contaminated soil without heating the soil to combustion temperatures. The LT³® system is divided into three treatment areas: soil treatment, emissions control, and condensate treatment. End products include treated soil, fabric filter dust, treated condensate, and treated stack gas. The transportable system is comprised of equipment assembled on three flat-bed trailers.

The LT³® system demonstration was conducted under the SITE program at the Anderson Development Company (ADC) site in Adrian, Michigan. During the demonstration, the LT³® system treated lagoon sludge from the site contaminated with VOCs and SVOCs, primarily 4,4'-methylenebis(2-chloroaniline) (MBOCA). During the development of the LT³® system, Weston conducted bench- and pilot-scale tests and collected treatability data for the following wastes: coal tar, drill cuttings (oil-based mud), leaded and unleaded gasoline, No. 2 diesel fuel, JP4 jet fuel, petroleum hydrocarbons, halogenated and nonhalogenated solvents, VOCs, SVOCs, and polynuclear aromatic hydrocarbons (PAH).

Based on the results of the SITE demonstration and other case studies, the following conclusions can be drawn: (1) the LT³® system can process a wide variety of soils with differing moisture and contaminant concentrations; (2) The LT³® system removes VOCs to below detection limits; (3) The LT³® system generally decreases SVOC concentrations, but some SVOC concentrations may increase, most likely due to chemical transformations during heating; (4) under certain conditions, dioxins and furans may be formed during treatment in the LT³® system and may be distributed in process residuals; and (5) remediation costs, including all activities from site preparation through demobilization, may range from \$373 to \$725 per ton of soil, depending on soil moisture content and regulatory requirements.

The report also discusses the applicability of the LT³® system based on compliance with regulatory requirements, implementability, short-term impact, and long-term effectiveness. In addition, the factors influencing the technology's performance in meeting these criteria are discussed.

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Acronyms, Abbreviations, and Symbols

$\mu\text{g/kg}$	Micrograms per kilogram
$\mu\text{g/L}$	Micrograms per liter
μm	Micron
AC-MBOCA	N-acetyl-MBOCA
ADC	Anderson Development Company
AFB	Air Force Base
ARAR	Applicable or relevant and appropriate requirement
ASTM	American Society of Testing and Materials
BTEX	Benzene, toluene, ethylbenzene, and xylenes
Btu	British thermal units
CAA	Clean Air Act
Canonie	Canonie Environmental Services Corporation
CBR	California bearing ratio
CCJM	C.C. Johnson & Malhotra
CDD	Polychlorinated dibenzo(p)dioxins
CDF	Polychlorinated dibenzofurans
CEM	Continuous emissions monitoring
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cm	Centimeters
CO	Carbon monoxide
CO ₂	Carbon dioxide
DAC-MBOCA	N,N'-diacetyl-MBOCA
DOD	Department of Defense
DRE	Destruction and removal efficiency
EA	Endangerment assessment
EOX	Extractable organic halide
EPA	U.S. Environmental Protection Agency
fpm	Feet per minute
FS	Feasibility study
GC/MS	Gas chromatography/Mass spectroscopy
g	Gram
gpm	Gallons per minute
gr/dscm	Grains per dry standard cubic meter
HCl	Hydrogen chloride
hr	hour
kWh	Kilowatt-hour
lb/hr	Pounds per hour
LC50	Median lethal concentration
LT ³⁰	Low temperature thermal treatment
LDR	Land Disposal Restrictions
MBOCA	4,4'-Methylenebis (2-chloroaniline)
m ² /g	Square meters per gram
mg/kg	Milligrams per kilogram
mg/L	Milligrams per liter
mg/m ³	Milligrams per cubic meter

mg/dscm	Milligrams per dry standard cubic meter
ND	Nondetectable
ng/dscm	Nanogram per dry standard cubic meter
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List
O ₂	Oxygen
O&M	Operation and maintenance
OCDD	Octachloro dibenzo(p)dioxin
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
PAH	Polynuclear aromatic hydrocarbon
PCE	Tetrachloroethene
ppb	Parts per billion
ppbv	Parts per billion by volume
PPE	Personal protection equipment
ppm	Parts per million
ppmv	Parts per million by volume
ppt	Parts per trillion
psi	Pounds per square inch
QA	Quality assurance
QC	Quality control
RCRA	Resource Conservation and Recovery Act
ROD	Record of Decision
RH	Relative humidity
rpm	Revolutions per minute
RREL	Risk Reduction Engineering Laboratory
RI	Remedial investigation
SITE	Superfund Innovative Technology Evaluation
SARA	Superfund Amendments and Reauthorization Act
START	Superfund Technical Assistance Response Team
SVOC	Semivolatile organic compounds
TCE	Trichloroethene
TCDD	Tetrachloro dibenzo(p)dioxin
TCLP	Toxicity characteristic leaching procedure
THC	Total hydrocarbon concentration
TNMHC	Total nonmethane hydrocarbon concentration
TOX	Total organic halides
TOC	Total organic carbon
tons/hr	Tons per hour
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
UST	Underground Storage Tank
VOC	Volatile organic compounds
WESTON	Roy F. Weston, Inc.

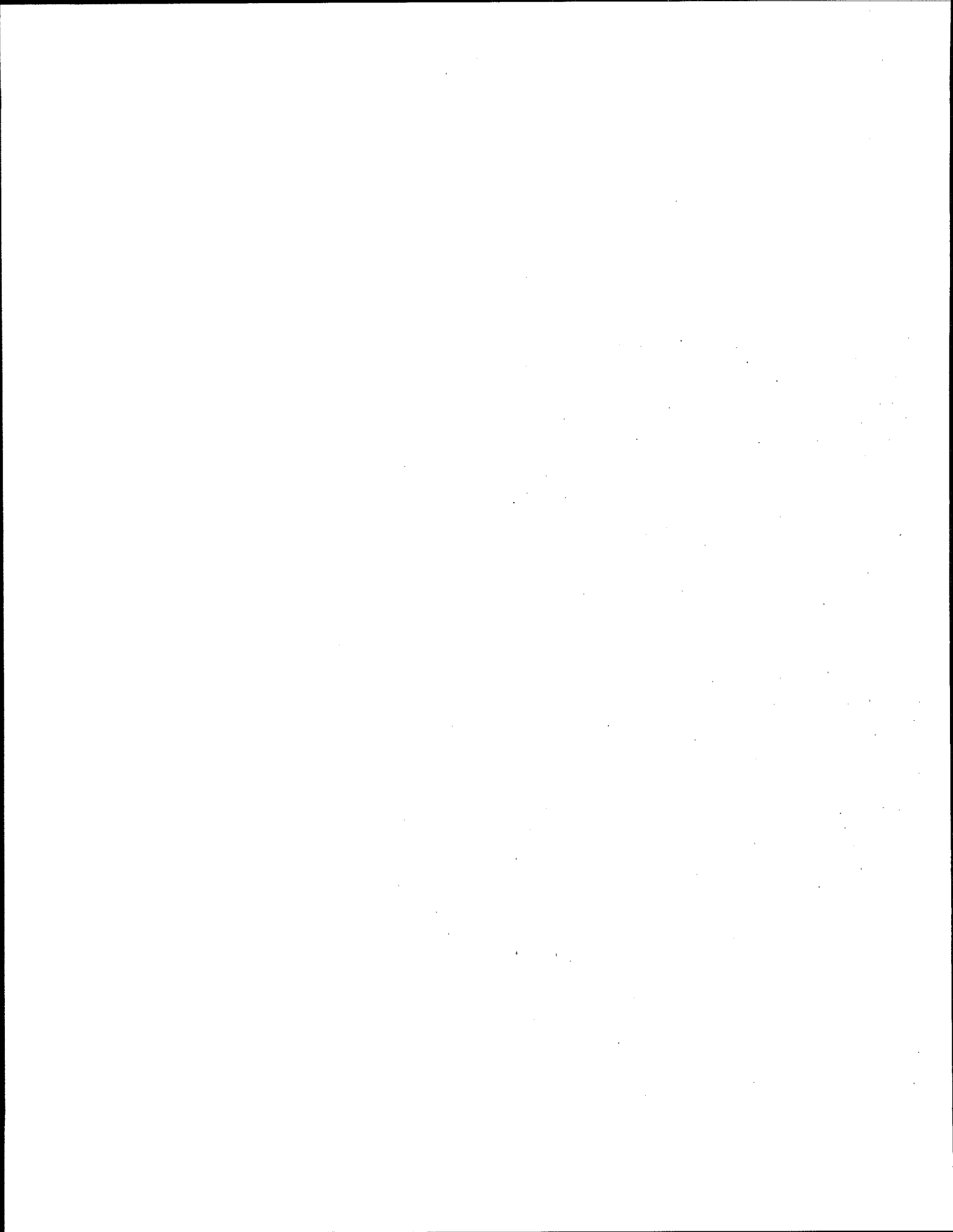
Conversion Factors

	<i>English</i>	<i>x</i>	<i>Factor</i>	<i>=</i>	<i>Metric</i>
Length:	1 inch (in)	x	2.54	=	centimeter (cm)
	1 foot (ft)	x	0.305	=	meter (m)
	1 mile (mi)	x	1.61	=	kilometer (km)
Area:	1 square foot (ft ²)	x	0.0929	=	square meter (m ²)
Volume:	1 gallon (gal)	x	3.78	=	liter (L)
	1 cubic foot (ft ³)	x	0.0283	=	cubic meter (m ³)
Mass:	1 grain (gr)	x	64.8	=	milligram (mg)
	1 pound (lb)	x	0.454	=	kilogram (kg)
	1 ton (t)	x	907	=	kilogram (kg)
Pressure:	1 pound per square inch (psi)	x	0.0703	=	kilogram per square centimeter (kg/cm ²)
Energy:	1 British Thermal Unit (Btu)	x	1.05	=	kilojoule (kJ)
	1 kilowatt hours (kWh)	x	3.60	=	megajoule (MJ)
Temperature:	(°Fahrenheit - 32)	x	0.556	=	°Celsius

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This report was prepared for the EPA SITE Program by Mr. Robert Foster, Dr. Chris Petropoulou, Mr. David Berestka, Mr. Jeffrey Swano, Mr. Tim Oliver, Ms. LouAnn Unger, Ms. Tammara Muhic, Mr. Michael Johnson, and Ms. Carol Adams of PRC Environmental Management, Inc. (PRC). Technical input was provided by Ms. Suzanne Smidt of Versar, Inc.; Mr. Mike Steele of Radian Corporation; and Mr. Alan Todruss of Construction Technology Laboratories. The report was edited by Ms. Regina Bergner and Ms. Shelley Fu of PRC. Peer reviewers were Ms. Michelle Simon, Mr. Richard G. Eilers, and Mr. Mark Meckes of RREL.



Section 1

Executive Summary

This report summarizes the findings of an evaluation for the Low Temperature Thermal Treatment (LT³®) system (U.S. Patent No. 4,738,206 and 5,076,674) developed by Roy F. Weston, Inc. (Weston). This study was conducted under the U.S. Environmental Protection Agency (EPA) Superfund Innovative Technology Evaluation (SITE) program. A series of demonstration tests of the technology were performed by EPA as part of this program. The demonstration tests were conducted in November and December 1991, at the Anderson Development Company (ADC) Superfund site in Adrian, Michigan. The evaluation of the LT³® system was based on the results of the SITE demonstration, subsequent remediation of the ADC Superfund site, and five other case studies performed by Weston for several private and governmental clients.

The LT³® system thermally desorbs organic compounds from contaminated soil without heating the soil to combustion temperatures. The LT³® system is divided into three treatment areas: soil treatment, emissions control, and water treatment. End products include treated soil, fabric filter dust, treated condensate, and treated stack gas. The transportable system can be assembled on three flat-bed trailers.

1.1 Conclusions

Based on the SITE demonstration and other case studies, the following conclusions may be drawn for the applicability of the LT³® system:

- The LT³® system can process a wide variety of soils with differing moisture and contaminant concentrations. Bench-, pilot-, or full-scale LT³® systems have been used to effectively treat soil contaminated with the following wastes: volatile organic compounds (VOC), semivolatile organic compounds (SVOC), coal tar, drill cuttings (oil-based mud), No. 2 diesel fuel, JP4 jet fuel, leaded and unleaded gasoline, petroleum hydrocarbons, halogenated and nonhalogenated solvents, and polynuclear aromatic hydrocarbons (PAH).
- Contaminant removal mechanisms in the LT³® system include thermal transformation and thermal desorption. The LT³® system desorbs and permanently removes VOCs and certain SVOCs from contaminated soil and sludge. Contaminant removal efficiency varies with analyte. In general, VOC removal efficiencies are greater than SVOC removal efficiencies. Also, among SVOCs, compounds with lower boiling points are removed more effectively than compounds with higher boiling points.
- The LT³® system is most appropriate for wastes with a moisture content of about 20 percent. Water can be added to dry wastes to control excessive dusting. To enhance the efficiency of the LT³® system, wastes with free liquids or with a moisture content of greater than 50 percent must be dewatered. Sludge dewatering affects site preparation costs significantly. In addition, chemical additives used as sludge conditioning agents may affect chemical reactions in the system.
- Screening or crushing oversized material (greater than 2 inches in size) or clay shredding may be required for some applications.
- Treatment residuals are not destroyed on site and require off-site treatment. Two types of residuals are generated from the LT³® system: (1) liquid condensate and (2) fabric filter dust. The long-term effectiveness of the LT³® system ultimately depends on the methods used to treat or dispose of these residuals.
- The concentration of contaminants in fabric filter dust is significantly higher than the concentration of contaminants in the treated material. These results indicate that contaminants adsorbed on smaller size particles are not effectively desorbed during treatment.

- Dry, warm weather conditions are ideal for operating the LT³® system. However, the SITE demonstration was conducted in subfreezing temperatures, and remedial activities at the site were conducted in subfreezing or wet weather conditions. Cold and wet weather caused only minor operational problems.
- The economic analysis of the LT³® system's performance compared the costs associated with treating soils containing 20, 45, and 75 percent moisture; the treatment cost per ton of treated material was estimated to be \$373, \$537, and \$725, respectively. Waste-related factors affecting costs include waste volume, waste type, soil moisture content, treatment goals, and regulatory permit requirements. Site-specific features affecting costs include site area, accessibility, availability of utilities, and geographic location. Also, the characteristics of the residual waste affect disposal costs.
- Several operational problems with the LT³® system were observed during shakedown and startup operations, during the SITE demonstration, and during routine remedial activities at the ADC site. Operational problems resulted from mechanical difficulties with the screws, an inadequately sized oil-water separator, oversized debris in the feed material, leaking sweep air gas, excess dust generation from reprocessed material, and leaking pipes in the heat transfer fluid system. All problems were corrected over the course of the remediation.
- Treatability studies are highly recommended before large-scale applications of the technology are considered. Because results may vary greatly with different solid matrices and waste characteristics, the LT³® system's performance is best predicted with preliminary bench-scale testing.

1.2 Results

This section summarizes the results of the LT³® system's performance during the SITE demonstration and during five other case studies. A full-scale LT³® system was demonstrated at the ADC site. A major advantage of demonstrating a full-scale system is that the results achieved are more likely to be duplicated by other systems at similar sites, especially compared to results from smaller, pilot-scale or prototype units. Also, the nature of operational problems encountered during the demonstration should be indicative of problems at other sites.

The LT³® system SITE demonstration was conducted as part of a proof-of-process test for full-scale remediation of the ADC lagoon sludge. The ADC lagoon sludge was

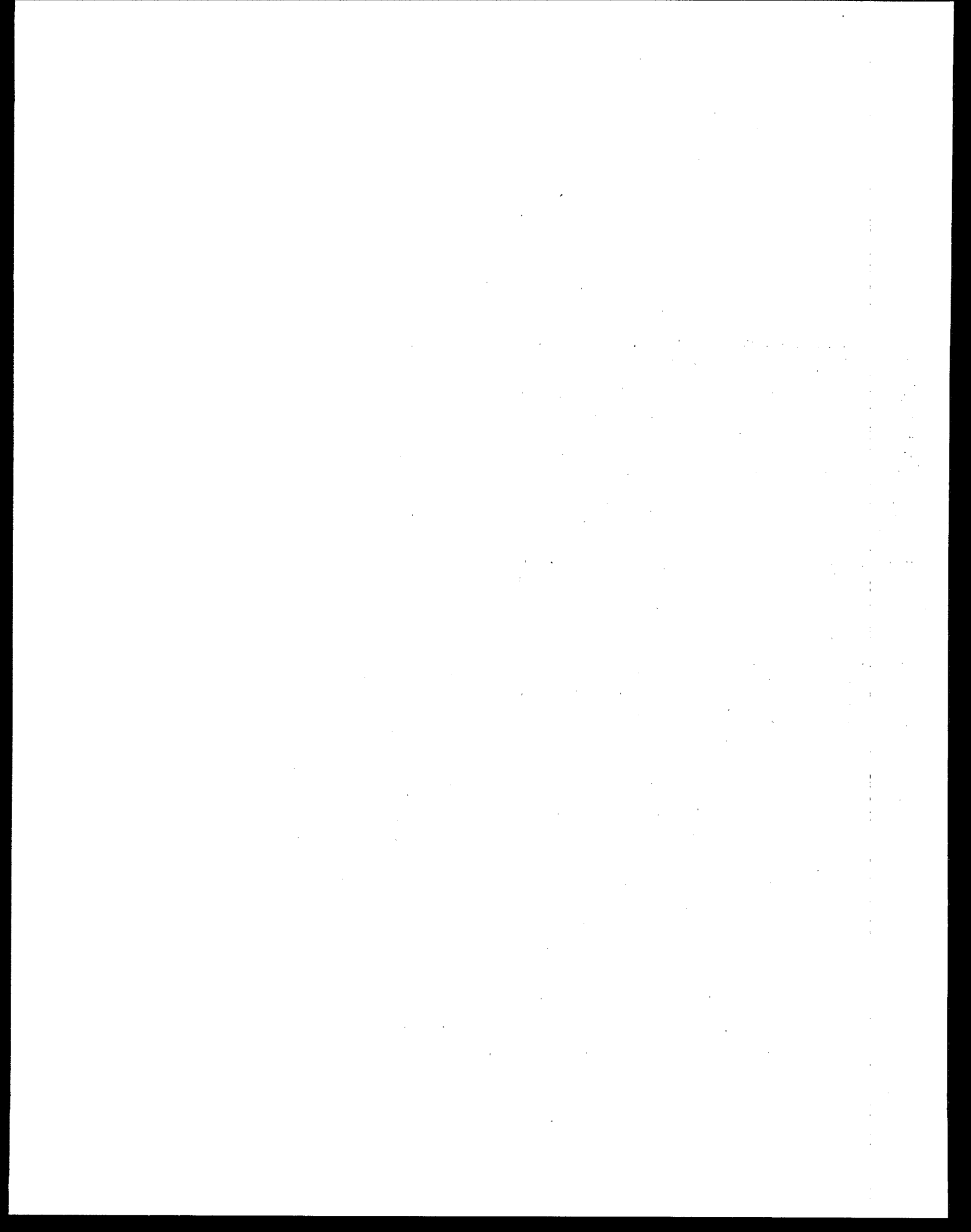
contaminated with VOCs, and SVOCs, primarily 4,4'-methylenebis(2-chloroaniline) (MBOCA). Six 6-hour replicate tests were conducted during the demonstration. During the tests, contaminated sludge was heated to above 500 °F for a residence time of 90 minutes. Sludge was processed at a rate of 2.1 tons per hour (tons/hr); a total of 80 tons of contaminated sludge was treated during the six SITE demonstration tests. Key findings from the SITE demonstration include the following:

- The LT³® system removed most VOCs to below method detection limits [less than 60 micrograms per kilogram ($\mu\text{g/kg}$) for most compounds]. VOC concentrations in untreated sludge ranged from 35 to 25,000 $\mu\text{g/kg}$.
- The LT³® system achieved MBOCA removal efficiencies ranging from 79.82 to 99.34 percent. MBOCA concentrations in untreated sludge ranged from 43.6 to 860 milligrams per kilogram (mg/kg). MBOCA concentration in the treated sludge ranged from 3 to 9.6 mg/kg .
- The LT³® system decreased the concentration of all SVOCs initially present in the sludge with two exceptions. First, phenol concentrations increased after treatment, probably because of chemical transformations during heating. Second, a minor leak of heat transfer fluid, which contains triphenylene, probably resulted in the measured concentrations of chrysene in the treated material; chrysene and triphenylene are indistinguishable under the analytical method used during the demonstration.
- Polychlorinated dibenzo(p)dioxins (CDD) and polychlorinated dibenzofurans (CDF) were formed in the LT³® system and distributed in treated sludge, fabric filter dust, exhaust gas, and liquid condensate. CDD and CDF concentrations in untreated liquid condensate increased with successive test runs. The condensate was treated through a liquid-phase carbon adsorption system before being sent off site for disposal. A vapor-phase carbon column removed CDDs and CDFs from the exhaust gas; removal efficiencies varied with congener, from 20 to 100 percent.
- The total nonmethane hydrocarbon concentration (TNMHC) in stack emissions from the LT³® system increased consistently. During the first test run, TNMHC was 6.7 part per million by volume (ppmv); during the second test run TNMHC was 7.6 ppmv; and during the third run TNMHC was 11 ppmv. The particulate concentration in the stack gas ranged from less than 8.5×10^{-4} to 6.7×10^{-3} grains per dry standard cubic meter (gr/dscm), and the

particulate emissions ranged from less than 1.2×10^{-4} to 9.2×10^{-4} pounds per hour (lb/hr). Chloride concentrations were below the method detection limit, which had an average value of 2.8×10^{-2} milligrams per dry standard cubic meter (mg/dscm). Chloride emissions were less than 6.0×10^{-5} lb/hr.

The five case studies evaluated included two full-scale applications for fuel contaminated sites, a pilot-scale study, and bench-scale studies at Weston's laboratory and at a private client's site. Key findings from other case studies include the following:

- Full-scale remedial activities using the LT³® system were conducted at a confidential site in Springfield, Illinois. About 1,000 cubic yards of soil contaminated with No. 2 fuel oil and gasoline was successfully treated at 350 °F for a 70-minute residence time.
- The U.S. Army Toxic and Hazardous Materials Agency (USATHAMA) selected Tinker Air Force Base (Tinker AFB) in Oklahoma City, Oklahoma, for the demonstration of a full-scale LT³® system. About 3,000 cubic yards of soil contaminated with trichloroethene (TCE), chlorobenzene, and JP4 jet fuel were treated during the demonstration. The LT³® system reduced the concentrations of all target contaminants to below cleanup levels.
- A pilot-scale test of the LT³® system was conducted for USATHAMA at the Letterkenny Army Depot in Chambersburg, Pennsylvania. More than 7.5 tons of soil contaminated with TCE, dichloroethene, tetrachloroethene (PCE), and xylene were treated at 320 °F for a residence time of 60 minutes. The LT³® system achieved removal efficiencies greater than 99.99 percent.
- Weston has conducted several studies using a bench-scale LT³® system at its Environmental Technology Laboratory in Lionville, Pennsylvania. Soils contaminated with VOCs, coal tar, and PAH were treated at temperatures varying from 250 to 450 °F and residence times ranging from 30 to 45 minutes. In general, target VOCs were removed to below detection limits and PAH removal efficiencies were greater than 93 percent.
- Weston also conducted bench-scale studies for a confidential client in Colorado on soil contaminated with chlorinated benzene. Soil was treated at 400 °F for a residence time of 44 minutes, achieving removal efficiencies greater than 99.9 percent.



Section 2

Project Background

This section provides background information on the SITE program, discusses the purpose of this applications analysis report, and describes the LT³® system developed by Weston. The LT³® system was demonstrated under the SITE program at the ADC Superfund site in Adrian, Michigan. For additional information about the SITE program, this technology, and the demonstration site, key contacts are listed at the end of this section.

2.1 Purpose, History, and Goals of the SITE Program

The SITE program is a unique, international effort dedicated to advancing the development, evaluation, and implementation of innovative treatment technologies applicable to hazardous waste sites. The SITE program was established in response to the 1986 Superfund Amendments and Reauthorization Act (SARA), which recognized a need for an alternative or innovative treatment technology research and development program. The SITE program is administered by the EPA Office of Research and Development (ORD) Risk Reduction Engineering Laboratory (RREL).

The SITE program consists of four component programs: (1) the Demonstration Program, (2) the Emerging Technology Program, (3) the Monitoring and Measurement Technologies Program, and (4) the Technology Transfer Program. This document was produced as part of the SITE Demonstration Program. The objective of the Demonstration Program is to provide reliable performance and cost data on innovative technologies so that potential users can assess a technology's suitability for specific site cleanups. To produce useful and reliable data, demonstrations are conducted at hazardous waste sites or under conditions that closely simulate actual wastes and site conditions.

Data collected during a demonstration are used to assess the performance of the technology, the potential need for pretreatment and posttreatment processing of the waste, applicable types of waste and media, potential operating problems, and approximate capital and operating costs.

Demonstration data can also provide insight into a technology's long-term operating and maintenance (O&M) costs and long-term application risks.

Technologies are selected for the SITE Demonstration Program primarily through annual requests for proposals. Proposals are reviewed by ORD staff to determine which technologies have the most promise for use at hazardous waste sites. To be eligible, technologies must be developed to the pilot- or full-scale stage, must be innovative, and must offer some advantage over existing technologies. Mobile technologies are of particular interest.

Cooperative agreements between EPA and the developer determine responsibilities for conducting the demonstration and evaluating the technology. The developer is responsible for demonstrating the technology at the selected site and is expected to pay the costs to transport, operate, and remove its equipment. EPA is responsible for project planning, sampling and analysis, quality assurance (QA), quality control (QC), preparing reports, and disseminating information.

Each SITE demonstration evaluates the performance of a technology in treating a particular waste at the demonstration site. To obtain data with broad applications, EPA and the technology developer try to choose a waste frequently found at other contaminated sites. In many cases, however, waste characteristics at other sites will differ in some way from the waste tested. Thus, a successful demonstration of the technology at one site does not ensure that it will work equally well at other sites. Data obtained from the SITE demonstration may have to be extrapolated and combined with other information about the technology to estimate the operating range and limits of the technology.

2.2 Documentation of the SITE Demonstration Reports

The results of each SITE demonstration are presented in two documents, each with a distinct purpose: (1) the Technology Evaluation Report and (2) the Applications Analysis Report. These documents are described below.

2.2.1 Technology Evaluation Report

The Technology Evaluation Report provides a comprehensive description of the SITE demonstration and its results. It is intended for engineers making a detailed evaluation of the technology's performance for the demonstration site and waste situation. These technical evaluators seek to understand, in detail, the performance of the technology during the demonstration and the advantages, risks, and costs of the technology for a specific application. The report also provides a detailed discussion of QA and QC measures during the demonstration.

2.2.2 Applications Analysis Report

To encourage wider use of technologies demonstrated under the SITE program, the Applications Analysis Report provides information on a technology's costs and its applicability to other sites and wastes. Prior to a SITE demonstration, the amount of data available for an innovative technology may vary widely. Data may range from limited laboratory tests on synthetic wastes to performance data on actual wastes treated in pilot- or full-scale treatment systems. The Applications Analysis Report synthesizes available information on the technology and draws reasonable conclusions about its broad-range applicability. This report is intended for those who are considering a technology for hazardous site cleanups; it represents a critical step in the development and commercialization of a treatment technology.

The principal use of the Applications Analysis Report is to assist in determining whether a technology should be considered further as an option for a particular cleanup situation. The Applications Analysis Report is intended for decision makers responsible for implementing remedial actions. The report discusses advantages, disadvantages, and limitations of the technology. Costs for different applications may be estimated using 12 cost categories that are based on available data from pilot- and full-scale applications. The report also discusses specific factors, such as site and waste characteristics, that may affect performance and cost.

2.3 Technology Description

The LT³® system thermally desorbs organic compounds from contaminated soil without heating the soil to combustion temperatures. The full-scale transportable system can be assembled on three flat-bed trailers. With ancillary and support equipment, the system requires an area of about 5,000 square feet.

2.3.1 Principal Treatment Operations

The LT³® system consists of three main treatment areas: soil treatment, emissions control, and condensate treatment.

A block flow diagram of the system (see Figure 2-1) is described below.

Soil is treated in the LT³® thermal processor. The thermal processor consists of two jacketed troughs, one above the other. Each trough houses four intermeshed, hollow-screw conveyors. A front-end loader transports feed soil (or sludge) to a weigh scale before depositing the material onto a feed conveyor. The feed conveyor discharges the soil into a surge hopper located above the thermal processor. The surge hopper is equipped with level sensors and provides a seal over the thermal processor to minimize air infiltration and contaminant loss. The conveyors move soil across the upper trough of the thermal processor until the soil drops to the lower trough. The soil then travels across the processor and exits at the same end that it entered. Hot oil circulates through the hollow screws and trough jackets and acts as a heat transfer fluid. During treatment in the processor, each hollow-screw conveyor mixes, transports, and heats the contaminated soil. The thermal processor discharges treated soil into a conditioner, where it is sprayed with water to cool it and to minimize fugitive dust emissions. An inclined belt conveys treated soil to a truck or pile.

A burner heats the circulating oil to an operating temperature of 400 to 650 °F (about 100 °F higher than the desired soil treatment temperature). Combustion gases released from the burner are used as sweep gas in the thermal processor. A fan draws sweep gas and desorbed organics from the thermal processor into a fabric filter. Dust collected on the fabric filter may be retreated or drummed for off-site disposal. Exhaust gas from the fabric filter is drawn into an air-cooled condenser to remove most of the water vapor and organics. Exhaust gas is then drawn through a second, refrigerated condenser, which lowers the temperature further and reduces the moisture and organic content of the off-gases. Electric resistance heaters then raise the off-gas temperature back to 70 °F. This temperature optimizes the performance of the vapor-phase, activated carbon column, which is used to remove any remaining organics. At some sites, caustic scrubbers and afterburners have been employed as part of the air pollution control system, but they were not used at the ADC site.

Condensate streams from the air-cooled and refrigerated condensers are typically treated in a three-phase, oil-water separator. The oil-water separator removes light and heavy organic phases from the water phase. The aqueous portion is then treated in the carbon adsorption system to remove any residual organic contaminants; after separation and treatment, the aqueous portion is often used for soil conditioning. The organic phases are disposed of off site. When processing extremely wet materials like sludge, the oil-water separation step may not be appropriate due to the high volume of condensate generated. In such cases, aqueous streams from the first and second condensers may

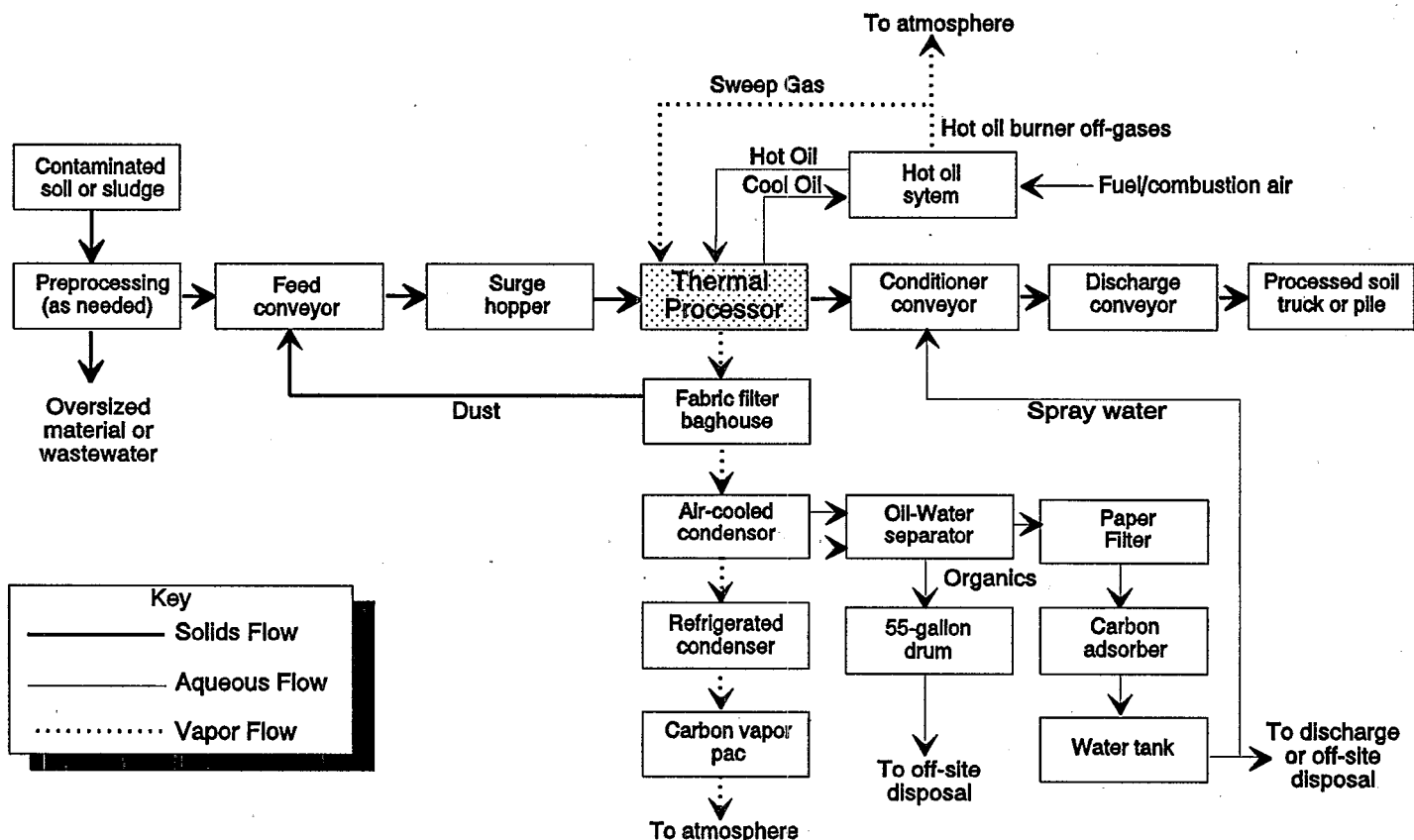


Figure 2-1 LT³® System Block Flow Diagram

be pumped through a disposable filter to remove particulate matter prior to carbon adsorption treatment and off-site disposal.

2.3.2 Innovative Features of the LT³® Technology

The LT³® system is a U.S.-patented process for the treatment of organic contaminants in soils and sludges. Figure 2-2 presents a general layout of the process equipment. The most innovative feature of the system is the use of hollow-screw augers for mixing, conveying, and indirectly heating the feed material. Figure 2-3 presents an internal view of the screw augers. The system's other process treatment units, including the residuals treatment units, are not unique.

2.3.3 LT³® Technology Limitations

Weston reports that the LT³® system can process a wide variety of soils with differing moisture and contaminant concentrations. The developer reports that the technology is best suited for soils with a moisture content of less than 20 percent and VOC concentrations of up to 1 percent. SVOCs

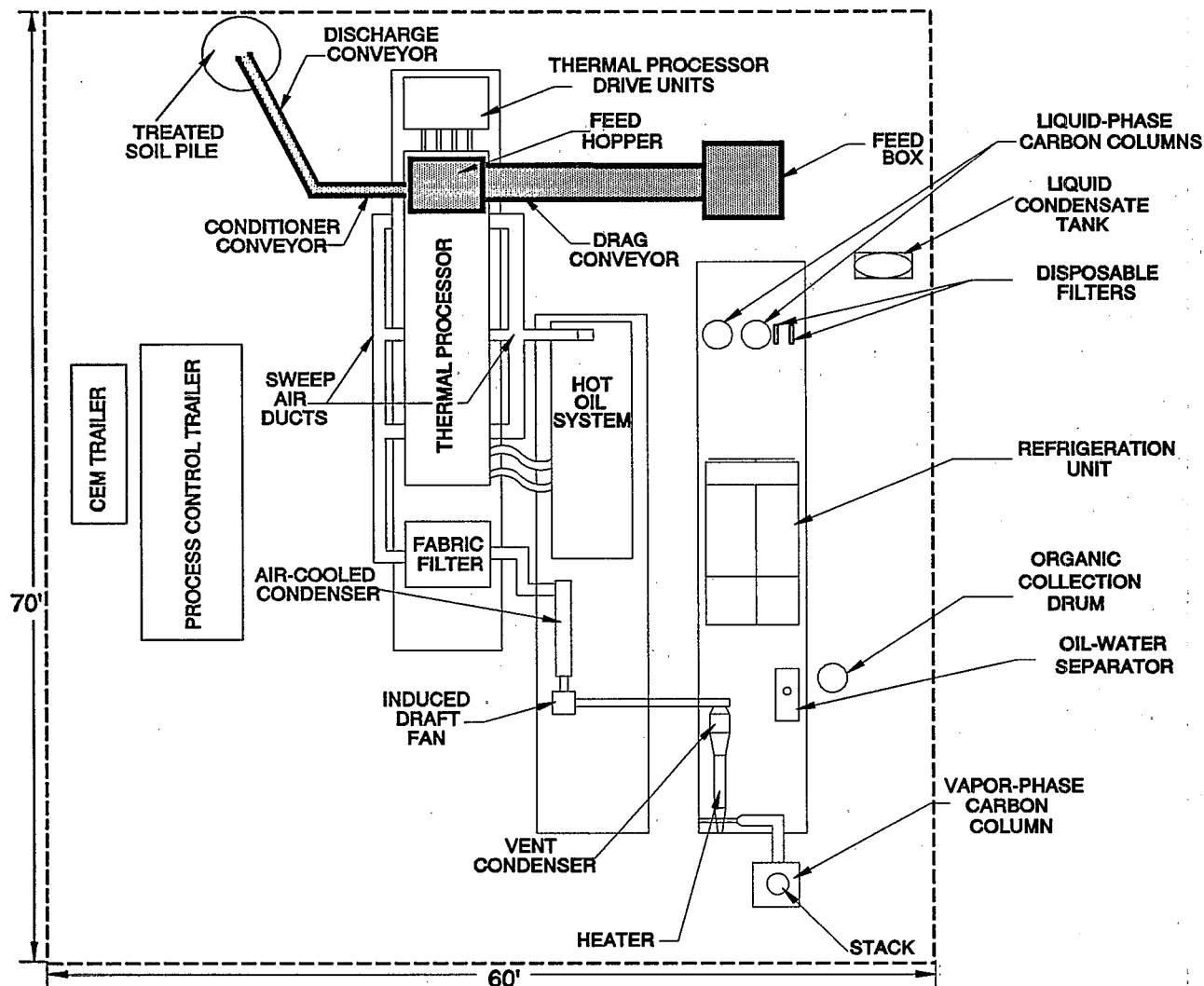
with boiling points greater than 500 °F can also be treated, but treatment must be evaluated based on cleanup objectives. Wastes with a moisture content between 20 and 50 percent can be treated at a reduced capacity basis. Wastes with a moisture content greater than 50 percent need to be dewatered to enable treatment in the LT³® system. Pretreatment screening or crushing of oversized material (greater than 2 inches in size) or clay shredding may also be required for some applications.

2.4 Key Contacts

Additional information on the LT³® technology, the SITE program, and the ADC site can be obtained from the following sources:

1. Vendor concerning the LT³® technology:

Mr. Michael Cosmos
Roy F. Weston, Inc.
1 Weston Way
West Chester, Pennsylvania 19380
(215) 430-7423



NOTE: LOCATIONS ARE APPROXIMATE; SOME ANCILLARY EQUIPMENT NOT SHOWN.

Figure 2-2 LT³ System Layout

2. The EPA Project Manager concerning the SITE Demonstration:

Mr. Paul R. dePercin
U.S. Environmental Protection Agency
Office of Research and Development
Risk Reduction Engineering Laboratory
26 West Martin Luther King Drive
Cincinnati, Ohio 45268
(513) 569-7797

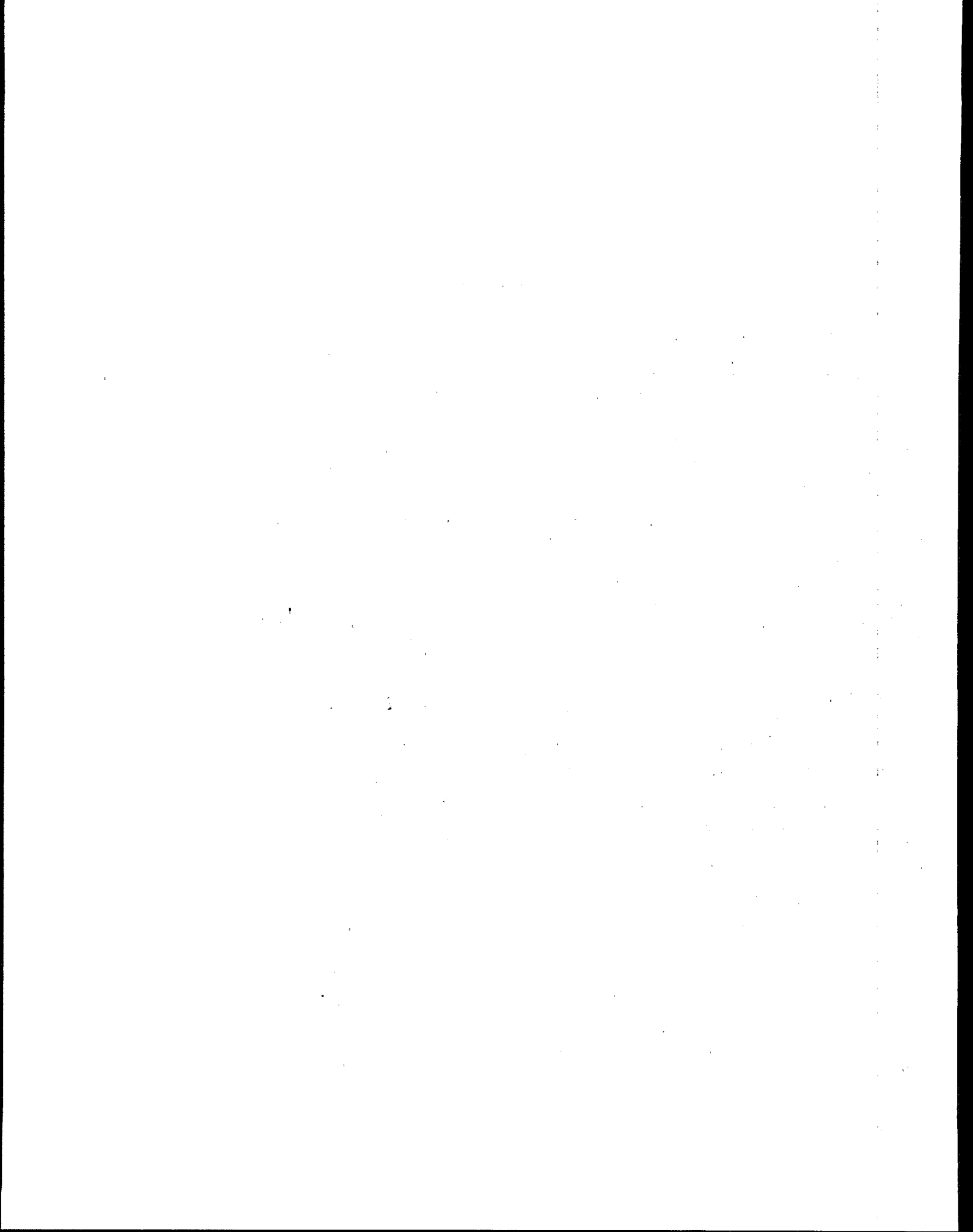
3. Concerning the ADC Site:

Mr. James Hahnenberg
U.S. Environmental Protection Agency
Region 5, Remedial Response Branch
77 W. Jackson Boulevard
Chicago, Illinois 60604
(312) 353-4213

Mr. James Huerta
Anderson Development Company
1415 E. Michigan Street
Adrian, Michigan 49221
(517) 263-2121



Figure 2-3 Internal View of Thermal Processor



Section 3

Technology Applications Analysis

This section addresses the applicability of the LT³® system to treat soils contaminated with VOCs and SVOCs. Weston's claims regarding the applicability and performance of the LT³® system are included in Appendix A.

The applicability of the LT³® system was evaluated in terms of technical criteria used to select remedial actions at Superfund sites. These criteria, which can also be applied to Resource Conservation and Recovery Act (RCRA), underground storage tank (UST), or other corrective action decisions, include the following: (1) treatment effectiveness for toxicity reduction, (2) compliance with regulatory requirements, (3) implementability, (4) short-term impact, and (5) long-term effectiveness. These criteria are discussed below. In addition, factors influencing the technology's performance in meeting these criteria are discussed at the end of this section.

The evaluation presented below is based on results of the LT³® system SITE demonstration, subsequent remediation of the ADC lagoon sludge (see Appendix B), and five other case studies (see Appendix C). The treatment conditions of the SITE demonstration and subsequent remediation of the ADC site, as well as the other case studies are summarized in Table 3-1. The results indicate that the LT³® system can process a wide variety of soils with differing moisture and contaminant concentrations. The LT³® system can effectively treat soil and sludge contaminated with the following wastes: VOCs, SVOCs, coal tar, drill cuttings (oil-based mud), No. 2 diesel fuel, JP4 jet fuel, leaded and unleaded gasoline, petroleum hydrocarbons, halogenated and nonhalogenated solvents, and PAHs.

Although an extensive data base has been generated on the LT³® system's effectiveness in treating various waste types under differing operating conditions, results may vary greatly with different solid matrices and waste characteristics. Therefore, the technology's performance is best predicted with some preliminary bench-scale testing. Contaminants may also behave differently in association with other compounds and with differing soil types, making preliminary testing very important in determining the technology's

applicability to meet treatment objectives. Treatability studies are recommended before considering large-scale applications of the technology. Testing prior to mobilizing the full-scale system may eliminate problems associated with applying the system to compounds and soils for which it is not suited. Preliminary treatability studies may also be able to approximate process rates and cleanup capabilities, allowing an assessment of the LT³® system's applicability for a specific site.

3.1 Treatment Effectiveness for Toxicity Reduction

The LT³® system's effectiveness for toxicity reduction was evaluated based on the following criteria: (1) VOC removal, (2) SVOC removal, (3) formation of thermal transformation by-products, and (4) stack emissions. These criteria are discussed below.

3.1.1 VOC Removal

The LT³® system removes most VOCs present in untreated soil to below method detection limits. Specific compounds treated to date include benzene, toluene, ethylbenzene, and xylenes (BTEX); TCE; and PCE. Removal efficiencies ranged from 96 to greater than 99 percent.

Toluene and PCE were identified as critical VOCs for the LT³® technology SITE demonstration. Toluene was present in untreated sludge at concentrations ranging from 1,000 to 25,000 µg/kg. The concentration of toluene in treated sludge was below the detection limit of 30 µg/kg. The concentration of toluene in fabric filter dust ranged from less than 28 to 410 µg/kg. For most samples analyzed, the concentration of toluene in the condensate was below the detection limit of 5 milligrams per liter (mg/L). However, toluene was detected in the off-gas before the carbon column at concentrations ranging between 8,000 and 10,000 parts per billion by volume (ppbv). Toluene was effectively removed by the vapor-phase activated carbon column.

Table 3-1 Treatment Conditions of the SITE Demonstration and Other Case Studies

Study	Scale	Site	Client	Treatment Conditions	Soil Type	Amount of Soil Treated	Contaminants
SITE Demonstration	Full-Scale	Adrian, Michigan	ADC	Temperature: 500 to 530 °F Residence Time: 90 min Processing Rate: 2.1 tons/hr	Sludge and Clay	80 ^a tons	VOCs, SVOCs, MBOCA
Case Study 1	Full-Scale	Springfield, Illinois	Confidential	Temperature: 350 °F Residence Time: 70 min	NS	1,000 cubic yards	VOCs, SVOCs, PAHs, Gasoline, No. 2 Fuel Oil
Case Study 2	Full-Scale	Tinker AFB, Oklahoma City, Oklahoma	USATHAMA	Processing Rate: 9 tons/hr	Clay	3,000 cubic yards	VOCs, SVOCs, Chlorinated Solvents, JP4 Aviation Fuel
Case Study 3	Pilot-Scale	Letterkenny Army Depot, Chambersburg, Pennsylvania	USATHAMA	Temperature: 320 °F Residence Time: 60 min	NS	7 tons	VOCs
Case Study 4	Bench-Scale	Environmental Technology Laboratory, Lionville, Pennsylvania	Various Industrial and Federal Clients	Temperature: 250 to 450 °F Residence Time: 30 to 50 min	NS	NS	VOCs, SVOCs, PAHs, Coal Tar, Petroleum Hydrocarbons, Oil and Grease, VOCs, SVOCs, PAHs
Case Study 5	Bench-Scale	Colorado Springs, Colorado	Confidential	Temperature: 400 °F Residence Time: 44 min	NS	NS	Chlorinated Benzene

^a = During the SITE demonstration at the ADC site, Weston treated 80 tons of sludge. Through July 1992, over 3,000 tons of sludge were treated during the remediation of the ADC site.

NS = Not Specified

PCE was also present in untreated sludge at concentrations ranging from 690 to 1,900 µg/kg. The concentrations of PCE in treated sludge and fabric filter dust were below the detection limit of 30 µg/kg for most samples analyzed. The concentration of PCE in the condensate was below the detection limit of 5 mg/L. PCE was detected in the off-gas before the carbon unit at concentrations ranging from 210 to 220 ppbv. PCE was effectively removed by the vapor-phase activated carbon column.

Results from the first case study (see Table 3-1) also showed that VOCs were effectively removed from contaminated soil. VOCs of concern included BTEX. Concentrations of these VOCs in untreated soil ranged from 1,000 to 110,000 µg/kg. Concentrations of the VOCs in treated soil ranged from less than 1 to 5.2 µg/kg. Removal

efficiencies greater than 99.48 percent were achieved.

Results from the second case study (see Table 3-1) showed that TCE, the primary VOC of concern, was effectively removed. The concentration of TCE in untreated soil was 6,100 mg/kg. The concentration of TCE in treated soil was below the cleanup goal for the site.

During the third case study (see Table 3-1), untreated soil was contaminated with the following VOCs: dichloroethene, PCE, TCE, and xylene. Concentrations of VOCs in untreated soil ranged from 586,000 to 27,200,000 µg/kg. Concentrations of VOCs in the treated soil ranged from 730 to 1,800 µg/kg. Removal efficiencies greater than 99.88 percent were achieved.

Results from the fourth case study (see Table 3-1) showed that soil contaminated with the following VOCs was treated effectively: methylene chloride; acetone; n-butanol; 1,2-dichloroethane; 1,2-dichloropropane; isopropanol; methanol; and cyclohexane. Concentrations of VOCs in untreated soil ranged from 120 to 120,000 $\mu\text{g}/\text{kg}$. Concentration of VOCs in treated soil ranged 340 to less than 6,000 $\mu\text{g}/\text{kg}$. Removal efficiencies greater than 98.9 percent were achieved.

In addition, during the fourth case study, soil contaminated with ethylbenzene and methylene chloride was effectively treated. The concentration of ethylbenzene before treatment was 78,000 $\mu\text{g}/\text{kg}$, and the concentration of methylene chloride was 14,000 $\mu\text{g}/\text{kg}$. After treatment both contaminants were reduced to below the detection limit of 5 $\mu\text{g}/\text{kg}$.

3.1.2 SVOC Removal

In general, the LT³® system reduces the concentration of SVOCs. Removal efficiencies ranged from 57 to greater than 99 percent. Among SVOCs, compounds with lower boiling points are removed more effectively than compounds with higher boiling points.

MBOCA, 4-methylphenol, and bis(2-ethylhexyl)-phthalate were identified as critical analytes for the LT³® system SITE demonstration. During the SITE demonstration the LT³® system achieved MBOCA removal efficiencies ranging from 79.82 to 99.34 percent. MBOCA concentrations in untreated sludge ranged from 162 to 860 mg/kg. MBOCA concentrations in treated sludge ranged from 3 to 9.6 mg/kg. MBOCA was detected in the condensate at concentrations ranging from 100 to 257 micrograms per liter ($\mu\text{g}/\text{L}$). No MBOCA was detected in the exhaust gas from the refrigerated condenser. The decrease in MBOCA concentration after treatment was accompanied by an increase in the measured concentration of N-acetyl-MBOCA (AC-MBOCA). AC-MBOCA is a known metabolite of MBOCA, indicating that the removal of MBOCA was probably due partially to thermal desorption and partially to the degradation of MBOCA to the AC-MBOCA metabolite. However, the presence of co-eluting compounds may have interfered with the quantitation of AC-MBOCA. The concentration of N,N'-diacetyl-MBOCA (DAC-MBOCA), another metabolite of MBOCA, decreased after treatment in most samples analyzed. The decrease in DAC-MBOCA concentration was probably due either to thermal desorption or to conversion to AC-MBOCA.

The LT³® system also decreased the concentration of other SVOCs initially present in the sludge. 4-Methylphenol and bis(2-ethylhexyl)phthalate were identified as critical analytes for the LT³® system SITE demonstration. The concentrations of 3- and 4-methylphenol ranged from 3,100

to 20,000 $\mu\text{g}/\text{kg}$ in the untreated sludge. After treatment, 3- and 4-methylphenol concentrations ranged from 540 to 4,000 $\mu\text{g}/\text{kg}$, representing removal efficiencies of between 57.0 and 97.4 percent. The concentration of 3- and 4-methylphenol in fabric filter dust ranged from 1,200 to 5,100 $\mu\text{g}/\text{kg}$. Liquid condensate contained 3- and 4-methylphenol at concentrations ranging from 7,900 to 25,000 $\mu\text{g}/\text{L}$. However, no 3- or 4-methylphenol was detected in the exhaust gas exiting the refrigerated condenser.

Bis(2-ethylhexyl)phthalate was present in untreated sludge at concentrations ranging from 1,100 to 7,900 $\mu\text{g}/\text{kg}$. After treatment, the concentration of bis(2-ethylhexyl)phthalate was reduced to below the detection limit, which was less than 820 $\mu\text{g}/\text{kg}$ for most samples. The concentration of bis(2-ethylhexyl)phthalate in fabric filter dust ranged from 650 to 3,600 $\mu\text{g}/\text{kg}$. Because of its high boiling point (723.2 °F), bis(2-ethylhexyl)phthalate is not likely to be desorbed during heating in the LT³® system, because the sludge treatment temperature ranged from only 500 to 530 °F. Therefore, the decreased concentration of bis(2-ethylhexyl)phthalate was probably due to thermal decomposition during heating. The decomposition scenario is supported by the sampling results of the liquid condensate and the exhaust gas from the refrigerated condenser. The concentration of bis(2-ethylhexyl)phthalate in the condensate was below the detection limit of 3,000 $\mu\text{g}/\text{L}$. Similarly, the concentration of bis(2-ethylhexyl)phthalate in the exhaust gas was below the detection limit of 28 ppbv.

Although concentrations of most SVOCs decreased with treatment, the concentration of the following two SVOCs increased with treatment: phenol and chrysene. The increased phenol concentration after treatment is most likely due to chemical transformations during heating, most likely the dehalogenation of 1,2-dichlorobenzene, a reaction that has been reported to take place at elevated temperatures and alkaline pH conditions (Larock, 1989). The dehalogenation scenario is supported by other demonstration results, which also indicate that the extractable organic halide (EOX) concentration in sludge is reduced after treatment, while the concentration of chloride is increased.

During the SITE demonstration, chrysene (or triphenylene), which was not originally present in the untreated sludge, was detected in treated sludge and fabric filter dust. A minor leak of heat transfer fluid, which contains triphenylene, probably caused the apparent increase in chrysene concentration. Triphenylene and chrysene produce indistinguishable responses in the gas chromatography/mass spectroscopy (GC/MS) analytical technique used.

During the fifth case study (see Table 3-1), soil contaminated with SVOCs was also effectively treated. The total concentration of SVOCs in the soil was 530 mg/kg. Of that amount, 523 mg/kg was 1,4-dichlorobenzene; the

remaining portion consisted of other SVOCs. The concentration of 1,4-dichlorobenzene after treatment was 6.25 $\mu\text{g/kg}$, representing a removal efficiency of greater than 99.9 percent.

Soils contaminated with PAHs were treated during the first and fourth case studies. Concentrations of PAHs in untreated soil ranged from 890 to 580,000 $\mu\text{g/kg}$. The concentration of PAHs in treated soil ranged from less than 330 to 14,000 $\mu\text{g/kg}$. Removal efficiencies ranged from 62.9 to greater than 99 percent.

3.1.3 Formation of Thermal Transformation By-Products

Chemical characteristics of contaminants in the waste feed determine the types of by-products formed during heat treatment. Under certain conditions, dioxins and furans may form in the LT³ system as thermal transformation by-products. The following specific treatment conditions tend to encourage the formation of dioxins and furans: (1) the presence of chemical precursors, (2) alkaline pH, (3) high concentrations of free chloride, (4) temperatures greater than 500 °F, and (5) long residence times. For some applications, such as the SITE demonstration, the LT³ system will operate under these conditions.

The following groups of compounds are associated with the formation of dioxins (EPA, 1980):

- Class I - Polyhalogenated Phenols
- Class II - Ortho-Halophenols and Ortho-Halophenyl Ethers
- Class III.- Aromatic Compounds and Ortho-Substituted Aromatic Compounds

Analytical results of the SITE demonstration showed that the following potential dioxin precursors were present in untreated and treated sludge samples: phenol; 1,2-dichlorobenzene; 4-chloroaniline; 4,6-dinitro-2-methylphenol; 2,4-dibromophenol; o-chloroaniline; aniline; 2-chlorophenol; 4-bromophenol; and 2,4-dibromophenol. Alkaline pH resulted from the addition of lime; high concentrations of free chloride resulted from the addition of ferric chloride. Both chemicals were added to the sludge prior to LT³ processing as conditioning agents before sludge dewatering. Treatment temperatures ranged from 500 to 530 °F.

Polychlorinated dibenzo(p)dioxins (CDD) and polychlorinated dibenzofurans (CDF) were formed in the LT³ system and distributed in fabric filter dust, treated sludge, condensate, and exhaust gas. Fabric filter dust consistently contained higher concentrations of CDD and CDF than treated sludge, and the dust was the only solid matrix containing measurable amounts of 2,3,7,8-tetrachloro dibenzo(p)dioxin (2,3,7,8-TCDD). The average concentrations of CDD and CDF in treated sludge ranged

from 0.066 to 2.42 $\mu\text{g/kg}$. Octachloro dibenzo(p)dioxin (OCDD) was the only congener found in one sample of untreated sludge. OCDD was detected at 0.63 parts per billion (ppb), near the detection limit of 0.54 ppb. CDD and CDF concentrations in condensate increased with successive test runs. The condensate was treated through a liquid-phase carbon adsorption system before being sent off site for disposal. The vapor-phase carbon column removed CDDs and CDFs from the exhaust gas; removal efficiencies varied with congener, from 20 to 100 percent.

3.1.4 Stack Emissions

Stack gas emitted from the LT³ system generally contains low concentrations of chloride and particulate matter. However, the total hydrocarbon concentration (THC) in the stack gas should be continuously monitored to determine when the vapor-phase activated carbon unit should be replaced. Contaminant breakthrough should be monitored to prevent emissions of VOCs and any thermal transformation by-products.

During the SITE demonstration and subsequent remediation at the ADC site, THC was monitored through a continuous emission monitoring (CEM) system operating as part of the LT³ system. The CEM system recorded THC values as high as 100 ppmv. To control emissions, Weston replaced the vapor-phase carbon adsorption column regularly.

During the SITE demonstration (see Table 3-1), the TNMHC in stack gas was determined. TNMHC includes both VOCs and SVOCs. VOC emissions from the stack were predominately composed of propylene and chloromethane. SVOC stack emissions did not contain any predominant contaminants, and testing indicated that all compounds were present in concentrations at or below instrument detection limits. TNMHC in stack emissions from the LT³ system increased consistently. During the first test run, TNMHC was 6.7 ppmv; during the second test run, TNMHC was 7.6 ppmv; and during the third run TNMHC was 11 ppmv. Because a new vapor-phase activated carbon column was used during the SITE demonstration, the results suggest that breakthrough occurred after a relatively short period of time.

The particulate concentration in the stack gas ranged from less than 8.5×10^{-4} to 6.7×10^{-3} gr/dscm, and particulate emissions ranged from less than 1.2×10^{-4} to 9.2×10^{-4} lb/hr. Chloride concentrations were below the method detection limit, which had an average value of 2.8×10^{-2} mg/dscm; chloride emissions were less than 6.0×10^{-5} lb/hr.

During the SITE demonstration and subsequent remediation at the ADC site, fugitive dust emissions from the treated sludge pile area were occasionally observed. Dust levels ranged from 0.16 to 0.99 milligrams per cubic

meter (mg/m^3) downwind of the treated sludge pile and inside the control trailer near the treated sludge pile. Fugitive dust concentrations were higher than the action level of $0.15 \text{ mg}/\text{m}^3$.

During the first case study (see Table 3-1), the following specific air emission limitations were met: (1) carbon monoxide (CO) less than 100 ppmv, (2) THC less than 100 ppmv, and (3) no visible dust emissions.

During the third case study (see Table 3-1), an afterburner was used as part of the emissions control system. No VOCs were detected in the stack, and stack emissions were in compliance with federal and state regulations for hydrogen chloride (HCl), CO, and particulates.

3.2 Compliance with Regulatory Requirements

This subsection discusses specific environmental regulations pertinent to the operation of the LT³® system, including the transport, treatment, storage, and disposal of wastes and treatment residuals. Applicable or relevant and appropriate requirements (ARAR) include the following: (1) the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); (2) the Resource Conservation and Recovery Act (RCRA); (3) the Clean Air Act (CAA); and (4) the Occupational Safety and Health Administration (OSHA). These four general ARARs are discussed below; specific ARARs must be identified for each site.

3.2.1 Comprehensive Environmental Response, Compensation, and Liability Act

CERCLA, as amended by SARA, provides for federal authority to respond to releases of hazardous substances, pollutants, or contaminants to air, water, and land. Section 121 of SARA provides cleanup standards and requires that selected remedies be cost-effective and protective of human health and the environment. The federal cleanup standards of SARA prefer highly reliable remedial actions that provide long-term protection. Preferred remedial actions permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances, pollutants, or contaminants. The LT³® system permanently reduces the toxicity of the feed wastes; a substantially reduced volume of residuals may require additional treatment or long-term management.

Federal cleanup standards also require that remedies selected at Superfund sites comply with federal and state ARARs. ARARs for a remedial action may be waived under six conditions: (1) the action is an interim measure, and the ARAR will be met at completion; (2) compliance with the ARAR would pose a greater risk to health and the environment than noncompliance; (3) it is technically impracticable to meet the ARAR; (4) the standard of performance of an ARAR can be met by an equivalent

method; (5) a state ARAR has not been consistently applied elsewhere; and (6) ARAR compliance would not provide a balance between the protection achieved at a particular site and demands on the Superfund for other sites. These waiver options apply only to Superfund actions taken on site, and justification for the waiver must be clearly demonstrated (EPA, 1988).

The ADC site was being remediated under CERCLA authority. Two significant ARARs were considered: state air pollution regulations and state ground-water protection and health risk standards. At a Superfund site, only the substantive requirements of an air pollution discharge permit must be met through appropriate pollution control. In most cases, the site manager will obtain a permit for the system. With the appropriate use of air pollution control equipment, such as vapor-phase carbon adsorption units to remove uncondensed toxic organics, the LT³® system can meet state requirements. The LT³® system cannot, however, meet ground-water protection standards for metals, because metals are not removed from soils during treatment. Pretreatment, posttreatment, or off-site disposal of treated material at a Subtitle D landfill may be required if the CERCLA substances are contaminated with metals.

3.2.2 Resource Conservation and Recovery Act

RCRA regulations define hazardous wastes and regulate their transport, treatment, storage, and disposal. Wastes defined as hazardous under RCRA include characteristic and listed wastes. Criteria for identifying characteristic hazardous wastes are included in 40 CFR Part 261 Subpart C. Listed wastes from nonspecific and specific industrial sources, off-specification products, spill cleanups, and other industrial sources are itemized in 40 CFR Part 261 Subpart D.

Residual wastes from the LT³® system include both liquid and solid wastes that may be hazardous under RCRA. Operation of the LT³® system generates the following wastes:

- Fabric filter dust -- Contaminants may adsorb on fine particles, thus precluding retreatment.
- Condensate organics -- Organic contaminants are generally condensed and then prepared for off-site disposal.
- Condenser water -- If oil-water separation or other suitable on-site treatment is not practical, discharge or off-site disposal may be possible.
- Condenser water filters -- Disposable filters contain solid-phase contaminants.
- Activated carbon -- Activated carbon units must be disposed of as waste if regeneration is not possible.

- Personal protection equipment (PPE) -- Disposable PPE is generally incinerated or landfilled.

Under both CERCLA and RCRA, treatment residuals generated by the LT³® system are subject to land disposal restrictions (LDR). Dioxins and furans may be present in low concentrations in treatment residuals from the LT³® system and other thermal desorption systems. Under 40 CFR Section 268.31, F020 to F023 and F026 to F028, dioxin-containing wastes are prohibited from land disposal unless the treatment standard of 1 part per billion (ppb) for each dioxin or furan isomer is met. Fabric filter dust generated during the SITE demonstration exceeded this value for some isomers, but concentrations of the 2,3,7,8-TCDD congener, which is considered the most toxic, were less than 1 ppb.

Requirements for corrective action at RCRA-regulated facilities are provided in 40 CFR Part 264, Subpart F (promulgated) and Subpart S (proposed). These subparts also generally apply to remediation at Superfund sites. Subparts F and S include requirements for initiating and conducting RCRA corrective actions, remediating ground water, and ensuring that corrective actions comply with other environmental regulations. Subpart S also details conditions under which particular RCRA requirements may be waived for temporary treatment units operating at corrective action sites. Thus, RCRA mandates requirements similar to CERCLA, and as proposed, allows treatment units such as the LT³® system to operate without full permits.

3.2.3 Clean Air Act

The CAA requires that treatment, storage, and disposal facilities comply with primary and secondary ambient air quality standards. To monitor gas emissions, the LT³® system includes CEM at the discharge stack for CO, carbon dioxide (CO₂), oxygen (O₂), and THC. A state air pollution permit is required, except at CERCLA sites where only the substantive requirements of a permit must be addressed. In addition to CEM parameters, permit limits may be established for total suspended particulates, acid gases, toxic organics such as dioxins and furans, and stack height. The LT³® off-gas treatment system can be modified to include an afterburner or caustic scrubber to meet site-specific requirements.

3.2.4 Occupational Safety and Health Administration

CERCLA response actions and RCRA corrective actions must be performed in accordance with OSHA requirements detailed in 29 CFR Parts 1900 through 1926, especially Part 1910.120, which provides for the health and safety of workers at hazardous wastes sites. On-site construction activities at Superfund or RCRA corrective action sites must be performed in accordance with Part 1926 of OSHA, which provides safety and health regulations for construction sites.

3.3 Implementability

The LT³® system implementation includes mobilization, O&M requirements, reliability, personnel requirements, and demobilization. These aspects of implementation are discussed below. In general, the system is easy to set up and operate. However, waste feed characteristics can impact system reliability if the feed is not adequately prepared.

3.3.1 Mobilization

The first step for the implementation of the LT³® system is equipment mobilization. Site characteristics are important factors to be considered prior to the mobilization of the LT³® system. These characteristics include site area, site preparation, and site access.

Site Area

Weston has developed three different thermal processors, each of a different size and capability. The bench-scale LT³® unit with two 3-foot screws was initially used to evaluate the treatment concept. This unit led to a pilot-scale unit with two 10-foot screws, which was used in initial field tests. Finally, the full-scale production unit was built with eight 20-foot screws. This full-scale unit was used during the SITE demonstration. The mobile unit is comprised of equipment assembled on three flat-bed trailers, with ancillary and support equipment on another three trailers. The entire system requires a relatively flat area of about 5,000 square feet.

Site Preparation

Site preparation is typically needed prior to operating the LT³® system. For the SITE demonstration the following site preparation was needed:

- Placement of gravel in areas where the LT³® system was to be located; gravel was needed to maintain a roughly consistent grade across the processing area.
- Placement of supports, such as steel plates, wood, concrete blocks, and so on in areas where the heaviest equipment would be situated. Support material should be placed below the tires and drop legs to prevent equipment from leaning or sliding in soft soil.
- Placement of gravel in areas of expected heavy vehicular traffic, as necessary.
- Construction of earthen ramps, as necessary, to provide access for excavation and transportation equipment.

- Establishment of health and safety zones to accommodate both on-site operating and off-site support personnel.

Site Access

Site access requirements for the LT³® equipment are minimal. The site must be accessible to trailer trucks delivering the LT³® equipment, and the bed of the access road must be able to support these vehicles. Because the LT³® unit trailer is oversized, some highway restrictions may apply. State and local authorities should be contacted for specific requirements and restructure.

3.3.2 Operations and Maintenance Requirements

O&M requirements for the LT³® system include general utility services as well as services and supplies. These requirements are discussed below.

Utilities

Operating the LT³® system requires the following utilities:

- **Electrical Power** -- The LT³® system requires 460-volt, three-phase, 600-ampere electrical service. Transformers in the LT³® system reduce the electrical service to 240-volt, three-phase and 120-volt, single-phase service to operate the CEM system and control circuits, respectively.
- **Diesel Fuel** -- Diesel fuel for heavy equipment, supplied by a tank-mounted pickup truck may be purchased from a nearby retailer.
- **Fuel** -- Natural gas at a pressure of 15 pounds per square inch (psi) is required for the burner that heats the heating fluid. The LT³® system's total maximum natural gas consumption is 7.2 million British thermal units per hour (Btu/hr). Propane can also be used as an alternative fuel.
- **Process Water** -- Process water is primarily needed for quenching treated material and for decontamination purposes. Water may be supplied by an existing on-site water distribution system. In many applications, treated condensate may be used for this purpose.

Services and Supplies

A number of readily obtainable services and supplies are required to operate the LT³® system. Major services needed for remedial activities may include (1) heavy equipment rigging, (2) sludge dewatering, (3) regular vacuum

cleaning of the LT³® system off-gas ducts, and (4) laboratory analyses to monitor the system's performance.

During the SITE demonstration and ADC site remediation, subcontractors or off-site facilities furnished the major services required by the remedial activities. Weston hired a national hazardous waste services subcontractor to dewater the sludge using a filter press. Weston hired local industrial services subcontractors to set up the unit and to vacuum ducts that carry off-gas and dust from the thermal unit to the fabric filter. When the system operated 24 hours per day, vacuuming was required about once a month. To monitor the performance of the LT³® system, samples were collected every 12 hours and sent to an off-site laboratory for analysis.

Supplies required for the remedial activities included (1) lime and ferric chloride stabilizing agents, (2) heat transfer fluid, (3) absorbing cloth and oil-dry material, (4) diesel fuel, (5) plastic sheeting, (6) steel drums, (7) fiber drums, (8) vapor-phase carbon adsorption columns, (9) paper filters, and (10) liquid-phase carbon adsorption columns. These supplies are discussed below.

At the ADC site, lime and ferric chloride were added to the untreated sludge before dewatering as conditioning agents at a rate of 0.1 pound of each chemical per gallon of raw sludge. Both chemicals were added directly to the mixing tank from 50-pound paper bags.

The heating fluid system has a capacity of about 1,000 gallons. At the beginning of LT³® operations, the heating fluid tank is filled with heating fluid; no additional heating fluid is normally needed for further operation of the system. However, heat transfer fluid is occasionally added to the LT³® system to replace heating fluid lost from accidental leaks. Absorbing cloth and oil-dry material were occasionally applied to the ground beneath the heating fluid system to contain accidental spills of the heating fluid.

Heavy equipment operation requires about 35 gallons of diesel fuel per day. Diesel fuel was supplied every week by a local retailer and stored on site in an aboveground storage tank.

A 20-foot by 20-foot plastic sheet was used to cover the pile of treated sludge produced every 12 hours. In addition, two 55-gallon steel drums are needed every 12 hours to collect and store fabric filter dust, and one 55-gallon fiber drum is needed each shift to store used PPE.

During the ADC site remediation, one vapor-phase carbon adsorption column was replaced every 5 to 10 days of LT³® system operation. The frequency with which the vapor-phase carbon adsorption units need to be changed depends on site-specific factors and contaminant concentrations.

The condensate treatment system at the ADC site used two paper filters with a nominal pore size of 50 micron (μm). The filters operated in series to remove particulate matter. Filters were changed after every 12 hours of system operation. Two liquid-phase carbon adsorption columns were used in series to treat liquid condensate exiting the paper filters. Both liquid-phase carbon columns were replaced about every 2 months of operation.

3.3.3 Reliability

The LT³® system may be subject to several operational problems. This section summarizes operational problems observed during (1) shakedown and startup operations, (2) the SITE demonstration, and (3) remedial activities at the ADC site. Operational problems resulted from mechanical difficulties with the screws, a malfunctioning oil-water separator, oversized debris in the feed material, leaking sweep air gas, excess dust generation from reprocessed sludge, and leaking pipes in the heat transfer fluid system. Operational problems with the LT³® system resulted in an on-line efficiency of about 70 percent. These problems are discussed below.

Startup operations at the ADC site lasted about 2 weeks, largely because of troubleshooting associated with the screws and the heating fluid system. Before the LT³® system arrived at the ADC site, the screws had been resurfaced to prevent heating fluid from leaking during processing. The screws were filled with water to check for leaks. However, after the leak check was completed, Weston estimated that about 400 gallons of water remained in the screws. When hot heating fluid passed through the screws, this water vaporized, causing a potentially dangerous pressure buildup in the system. To avoid this potential problem, the system was drained and filled with new heating fluid. Several days of operation were needed to evaporate the residual water, which was released through pressure control valves.

Another operational problem during shakedown was associated with the rotational speed of the screws. The residence time required to achieve proper treatment was approximately 90 minutes. However, the LT³® system was equipped with motor drives that could not provide a residence time longer than about 70 minutes. To rectify this problem, Weston replaced the motor drives with units that were capable of sustaining a longer residence time.

The LT³® system includes a three-phase oil-water separator and a liquid-phase carbon adsorption unit for treating liquid streams exiting the air-cooled and refrigerated condensers. However, the oil-water separator did not function properly during shakedown operations at the ADC site because of the unexpectedly large volume of condensate produced. The liquid stream flowed out of the air-cooled condenser at a rate of about 2 gallons per minute (gpm), and the liquid stream exited the refrigerated condenser at a

rate of about 0.6 gpm. Both liquids were routed into a holding tank and were treated through a paper filtration unit prior to the carbon adsorption system.

The most severe and common operational problems during the ADC site remediation resulted from large rocks or oversized debris in the feed sludge. On several occasions, large rocks became wedged in the screw conveyors, resulting in several days of downtime. In two instances, the gear box broke when rocks became wedged between screws. On both occasions, machining new parts and reinstalling the gearbox took about 11 days. On another occasion, a rock in the feed sludge broke the coupling that connects the screws to the gearbox. Machining new parts and repairing the system required about 15 days of downtime.

In each case, before repairs could begin, the LT³® system had to be shut down and allowed to cool. After about 12 hours of cooling, Weston personnel could enter the LT³® system's thermal processor to remove the remaining sludge and locate the obstruction in the screws. This operation requires a confined space entry permit. In some cases, the jammed rock had to be chipped out using a pneumatic hammer.

On several other occasions when the screws became jammed, downtime was avoided by repeatedly reversing the screws' rotation until the obstructive rock worked free. On these occasions, Weston personnel cleared the system by manipulating it from the control room, eliminating any need for a confined space entry.

Following repeated shut downs due to jammed screws, Weston rented a diesel-powered shaker screen. Initially, a screen with 2.5-inch openings successfully removed oversized material from the feed. However, additional downtime resulted when a 2-inch-diameter rock jammed the screws. To ensure that the LT³® system would continue operating with no downtime, Weston installed a screen with 1.25-inch openings below the screen with 2.5-inch openings. The two screens successfully prevented oversized material from jamming the screws, however, it increased screening time for the wet, clay material at the ADC site.

Several operational changes could minimize or prevent downtime caused by rocks in the feed. First, screening the feed with the shaker screen proved to be a successful, but not foolproof, method of keeping the screws free of obstructions. Failure of the gearbox and couplings could be avoided by replacing the steel pin that connects the screw couplings to the gearbox couplings. If the steel pin were replaced with a pin of weaker material, the expendable pin would break before more expensive and intricate parts of the system failed. Keeping a ready supply of spare parts and their specifications could also minimize replacement time.

Another operational problem was associated with sweep air leaking from the LT^{3®} system feed hopper. Sweep air is held in the LT^{3®} system by sludge in the feed hopper. As sludge was drawn in to the LT^{3®} system, gaps formed in the feed flow in the hopper, allowing sweep air to escape. Sweep air leaked approximately once every 3 hours of operation. Weston rectified the situation in less than 5 minutes by adding more feed and manually poking the feed with a shovel to make the feed flow more uniform.

Other operational problems occurred when treated sludge was reprocessed to meet MBOCA cleanup goals. Treated sludge had a low moisture content and a large amount of small particles. When it was reprocessed, large amounts of dust were picked up by the sweep air, clogging the sweep air ducts. The ducts had to be cleaned out periodically, resulting in several 1-hour periods of downtime.

During remedial activities at the ADC site, heating fluid leaked from a valve in the return line running from the LT^{3®} system to the heating system. To repair the leak, the heating system's burner was turned off, and the leaking pipe was isolated. Heating fluid contained in the leaking part of the pipe was then drained into a drum. After the valve was replaced, the heating fluid no longer leaked. Operations began again after about 5 hours of downtime. Only about 10 to 20 gallons of heating fluid was lost due to the leak, a relatively small amount compared to the 1,000-gallon capacity of the heating fluid system. The heating fluid discharged was not reused; it was kept on site for future disposal.

3.3.4 Personnel Requirements

Operation of the LT^{3®} system requires six people. This number includes a field project manager, an O&M supervisor, a site safety officer, and three equipment operators. Two equipment operators supply a constant feed of untreated sludge, one operating a front-end loader while the other inspects the feed traveling up the feed conveyor. These two persons are also responsible for ensuring a steady flow from the feed hopper into the LT^{3®} system. The other operator performs general site activities, including moving treated waste. For sludge dewatering, feed screening, or under special circumstances such as ambient air sampling, additional personnel are required on site.

3.3.5 Demobilization

After the SITE demonstration, the LT^{3®} system remained on site to perform remedial activities at the ADC site. Therefore, equipment demobilization was not part of the SITE demonstration. This section summarizes typical demobilization activities, such as those planned by Weston at the completion of the remedial activities at the ADC site.

Demobilization includes removal of the LT^{3®} system and the trailer containing the control room and office. Decontamination of the exterior of the LT^{3®} system trailers and ductwork and all excavation and material handling equipment will be conducted using a high-pressure spray washer in the decontamination area. The interior of the LT^{3®} processor will be decontaminated by operating the heat processor for several hours at the maximum operating temperature to remove remaining contaminants. Other demobilization activities include the removal and off-site disposal of all plastic liners from the material staging area. Liners will be decontaminated with high-pressure water and detergent, if practical.

All decontamination water will be treated on site using granular activated carbon. Spent activated carbon units will be returned to the supplier for regeneration. Disposable PPE will be collected in drums, manifested, and sent off site for disposal.

3.4 Short-Term Impact

The potential short-term impact of the LT^{3®} system application includes worker safety and potential community exposures. Personnel operating the LT^{3®} system and performing remedial activities are required to have health and safety training in order to perform site activities in a safe manner. Also, with proper operation and monitoring of the LT^{3®} system, community exposures are minimal. The LT^{3®} system's impact on workers and the nearby community is discussed below.

3.4.1 Worker Safety

Worker safety considerations associated with LT^{3®} operations can be grouped in two categories: (1) physical site hazards and (2) potential chemical hazards. General site hazards during the operation of the LT^{3®} system include the following:

- Heavy equipment hazards
- Occupational noise exposure
- Potential slip, trip, or fall hazards
- Potential for contact with mechanical equipment (motors, fans, and conveyors) and electrical equipment or utility lines
- Open trench and excavation hazards
- Airborne dust hazards
- Potential splashing of liquid
- Confined space entry

In addition, the heating fluid system presents potential burn hazards. The hot oil circulates through the LT³® processor at up to 650° F, presenting a great hazard at transfer points in the lines or in the event of a line rupture. Potential chemical hazards involve inhaling, absorbing, ingesting, and coming in contact with constituents of concern in contaminated material. The exposure likelihood of this activity is high during excavation and handling of contaminated sludge. At the ADC site, primary constituents of concern included MBOCA; manganese; 4-methylphenol; phenol; 1,2-dichlorobenzene; and toluene.

All personnel working at the site had a minimum of 40 hours of health and safety training, and all were under routine medical surveillance. Remedial activities at the ADC site were conducted using Level C PPE.

3.4.2 Potential Community Exposures

Potential community exposures to health hazards from the operation of the LT³® technology include exposure to (1) stack gas emissions, (2) fugitive dust emissions, (3) liquid spills resulting from condensate handling, and (4) noise from the operation of the LT³® system. When the LT³® system operates properly and is regularly maintained, the potential for community exposures are minimal.

3.5 Long-Term Effectiveness

The LT³® system permanently removes contaminants from soil. However, treatment residuals are not destroyed on site and require proper off-site treatment and disposal. Long-term effectiveness of the LT³® system was assessed based on the permanence of the treatment and the handling of process residuals. These items are discussed below.

3.5.1 Permanence of Treatment

The LT³® system desorbs and permanently removes contaminants from the contaminated soil. Approximately 25 tons of treated material were produced every 12 hours of LT³® system operation at the ADC site. Treated material from each processing period was staged separately. During remedial activities at the ADC site, treated material was transported to a clean staging area to await analytical results. If analytical results indicated that the thermal treatment had not achieved the required level of treatment, the material was reprocessed in the LT³® system.

3.5.2 Residuals Handling

Two types of residuals are generated from the LT³® process: (1) condensate and (2) fabric filter dust. The long-term effectiveness of the LT³® system ultimately depends on the methods used to treat or dispose of these residuals.

Operation of the LT³® system generated condensate at a rate of about 2 to 2.8 gpm. The amount of condensate produced may differ significantly, depending on the moisture content of the sludge. During the SITE demonstration and full-scale remediation at the ADC site, condensate from the LT³® process was routed to a holding tank. From the tank it was pumped through a filter to remove particulate matter and through a liquid-phase carbon adsorption system to remove organic contaminants. Treated condensate was then shipped off-site for disposal at a hazardous waste disposal facility. In other LT³® system applications, treated condensate was used to quench and control dust from treated sludge.

Another residual generated from the condensate treatment system is a separated organic stream. At the ADC site, the organic stream was a heavy residue that accumulated in the bottom of the holding tank. This heavy residue most likely consisted of organic solids settling in the bottom of the tank. After the SITE demonstration tests, the solid residue was removed from the bottom of the holding tank and mixed with contaminated sludge for reprocessing during remedial activities. However, during remedial operations at the site, the heavy residue was drummed for future off-site disposal.

In previous LT³® system applications, condensate was treated by a three-phase, oil-water separator, which allowed water to separate from insoluble light and heavy organic components. Light organics were removed by a skimmer and weir. The heavy organic phase was removed through a manually operated drain at the bottom of the separator. Both organic phases removed from the oil-water separator were drummed for off-site disposal. Drummed organics were manifested and shipped off site for treatment and disposal at a RCRA-permitted facility. Water flowing out of the separator was directed to a liquid-phase carbon adsorption system. The water treatment system can be modified to include other standard processes to meet site-specific discharge disposal requirements.

At the ADC site, approximately two 55-gallon drums of fabric filter dust were collected every 12 hours of LT³® system operation. Three disposal options were considered for fabric filter dust. Depending on sample analytical results, the dust would be (1) mixed with treated material for on-site disposal, (2) recycled for further treatment, (3) or drummed for off-site disposal. SITE demonstration analytical results showed that the concentrations of contaminants in the fabric filter dust were above cleanup goals. Dust produced during the SITE demonstration and during full-scale operation was drummed for off-site disposal. Special care should be taken when retreating fabric filter dust. The dust contains large amounts of small particles, which can easily be carried away by the off-gas, clogging the system's off-gas ducts.

3.6 Factors Influencing Performance

Several factors may influence the LT³® system's performance, including waste characteristics, operating parameters, and climate. Waste characteristics that may influence the performance of the LT³® system include the waste feed material's size, its moisture content, its particle size distribution, and its pH. Two primary operating parameters found to affect contaminant removal efficiency were optimized during shakedown operations before the SITE demonstration: (1) contaminated sludge flow rate and (2) heating fluid temperature. The effects of the feed materials waste characteristics, the LT³® system operating parameters, and the climate are discussed below.

3.6.1 Size of the Waste Feed

The LT³® system operates best when the waste feed material consists of small, uniformly sized particles, preferably less than 2 inches in diameter. Severe operational problems may result from large rocks or oversized debris in the feed material. Large rocks may become wedged in the screw conveyors, resulting in several days of downtime. During the SITE demonstration, oversized material in the sludge was removed manually before dewatering operations and before the waste feed entered the LT³® system. In previous LT³® applications, feed material was shredded, and only material smaller than 2 inches in size was processed. During remedial activities at the ADC site, a vibrating screen was used to pretreat dewatered sludge.

3.6.2 Moisture Content of the Waste Feed

The LT³® process is most efficient for wastes with a moisture content of about 20 percent. Wastes with a high moisture content require additional thermal energy to maintain the treatment temperature while removing the water, thereby increasing operating costs. Wastes with a high moisture content also generate more condensate, thereby increasing handling requirements. Wastes with a low moisture content produce large amounts of dust during treatment, and they may create operational problems. To enhance the efficiency of the LT³® system, wastes with a moisture content greater than 50 percent must be dewatered. Water can be added to dry wastes to control excessive dusting.

The ADC lagoon sludge had a fluid consistency, with a moisture content ranging from 65 to 70 percent. Thermal desorption by the LT³® system cannot be used when the feed material contain free liquids. Free liquids may leak through the seals of the thermal processor and flush through the system without being treated. To maximize the efficiency of the LT³® system, ADC lagoon sludge was excavated with a Mudcat hydraulic dredge and was dewatered using a plate and frame filter press. The average dewatering time was 40 minutes. Before dewatering, lime and ferric chloride were

added to the sludge as stabilizing agents. For each gallon of sludge, 0.1 pound of each chemical was added. The moisture content of the dewatered sludge ranged from 41 to 44 percent. Dewatered sludge was stockpiled in a storage building prior to treatment.

3.6.3 Particle Size Distribution of the Waste Feed

The waste feed's particle size distribution and available surface area are important factors that affect the performance of the LT³® system. Contaminants tend to be adsorbed on smaller soil particles, because soil composed of small particles has a larger surface area, making more sites available for contaminant sorption. In general, sandy soils are more effectively treated compared to clay type soils, which consist of small particles.

SITE demonstration results indicated that the available surface area of the contaminated sludge ranged from 49.1 to 52.3 square meters per gram (m²/g). These values are comparable to the surface area of kaolinite, a clay material, which has been reported to be 25 m²/g (Stumm and Morgan, 1981). During excavation and stockpiling activities, ADC lagoon sludge was mixed with clay from the base of the lagoon, which may account for the similarity between the surface area of the sludge and the surface area of kaolinite.

SITE demonstration results also showed that the contaminant concentration in the fabric filter dust was significantly higher than the contaminant concentration in the treated material. These results indicate that contaminants were adsorbed on smaller soil particles and were not effectively desorbed during heating; instead contaminants remained attached to the smaller particles, which were carried away in the sweep gas stream and trapped in the fabric filter.

Large amounts of small particles in the feed material could possibly cause operational problems by blocking the system's off-gas ducts. During the full-scale remediation of the ADC lagoon sludge, Weston reprocessed treated sludge that did not meet cleanup requirements. Because the treated sludge consisted of very small particles, reprocessing produced large amounts of dust, causing operational problems and increased maintenance requirements.

3.6.4 pH of the Waste Feed

The pH of the waste feed may also affect the performance of the LT³® system. The pH of the waste feed controls the net surface charge of the soil particles, which is in turn related to contaminant sorption. In addition, soil pH determines the type and extent of chemical reactions that occur during heat treatment in the LT³® system. Because lime was added to the ADC lagoon sludge as a conditioning agent, the pH of the untreated sludge was alkaline, ranging from 10.9 to 11.2. The alkaline pH of the sludge may have

induced several chemical transformation reactions during heat treatment. For example, based on the SITE demonstration results, the phenol concentration in the sludge was found to increase after treatment, while the concentration of 1,2-dichlorobenzene, which was originally present, decreased. The increase in phenol concentration is most likely due to the dehalogenation of 1,2-dichlorobenzene, a reaction that has been reported to take place at elevated temperatures and alkaline pH (Larock, 1989). The dehalogenation scenario is supported by other demonstration results, which also indicate that the EOX concentration in sludge is reduced after treatment, while the concentration of chloride is increased. In addition, the pH of treated sludge was lower than the pH of untreated sludge, ranging from 9.1 to 9.6. The reduction in pH is probably caused by the formation of HCl during dehalogenation reactions.

The pH of the condensate stream was also alkaline, ranging from 10.1 to 10.2. This alkaline pH may have resulted from lime particles being carried away in the off-gas stream before becoming dissolved in the condensate.

If lime had not been added to the waste feed, the pH of the treated material and the liquid condensate would probably be acidic, due to the formation of HCl from dehalogenation reactions. Acidic pH and elevated temperatures can cause equipment corrosion, which could cause additional equipment problems.

3.6.5 Contaminated Sludge Flow Rate

The feed material's flow rate determines its residence time in the LT³® processor. At a selected heating fluid temperature, the residence time determines the treatment temperature. The treatment temperature in turn determines the efficiency of contaminant removal and the extent of chemical transformations during heating. The LT³® system can process contaminated material at a rate of up to 10 tons/hr. However, during the SITE demonstration, sludge was treated at a rate of only 2.1 tons/hr, which resulted in a residence time of 90 minutes. The sludge residence time in the heat processor was maintained by adjusting the rotational speed of the screws.

3.6.6 Heating Fluid Temperature

A heated, circulating fluid indirectly provides the thermal energy needed to maintain the desired treatment temperature in the heat processor. The treatment temperature affects the rate and degree of contaminant volatilization and formation of thermal transformation by-products. For the SITE demonstration, the LT³® heat processor needed to maintain a sludge temperature of above 500 °F in order to volatilize organics from the contaminated sludge. The heat transfer fluid used during the SITE demonstration and the full-scale remediation was Therminol 66, produced by Monsanto. According to manufacturer guidelines, Therminol 66 performs best in temperatures ranging from 20 to 650 °F. During the SITE demonstration, the operating temperature of the heating fluid was 650 °F. In previous LT³® operations, Dowtherm HT, manufactured by Dow Chemical, was used as heating fluid. The maximum recommended temperature for continuous operation with Dowtherm HT is also 650 °F.

A heating fluid temperature of 650 °F and a 90-minute residence time resulted in a sludge treatment temperature between 500 °F and 530 °F. The operating treatment temperature of the sludge was maintained by controlling the temperature, pressure, and flow rate of the heating fluid. However, because the moisture content of the contaminated sludge varied, the sludge treatment temperature also varied. Variations in treatment temperature can influence the treatment efficiency of the LT³® system.

3.6.7 Climatic Conditions

Dry, warm weather conditions are ideal for operation of the LT³® system. However, the SITE demonstration was conducted in subfreezing temperatures, and remedial activities at the site were conducted in subfreezing or wet weather conditions. Cold and wet weather caused minor operational problems. The hose supplying water to the treated sludge conditioner had to be covered with insulation tape due to freezing temperatures. The insulated tape was occasionally damaged, and the water supply hose subsequently froze. Weston personnel thawed the hose with a portable heater. Snowy conditions hampered visibility at the site but did not affect the performance of the LT³® system. Wet weather hampered sludge excavation and handling. The LT³® system was not operated in extremely hot conditions at the ADC site.

Section 4

Economic Analysis

This section presents cost data associated with the LT³® technology. Costs have been placed in 12 categories applicable to typical cleanup activities at Superfund and RCRA sites. This economic analysis discusses site-specific factors affecting costs, assumptions the analysis is based on, and each of the 12 cost categories as they apply to the LT³® technology. Costs are presented in August 1992 dollars for Weston's full-scale production unit with eight 20-foot screws. Data was compiled during several pilot studies and during the SITE demonstration and subsequent full-scale operations at the ADC site. This analysis presents the costs associated with treating 3,000 tons of VOC-contaminated soil, with a VOC concentration of 10,000 parts per million (ppm). The analysis also compares the costs associated with treating soils containing 20 percent, 45 percent, and 75 percent moisture content.

An economic analysis of the LT³® technology reveals that operating costs are most affected by the feed rate and residence time. The soil moisture content and the soil treatment temperature (which is determined by contaminant type and concentration) are site-specific factors that affect costs. The treatment temperature and the soil moisture content determine the feed rate and residence time needed to properly treat soil and, to some degree, the amount of residual waste produced.

4.1 Site-Specific Factors Affecting Costs

Site-specific wastes and features affect the costs of this soil treatment technology. Waste-related factors affecting costs include waste volume, waste type, soil moisture content, treatment goals, and regulatory permit requirements. Site-specific features affecting costs include site area, accessibility, availability of utilities, and geographic location. The characteristics of the residual waste also affect supply and disposal costs. Residual wastes produced by the LT³® system and their characteristics determine if the wastes can be recirculated for treatment in the system or if they must be disposed of off site as hazardous wastes.

4.2 Basis of Economic Analysis

Table 4-1 presents a breakdown of the factors considered for each of the 12 cost categories. These costs are considered to be order-of-magnitude estimates, with an expected accuracy within 50 percent above and 30 percent below the actual costs. The table presents a breakdown of costs for a 3,000-ton remedial action site; it also compares treatment costs for soils containing 20, 45, and 75 percent moisture. Larger or smaller projects may have different cost per ton values. Because fixed costs are not affected by the volume of soil treated, larger projects will usually have a lower cost per ton. The following sections present underlying assumptions about (1) the LT³® technology and capital costs, (2) soil and site conditions, and (3) the LT³® system used in this economic analysis.

4.2.1 Assumptions about the LT³® Technology and Capital Costs

This analysis is intended for potential clients needing to treat soils contaminated with VOCs or SVOCs. This analysis assumes that Weston will subcontract the LT³® system to government or private clients for on-site soil treatment. The LT³® technology will be delivered to the site by six semitrailer trucks and will be assembled by Weston. The assembled equipment will consist of the LT³® system used at the ADC demonstration, with no deviations. Neither depreciation nor salvage value is applied to the costs presented in this analysis.

4.2.2 Assumptions about the Soil and Site Conditions

Soil and site conditions have a great impact on total project cost, primarily because they determine how long the LT³® system will need to operate. The amount and type of contaminants in soil and the cleanup goals for the site will determine the temperature and residence time necessary for treatment. High soil moisture content will increase residence time and the amount of residual water produced. As a result, costs are affected by lower production speeds

Table 4-1 Cost Analysis for Operating the LT[®] System

Cost Categories	Cost Per Ton of Soil Treated ^a Soil Moisture Content		
	20%	45%	75%
<u>Site Preparation Costs^b</u>			
Administrative Costs	11.00	11.00	11.00
Fencing Costs	.40	.40	.40
Construction Costs	.70	.70	.70
Dewatering Costs	NA	NA	187.90
Total Site Preparation Costs	12.10	12.10	200.00
<u>Permitting and Regulatory Costs^b</u>			
Permit	3.30	3.30	3.30
Engineering Support	80.00	80.00	80.00
Total Permitting and Regulatory Support	83.30	83.30	83.30
<u>Equipment Costs</u>			
LT [®] Rental ^c	13.00 ^d	22.00	22.00
Support Equipment Rental			
Dumpsters ^e	.70	1.35	1.35
Wastewater Storage Tanks ^e	1.00	2.00	2.00
Steam Cleaner	.10	.10	.10
Portable Toilet ^e	.10	.20	.20
Optional Equipment Rental ^c	12.00	20.00	20.00
Total Equipment Costs	26.90	45.65	45.65
<u>Startup Costs^b</u>			
Mobilization	10.00	10.00	10.00
Assembly	25.00	25.00	25.00
Shakedown	15.00	15.00	15.00
Total Startup Costs	50.00	50.00	50.00
<u>Labor Costs^c</u>			
Operations Staff	39.00	79.50	79.50
Site Manager	21.60	44.30	44.30
Maintenance Supervisor	7.20	14.60	14.60
Site Safety Officer	7.20	14.60	14.60
Total Labor Costs	75.00	153.00	153.00
<u>Supply and Consumable Costs</u>			
PPE ^c	6.00	10.00	10.00
PPE Disposable Drums	.50	1.00	1.00
Residual Waste Disposal Drums	1.20	1.20	1.20
Activated Carbon ^e	8.00	24.00	24.00
Diesel Fuel ^c	.65	1.00	1.00
Calibration Gases ^e	.35	1.10	1.10
Total Supply and Consumable Costs	16.70	38.30	38.30

Cost Categories	Cost Per Ton of Soil Treated ^a Soil Moisture Content		
	20%	45%	75%
<u>Utility Costs</u>			
Natural Gas (@ \$1.43/1,000 ft ³)	7.80	26.00	26.00
Electricity (@ \$0.18/kWh)	2.10	6.30	6.30
Water (@\$1.00/100 gallons)	.60	.60	.60
Total Utility Costs	10.50	32.90	32.90
<u>Effluent Monitoring Costs^f</u>	0.00	0.00	0.00
<u>Residual Waste and Waste Shipping, Handling, and Transportation Costs</u>			
Oversized Material (2% of feed soil)	5.40	5.40	5.40
Drums	27.00	27.00	27.00
Wastewater	7.20	14.40	14.40
Total Residual Waste and Waste Shipping, Handling, and Transportation Costs	39.60	46.80	46.80
<u>Analytical Costs</u>			
Treatability Study ^b	10.00	10.00	10.00
Sample Analysis for VOCs	4.20	12.00	12.00
Total Analytical Costs	14.20	22.00	22.00
<u>Equipment Repair and Replacement Costs</u>			
Maintenance	11.70	19.80	19.80
Design Adjustments ^f	0.00	0.00	0.00
Facility Modifications ^f	0.00	0.00	0.00
Total Equipment Repair and Replacement Costs	11.70	19.80	19.80
<u>Site Demobilization Costs</u>	33.00	33.00	33.00
TOTAL COST PER TON OF SOIL TREATED^a	373.00	536.85	724.75

NA = Not Applicable

^a = Cost per ton of soil treated; figures are rounded and have been developed for a 3,000-ton project.

^b = Fixed cost not affected by the volume of soil treated.

^c = Costs are incurred for the duration of the project.

^d = Feed rate is double that of soils with 45 percent moisture content.

^e = Costs are incurred only during soil treatment activities.

^f = Cost included in the cost of renting the LT³® system.

and increased handling requirements. For example, soils with 20 percent moisture content have a feed rate double that of soils with 45 percent moisture content. In addition, a higher soil moisture content, such as 75 percent, may require soil dewatering, a process that will further increase costs.

Site preparation costs are determined by the volume of contaminated soil, the size of the site, and the availability of utilities. This analysis assumes that a natural gas pipeline is available at the site. Utility costs can be minimized if natural gas is available to power the LT³® system's heating units. Otherwise, propane, which can be transported to the site, is the least expensive alternative fuel capable of achieving the necessary operating temperatures. This analysis also assumes that the contaminated soil is a fairly homogenous clay-type soil, with a low moisture content and only a minimal amount of oversized material. These soil characteristics will lower site preparation costs.

4.2.3 Assumptions about LT³® System Operation

For soils with a 45 percent moisture content, this analysis assumes that the LT³® system can treat contaminated soil in batch cycles at 70 percent efficiency until the job is done. The soil feed processing rate is assumed to be 2.1 tons per hour (tons/hr) for a residence time of 90 minutes. This feed rate was used at the ADC site. Operating at 70 percent efficiency, about 250 tons of soil can be treated per week. At this rate, treating 3,000 tons of contaminated soil would take about 3 months, excluding mobilization and demobilization. Soil with a 75 percent moisture content must first be dewatered. Once the soil is dewatered to 45 percent moisture content, it can be treated according to the schedule described above.

For soils with 20 percent moisture content, this analysis assumes that the LT³® system can treat contaminated soil in batch cycles at 70 percent efficiency until the job is done. However, in this scenario, the soil feed processing rate is assumed to increase to 7 tons/hr for a residence time of 30 minutes. Operating at 70 percent efficiency, about 820 tons of soil can be treated per week. At this rate, treating 3,000 tons of contaminated soil would take almost 1 month, excluding mobilization and demobilization.

The LT³® system requires three operators and one supervisor working two 12-hour shifts per day. One maintenance technician and one site safety officer will be employed during the first 12-hour shift and as needed during the second shift.

Weston's full-scale LT³® system, with eight 20-foot screws, is the only model available. Therefore, no equipment cost alternatives are presented here. This analysis presents fixed and variable costs for operating the full-scale LT³® model.

This analysis is also based on the following assumptions:

- Residual wastes will be disposed of off site.
- Access roads exist and will not have to be constructed.
- Utility lines, such as electricity and telephone lines, exist on site.
- Air emissions monitoring will be continuous.
- Treated soil or sludge will be used as backfill at the site.

4.3 Cost Categories

Cost data associated with the LT³® technology have been assigned to the following 12 categories: (1) site preparation costs; (2) permitting and regulatory costs; (3) equipment costs; (4) startup costs; (5) labor costs; (6) consumable material costs; (7) utility costs; (8) effluent monitoring costs; (9) residual waste shipping, handling, and transportation costs; (10) analytical costs; (11) equipment repair and replacement costs; and (12) site demobilization costs. Each of these cost categories is discussed below.

4.3.1 Site Preparation Costs

Site preparation costs include administrative, fencing, and construction costs. Site preparation costs will vary depending on the amount of contaminated soil, the size of the site, and the availability of utilities and access roads. Site preparation costs will be lower if the contaminated soil is fairly homogenous and clay-like, with a low moisture content and only minimal amounts of oversized materials, such as rocks and debris. Soils with high moisture content will need to be dewatered.

For this analysis, site preparation administrative costs, such as legal searches, access rights, and other site planning activities, are estimated to be \$33,000. This analysis also assumes that minimal site grading is required, natural gas and water supply lines exist at the site, and heavy equipment is rented. The costs for heavy equipment are included in equipment costs (see Section 4.3.3), because the equipment will be on site for the duration of the treatment.

A 6-foot-high, chain-link security fence with a 12-foot-wide gate will be needed to surround the 75-square-foot LT³® system. The site area totals 5,000 square feet. The fence will cost about \$730 for materials, and it is assumed that the LT³® crew will install it. About 500 feet of moveable snow fencing was used to enclose active excavation areas at the ADC site. The fence was intended to prevent accidents near and around the excavation area. Snow fencing is available in 50-foot bundles for about \$50.00 per

bundle. Other construction costs include assembling the LT³® system and installing concrete foundations and soil staging and storage areas. These construction costs are assumed to be 10 percent of total site preparation costs.

The primary costs associated with dewatering include labor, rental of dewatering equipment (such as a filter press and a slurry pump), mobilization, and demobilization. At the ADC site these costs were about \$187.90 per ton of soil dewatered from 75 to 45 percent moisture content (Weston, 1992). It is assumed that a filter press can process about 120 tons of soil per day or 840 tons per week. Once a stockpile of dewatered soil is available, dewatering and thermal processing may occur concurrently. Because the LT³® is assumed to process 250 tons of soil per week, dewatering will not significantly increase the amount of time needed to complete the project and, therefore, is not considered in this analysis.

A treatability study will need to be performed to determine site- and waste-specific temperature requirements and residence times. Because treatability study costs are primarily analytical, they are included in analytical costs (see Section 4.3.10).

4.3.2 Permitting and Regulatory Costs

Permitting and regulatory costs include fees for highway permits for oversized vehicles and air permits for the LT³® system's heating unit and monitoring equipment. These fees are assumed to cost about \$5,000 each.

Weston estimates typical total permitting costs to average \$240,000 for engineering support, such as acting as a liaison to regulatory agencies and generating various reports. Proof-of-process testing, analysis, and reporting increase these costs by an average of \$100,000 (Weston, 1986). In some cases, condensate from the LT³® system could possibly be discharged to a publicly owned treatment works, which would require a National Pollutant Discharge Elimination System (NPDES) permit. This permit would increase permitting and regulatory costs and effluent monitoring costs.

RCRA corrective action sites require additional monitoring records and sampling protocols, which can increase the regulatory costs by an additional 5 percent (EPA, 1991b). CERCLA and SARA require remedial actions to be consistent with ARARs of environmental laws, ordinances, regulations, and statutes, including federal, state, and local standards and criteria. In general, ARARs must be determined on a site-specific basis.

4.3.3 Equipment Costs

Equipment costs include renting the complete LT³® system and support equipment. Weston will only lease the

LT³® system to its clients. The rental rate is assumed to be about \$13,000 per month. Support equipment includes roll-off dumpsters for oversized material; 2,000-gallon storage tanks for treated wastewater; and a steam-cleaner for decontaminating equipment. Support equipment costs are discussed below.

This analysis assumes that oversized material removed from contaminated soil is stored in a 40-cubic-yard roll-off dumpster prior to disposal. Oversized material is assumed to constitute 2 percent of the feed soil. By this estimate, 3,000 tons of contaminated soil will contain 60 tons of oversized material, which would fill nearly two dumpsters. The average rental cost of a 40-cubic-yard roll-off dumpster is \$500 per month (Ravenswood Disposal Services, 1992). Disposal costs for oversized material are included in residuals and waste shipping, handling, and transportation costs (see Section 4.3.9).

Treated wastewater is generated when processor off-gasses are filtered and cooled in the LT³® system's condensers. Condensate is treated in a vapor-phase carbon adsorption unit before being stored in tanks prior to off-site disposal. The costs associated with the vapor-phase carbon adsorption unit are included in consumable material costs (see Section 4.3.6). Storage tanks are needed for the duration of the project. At the ADC site, the soil had a 45 percent moisture content, which generated about 120 gallons of wastewater per hour, or 57 gallons per ton of soil treated. If two 2,000-gallon tanks are rented, wastewater will have to be disposed of almost every other day. Each tank can be rented for about \$1,000 per month.

The actual amount of wastewater generated and the subsequent size of the tanks depends on the moisture content of the feed soil. It is assumed that soils with 20 percent soil moisture content will generate about half as much water as soils with 45 percent moisture content. In this scenario two storage tanks should still be rented, but they will be emptied less frequently and over a shorter period of time. Disposal costs for wastewater are included in residuals and waste shipping, handling, and transportation costs (see Section 4.3.9). Under some circumstances, treated condensate water can be sprayed directly on the treated soil to control dust, thus eliminating storage and disposal costs.

A steam-cleaner is needed at the end of the project to decontaminate equipment. Steam-cleaning units can be rented for \$300 per month (EPA, 1991a). No mobile office trailer is necessary because it is included with the complete LT³® system. However, portable toilets are not available with the system and may have to be rented. Weston estimates the cost of renting a portable toilet to be \$120 per month.

Optional support equipment needed depends on the depth and amount of soil to be treated. Either front-end

loaders or backhoes can be used to transport soil. At a minimum, one excavator and two loaders or backhoes are needed for soil excavating, transporting, and regrading activities. All this equipment can be rented for about \$12,000 per month, based on normal use during the two-shift days. It is assumed that LT³ personnel will be licensed to operate this equipment.

4.3.4 Startup Costs

Startup costs include mobilization, assembly, and shakedown costs. This analysis assumes that startup will take 5 weeks and that Weston will provide trained personnel to deliver, assemble, operate, and maintain the LT³ system and any necessary support equipment. Also, it is assumed that Weston's personnel are trained in health and safety procedures. Therefore, training costs are not incurred as a direct startup cost. Total startup costs are about \$150,000 and include the activities mentioned in this section.

Mobilization involves transporting all equipment to the site. Transportation costs are site-specific and will vary depending on the location of the site in relation to all equipment vendors. Five semitrailers with five drivers are required to ship the LT³ system to the site from West Chester, Pennsylvania. Mobilization is assumed to comprise about 20 percent of total startup costs, costing about \$30,000.

Assembly costs include the costs of unloading equipment from trailers and assembling the LT³ system. These activities require a crane rental and a crew of four working 12 hours per day for about three weeks. After assembly, equipment must be hooked up to utilities. Assembly is assumed to comprise about 50 percent of total startup costs, costing about \$75,000.

Shakedown costs include initial setup, initial startup, and proof-of-process tests. About 600 tons of sand is used for 2 to 3 days during initial startup. Trial runs take about 2 weeks to complete, after which full-scale operations may begin. Shakedown costs are assumed to constitute about 30 percent of total startup costs, which total about \$45,000.

4.3.5 Labor Costs

Labor costs include the total staff needed for startup, O&M of the LT³ system. Startup costs were discussed in the previous section. Labor wage rates, which include overhead and fringe benefits, are discussed below.

Unless air permits or local requirements dictate otherwise, the LT³ system will be operated during two 12-hour shifts, 7 days per week in order to avoid shutting down the system. System shutdown should be avoided because it takes about 12 hours for the unit to reach treatment temperatures. Each shift will have three operators (\$27 per hour), one site manager (\$45 per hour), one maintenance

supervisor (\$30 per hour), and one site safety officer (\$30 per hour). The site safety officer will work during the first shift and as needed during the second shift. In addition, part-time project management and office support may be needed.

4.3.6 Consumable Material Costs

Consumable material costs include the costs of PPE, drums for used PPE and residual wastes, activated carbon for off-gas vapor and liquid treatment, diesel fuel for heavy equipment, and calibration gases for air monitoring equipment. The quantities of all consumables will depend on the amount of soil treated.

PPE includes hard hats, safety glasses, respirators, and disposable protective clothing. Disposable clothing is worn by three operators who change PPE four times per shift, costing about \$200 per day. Used PPE fills about one 24-gallon fiber drum per shift, costing about \$12.30 per drum, or \$25.00 per day.

The LT³ system typically generates residual wastes such as dust and spent carbon, both of which require containers and proper off-site disposal. Dust is removed from the baghouse about once per shift and is collected in 55-gallon drums. For the ADC site, about one 55-gallon carbon-steel drum of dust is generated for every 12.5 tons of soil treated. Drums cost about \$15 each.

The vapor-phase carbon adsorption unit is exhausted every 10 days of operation and is replaced with a new one. The vapor-phase carbon adsorption unit contains 1,800 pounds of activated carbon and costs \$5,000. Beginning in the third month of operation, a monthly service charge of \$420 is incurred for covering the costs of handling spent carbon and maintaining the unit. Transportation costs for carbon adsorption units are included in the round-trip freight charges between Pittsburgh, Pennsylvania, and the site. The carbon vendor will either dispose of or regenerate the carbon, the cost of which is included in the cost of the unit.

The liquid-phase carbon adsorption unit is exhausted every 14 days of operation and is replaced with a new one. The liquid-phase carbon adsorption unit contains 165 pounds of carbon and costs about \$4,200, plus round-trip freight charges between Pittsburgh, Pennsylvania, and the site. Costs can vary by up to \$200 for the liquid-phase unit, depending on the type of carbon used. The rate of carbon use depends on contaminant types and concentrations. Vapor-phase carbon adsorption units are needed only during treatment activities.

Diesel fuel is used to operate all heavy equipment. Fuel costs are site-specific and will vary depending on the market price of diesel fuel and the extent of equipment usage at the

site. At the ADC site, about 250 gallons of diesel fuel were used per week.

Cylinders of CO, O₂, CO₂, and total hydrocarbon gases are needed to calibrate LT³® air monitoring equipment. Each cylinder of gas costs about \$200 and is replaced every 3 weeks. The LT³® system requires calibration once per day.

4.3.7 Utility Costs

Utilities used by the LT³® system include natural gas, electricity, and water. This analysis assumes that natural gas lines will be available at the site. The LT³® heating unit generates 6 million Btu/hr and is usually powered with natural gas, propane, or oil. For soils with a 45 percent moisture content, about 38,000 cubic feet of natural gas is used to process about 2.1 tons of soil each hour. About 7 tons of soil are processed per hour for soils with a 20 percent soil moisture content. Assuming current market conditions, natural gas costs about \$1.43 per 1,000 cubic feet. Therefore, for soils with 45 percent moisture content, natural gas usage costs about \$25.88 per ton treated. For soils with 20 percent soil moisture content, using natural gas costs about \$7.80 per ton treated.

Electricity runs the rest of the LT³® system. The system is estimated to consume 8,750 kilowatt-hours (kWh) per week when operating at 70 percent capacity (Weston, 1986). Electric costs per Kilowatt-hour (kWh) vary depending on local utility rates. For this analysis, power is assumed to cost \$0.18 per kWh. Therefore, electricity costs about \$6.30 per ton of soil with a 45 percent soil moisture content, and about \$2.10 for soils with a 20 percent soil moisture content. Total electric power requirements depend on the amount of soil treated.

To eliminate fugitive dust emissions at the ADC site, about 2 gpm of potable water is sprayed on treated soil. This action requires about 60 gallons of water per ton of soil. Water costs are estimated to be \$0.01 per gallon (Weston, 1986). Therefore, water costs about \$0.60 per ton of soil treated. This cost can vary by as much as 1,000 percent, depending on the geographic location of the site, availability of water, and distance to the nearest water main or uncontaminated well (EPA, 1991b). In future application, it is anticipated that condensate wastewater can be treated sufficiently to allow it to be used for additional dust control.

4.3.8 Effluent Monitoring Costs

Effluent monitoring costs include costs associated with air emissions monitoring for compliance with air permit limits. Monitoring treated off-gas vapors emitted to the atmosphere is part of the LT³® system and is accounted for in the rental cost of the system. The only variable affecting these costs is the cost of calibration gas. Gas costs are included in supply and consumable costs (see Section 4.3.6).

In addition, condensate could possibly be discharged to a publicly owned treatment works, which would require a NPDES permit. This permit would increase permitting and regulatory costs as well as effluent monitoring costs.

4.3.9 Residual Waste Shipping, Handling, and Transportation Costs

Disposal-related costs include costs associated with the disposal of carbon adsorption units, PPE, and other residuals, such as oversized material, drums of fabric filter dust, and wastewater. These costs depend on geographic location, distance to disposal sites, and site-specific soil conditions. Transportation costs for carbon adsorption units are included in the round-trip freight charges between Pittsburgh, Pennsylvania, and the site. The carbon vendor will either dispose of or regenerate the carbon, the cost of which is included in the cost of the unit.

Wastes drummed or containerized on site include PPE, oversized material, and fabric filter dust. Approximately one 24-gallon drum of PPE is generated during each 12-hour shift. The disposal cost is \$150 per drum or \$300 per day. Drums of PPE are assumed to be transported by truck to disposal facilities. Oversized material is estimated to be 2 percent of feed soil. The cost for disposing of oversized material is assumed to be \$270 per ton. The material will be transported off site in the 40-cubic-yard roll-off container it is collected in. Filter dust at the ADC site is generated at a rate of two 55-gallon drums per 12-hour shift. Disposal costs are estimated to be \$150 per drum or \$600 per day.

For soil with a 45 percent moisture content, about 57 gallons of wastewater is generated per ton treated. Wastewater is stored on site until it is transported off site by 5,000-gallon tanker trucks, approximately every other day. Transportation and disposal costs will average about \$0.24 for every gallon of water generated. Soils with a 20 percent soil moisture content will generate about half as much water. For future applications, it is anticipated that filter dust can be recirculated into the system, and wastewater can be used for dust control. The actual amount and type of residuals generated will vary from site to site. For example, soils containing fewer fine particles will generate less dust.

4.3.10 Analytical Costs

A treatability study will need to be performed to determine the temperature requirements and residence times of soil to be treated. This study is estimated to cost \$30,000. Continuous air monitoring of stack emissions is included in the rental cost of the LT³® system.

During the ADC SITE demonstration, all samples were shipped off site and analyzed only for the contaminant of concern. Analytical samples typically consisted of one VOC

sample shipment per shift, at a cost of approximately \$210 per shipment. Total analytical costs depend on the number and types of analyses that must be conducted and the site-specific contaminants of concern. For example, if four contaminants of concern by using only one technique, analytical costs will be significantly reduced. VOC analyses cost about \$210 per sample; SVOC analyses cost about \$440 per sample.

4.3.11 Equipment Repair and Replacement Costs

Maintenance labor has been included in labor costs (see Section 4.3.5). Maintenance material costs are assumed to be 90 percent of total rental costs. Costs for design adjustment, facility modifications, and equipment replacements are assumed to be incurred by Weston.

4.3.12 Site Demobilization Costs

Site demobilization includes LT³ shutdown and disassembly, site cleanup and restoration, rental equipment return, and disconnection of utilities. These activities will require a crew of six. Complete site demobilization is assumed to take about 3 weeks and costs \$100,000.

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Appendix A

Developer's Claims

This appendix summarizes claims made by the developer Roy F. Weston, Inc. (Weston), regarding its low temperature thermal treatment (LT³®) system. The information presented therein represents the developer's point of view and does not constitute U.S. Environmental Protection Agency (EPA) approval or endorsement of the statements made in this appendix.

A.1 Introduction

The Weston LT³® system is a patented process (U.S. Patents No. 4,738,206 and 5,072,674) used to remove volatile and semivolatile organic compounds (VOC and SVOC) from a variety of solid matrices, including soil, sludge, and sediments. The LT³® system desorbs or evaporates contaminants from the solid matrix using an indirect heat exchanger. The main part of the heat exchanger is a hollow-flight screw conveyor. Volatile contaminants and moisture are evaporated from the solid matrix and drawn into an air emission control system under vacuum. The air emission control system collects contaminants using a series of condensers and adsorbers.

A.2 Potential Application

The LT³® system can be used to treat solid matrices contaminated by a variety of VOCs and SVOCs. The LT³® system has been used to treat soil contaminated with chlorinated solvents, nonchlorinated solvents, fuel-derived hydrocarbons, polynuclear aromatic hydrocarbons, and chlorinated anilines. Following treatment, solids may typically be backfilled on site.

The LT³® system is typically mounted on a truck to facilitate mobility. However, fixed facility operations are possible and, in specific cases, are more cost effective than mobile operations, particularly for large sites or facilities that continually generate wastes. Remedial activities conducted under the Superfund or Underground Storage Tank (UST) programs have been successfully completed using the mobile LT³® system.

Resource Conservation and Recovery Act (RCRA) classified wastes have been treated in bench- and pilot-scale tests. Following treatment, solid residuals have complied with federal Land Disposal Regulations (LDR). RCRA wastes can be treated by using the mobile system or by constructing fixed facilities when handling routinely generated solid wastes.

Prior to application, a bench-scale test should be performed to determine the technology's ability to meet cleanup criteria and to establish the operating conditions necessary. Bench-scale tests generally provide sufficient information to develop full-scale processing systems. Weston offers bench-scale testing through the Environmental Testing Laboratory (ETL) in Lionville, Pennsylvania. The ETL has a RCRA permit to receive and test hazardous waste samples in order to determine their treatability.

A.3 System Advantages

The LT³® system offers the following advantages over other remedial methods and thermal treatment systems:

- By heating soils to evaporate volatile contaminants and moisture at temperatures well below the combustion temperature associated with incineration operations, the system operates with substantial fuel and energy savings.
- Indirect heating of the soil reduces the quantity of off-gas contacting the solid matrix and contaminants. With gas flows 10 to 20 times smaller than direct-fired desorbers or incinerators, the emissions control equipment is greatly reduced in size. Furthermore, the total amount of off-gas to which the public could potentially be exposed is greatly reduced.
- By controlling emissions using condensation and carbon adsorption, the LT³® system can recycle usable products, thus avoiding the generation of harmful products of incomplete combustion that are

sometimes associated with improperly operated incinerators.

- The LT³® system can provide for retention times of up to 90 minutes, as demonstrated at the Anderson Development Company (ADC) site. These long residence times are well above the residence times possible in similar rotary-type desorbers and incinerators.
- The hollow-flight screw conveyor provides substantial mixing and breakdown of soil clumps. Clay materials, which tend to ball and clump, are broken down and handled readily by the LT³® system.

A.4 System Limitations

The LT³® system has the following physical and chemical limitations:

- The LT³® system is intended for ex situ treatment of solids. Material that is excessively wet must be

dewatered or blended. All solid material must be screened to remove material greater than 2 inches in size. Oversized material may be shredded or crushed to meet this feed-restriction criterion.

- The LT³® system is designed to treat solids contaminated by VOCs and SVOCs. While the system's ability to treat metals has been tested, no removal of metals has been observed.

A.5 Costs

The costs for applying the LT³® system are provided on a lump sum basis for fixed costs, such as mobilization, permits, and demobilization, and unit costs for solid treatment. Costs are developed on a site-specific basis and depend on (1) the quantity of solid to be treated, (2) the contaminants in the solid, the (3) solid moisture content, and (4) the location of the facility.

Appendix B

SITE Demonstration Results

B.1 Introduction

Since early 1991, the U.S. Environmental Protection Agency (EPA) Superfund Technical Assistance Support Team (START) and its Office of Research and Development (ORD) have provided technical support to EPA Region 5 in evaluating remedial options for the Anderson Development Company (ADC) Superfund site in Adrian, Michigan. EPA determined that low temperature thermal desorption was an appropriate technology to treat contaminated sludge at the site. The record of decision (ROD) for the site stated that, following successful proof-of-process testing, the Low Temperature Thermal Treatment (LT³) system developed by Roy F. Weston, Inc. (Weston), could be used to remediate organic contaminants. Proof-of-process testing would be conducted under the EPA Superfund Innovative Technology Evaluation (SITE) program. The SITE demonstration of the LT³ technology was conducted at the ADC site in November and December 1991, in a cooperative effort among ORD, EPA Region 5, ADC, and Weston. This appendix briefly describes the ADC site and summarizes the SITE demonstration activities and results.

B.2 Site Description

The ADC facility covers approximately 12.5 acres within a 40-acre industrial park. The facility is located on the southeast side of Adrian, Lewance County, Michigan. ADC manufactures specialty organic chemicals. Between 1970 and 1979 it manufactured and sold 4,4'-methylenebis (2-chloroaniline), also known as MBOCA or Curene 442. In 1979, sludge from the City of Adrian wastewater treatment plant was found to be contaminated with MBOCA. The source of this contamination was a lagoon at the ADC site. In 1983, the ADC site was included on the National Priorities List (NPL). A remedial investigation (RI), an endangerment assessment (EA), and a feasibility study (FS) were subsequently conducted by C.C. Johnson & Malhotra, P.C. (CCJM, 1989).

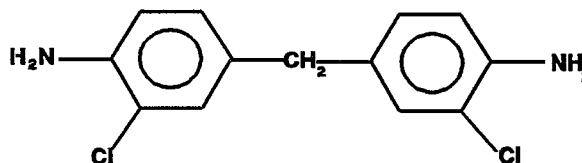
The RI indicated contamination of some surface soil in the lagoon area, all the sludge in the lagoon, and some clay

on the side slopes of the lagoon and underneath the sludge. MBOCA contamination in these areas exceeded the health-based cleanup goal of 1.6 milligrams per kilogram (mg/kg), as determined by the EA. Volatile organic compounds (VOC), semivolatile organic compounds (SVOC) other than MBOCA, and some metals were also detected, primarily in the lagoon sludge and clay.

In September 1990, bench-scale tests conducted by Canonic Environmental Services Corporation (Canonic) determined that low temperature thermal desorption was a viable remedial technology to remove MBOCA from the ADC lagoon sludge and clay. Treatability study results indicated that thermal desorption was capable of reducing MBOCA concentrations in the lagoon sludge and clay to below the cleanup goal of 1.6 mg/kg. Bench-scale tests were conducted using treatment temperatures greater than 520 °F and a residence time of 12.5 minutes. Because of scheduling conflicts, Canonic could not perform the remediation of the site. ADC contracted Weston to perform remedial activities at the site using the LT³ system. Optimum operating conditions were determined by Weston during shakedown and startup operations before the SITE demonstration.

B.3 Contaminant Characteristics

MBOCA (CAS No. 101-14-4) is a yellow to light gray-tan, nearly odorless, crystalline solid. The physical form of MBOCA is granular, with a size range of 0.5 to 1.0 centimeters (cm). MBOCA is a member of the class of compounds known as aromatic amines. The chemical formula of MBOCA is $\text{CH}_2 (\text{C}_6\text{H}_3\text{ClNH}_2)_2$. The structure of MBOCA is presented below.



The physical and chemical properties of MBOCA determine its removal mechanisms during thermal treatment in the LT³ system. MBOCA has a relatively low solubility in water and an extremely low vapor pressure, ranging from 3.7×10^{-6} to 5.4×10^{-5} torr over a broad temperature range. Several values have been reported for its melting point, ranging from 210.2 to 230 °F. Because MBOCA decomposes at above 392 °F, physical and chemical transformations may govern the fate of MBOCA during thermal treatment. Two known degradation products (metabolites) are N-acetyl-MBOCA (AC-MBOCA) and N,N'-diacetyl-MBOCA (DAC-MBOCA) (Versar, 1983).

Sorption of MBOCA to organic material and clay dominates its fate in soil and aquatic environments. MBOCA is easily adsorbed by granular activated carbon. Soil adsorption of two similar aromatic amines, aniline and parachloroaniline, has been found to depend both on the organic matter and the clay content of the soil. The cationic bonding of MBOCA with soil may be irreversible. Photooxidation and chemical oxidation may also be important transformation processes in the atmosphere and in the uppermost layer of soil and water systems. Biodegradation of MBOCA has been demonstrated, and it is probably effective in removing MBOCA from soil and from wastewater with sufficiently acclimated microorganisms (Versar, 1983).

B.4 Technology Demonstration Testing and Sampling Procedures

The original experimental design for the SITE demonstration test specified four test runs at optimum conditions: two test runs for sludge and two test runs for clay treatment. However, much of the clay was excavated and stockpiled together with the sludge, and a distinguishable clay matrix could not be found. Therefore, to collect the number of samples needed, three replicate tests for sludge treatment were conducted the week of November 25, 1991. Approximately 40 tons of contaminated material (13 for each of three runs) were processed during the demonstration. Each demonstration test required approximately 6 hours of LT³ system operation. The residence time and the temperature in the thermal processing unit were optimized during Weston's shakedown period prior to the demonstration. Table B-1 summarizes the system's operating parameters.

Sampling began when the system reached steady-state conditions in terms of temperature and sludge flow rate. For each run, sludge and liquid samples were collected every 30 minutes for the 6-hour test period. Stack gas samples were collected over a period of about 4 hours during the middle of each run.

During the demonstration, samples were collected from six process points: (1) untreated sludge, (2) treated sludge,

(3) fabric filter dust, (4) condensate (5) exhaust gas before the carbon unit, and (6) stack gas after the carbon unit. Samples were also collected from the City of Adrian service water line. Solid, liquid, and gas samples were analyzed for the following critical parameters: MBOCA, VOCs, SVOCs, dioxins, and furans. To trace the fate of chloride through the system, samples were also analyzed for chloride, total organic halide (TOX), and extractable organic halide (EOX). Noncritical parameters were also analyzed to characterize the feed and treated sludge. These parameters were metals, toxicity characteristic leaching procedure (TCLP) metals, particle size distribution, moisture, density, total organic carbon (TOC), soil classification, available surface area, total toxicity bioassay, California bearing ratio (CBR), and pH. All sampling and analyses procedures met the requirements of a EPA Category II quality assurance project plan (EPA, 1991).

After the first SITE demonstration, the truck carrying gas samples and sample logbooks caught fire and burned completely. Because the fire destroyed all stack samples for particulate matter, VOCs, SVOCs, chloride, and moisture, SITE demonstration tests had to be repeated. The second SITE demonstration was performed the week of December 15, 1991.

The objective of the second SITE demonstration was to collect liquid, solid, and gas samples for all contaminants sampled in the gas phase. Sampling was performed for VOCs, SVOCs, MBOCA, TOX, and chloride. All liquid and solid samples were collected as daily composites, because their purpose was primarily to correlate contaminant concentrations in the gas, liquid, and solid phases. Therefore, composite samples for each run were collected and analyzed for each of the contaminants of concern. In addition, liquid condensate samples were collected and analyzed for pH. No sludge samples were collected for dioxins and furans, because gas samples from the November testing were not lost in the truck fire. Also, noncritical parameters were not included in the December sampling program.

B.5 Treatment Results

This section summarizes analytical results of the LT³ system SITE demonstration and evaluates the system's effectiveness in treating sludge contaminated with VOCs and SVOCs. SITE demonstration results are based on extensive laboratory analyses under rigorous quality control procedures. Analytical results from all six replicate runs (three in November and three in December) were analyzed to determine the system's efficiency. The following sections discuss (1) VOC removal, (2) MBOCA removal, (3) SVOC removal, (4) the fate of chloride in the LT³ system, (5) the formation and distribution of dioxins and furans, (6) the fate

Table B-1 LT³® System Operating Conditions During SITE Demonstration

Equipment	Parameter	Value
Thermal Processor	Temperature	Greater than 500 °F
	Feed Material Flow Rate	2.1 tons/hour
	Screw Rotational Speed	0.73 to 0.76 rpm ^a
	Residence Time	90 minutes
Fabric Filter	Air/Cloth Ratio	4.27
	Cleaning Frequency	Every 15 to 30 seconds
Air-Cooled Condenser	Ambient Air Temperature	20 to 30 °F
Refrigerated Condenser	Discharge Temperature	60 to 70 °F
Vapor-Phase Carbon Units	Empty Bed Velocity	55 fpm ^b
	Empty Bed Contact Time	0.07 minutes
	Operating Temperature	70 °F
	Operating Humidity	70% RH ^c
Liquid-Phase Carbon Units	Flow Rate	See note d
	Surface Loading Rate	
	Empty Bed Contact Time	
Oil-Water Separator	Surface Area Loading	See note e
	Residence Time	

^a = rpm (revolutions per minute)

^b = fpm (feet per minute)

^c = RH (relative humidity)

^d = The liquid-phase carbon adsorption units were not used as part of the condensate liquid treatment system during the SITE demonstration.

^e = The oil-water separator did not operate during the SITE demonstration or subsequent remedial activities.

of metals in the LT³® system, (7) stack emissions, (8) physical properties of sludge, and (9) toxicological properties of sludge.

B.5.1 VOC Removal

For most VOCs present in untreated sludge, the LT³® technology achieved residual concentrations below the method detection limits, which for most VOCs were below 60 µg/kg. Toluene and tetrachloroethene (PCE) were identified as critical VOCs for the LT³® technology SITE demonstration.

Toluene was present in untreated sludge at concentrations ranging from 1,000 to 25,000 µg/kg. The concentration of toluene in treated sludge was below the detection limit of 30 µg/kg. The concentration of toluene in fabric filter dust ranged from less than 28 to 410 µg/kg. For most samples analyzed, the concentration of toluene in the condensate was below the detection limit of 5 milligrams per liter (mg/L). Toluene was detected in the off-gas before the carbon column at concentrations ranging between 8,000 and 10,000 parts per billion by volume (ppbv), and was effectively removed by the vapor-phase activated carbon column.

PCE was present in untreated sludge at concentrations ranging from 690 to 1,900 µg/kg. The concentrations of PCE in treated sludge and fabric filter dust were below the detection limit of 30 µg/kg for most samples analyzed. The concentration of PCE in the condensate was below the detection limit of 5 mg/L. PCE was detected in the off-gas before the carbon unit at concentrations ranging from 210 to 220 ppbv; PCE was effectively removed by the vapor-phase activated carbon column.

Toluene has a boiling point of 231.1 °F and PCE has a boiling point of 249.8 °F. Because of their low boiling points, toluene and PCE were apparently easily desorbed from the sludge and remained in the off-gas stream after the air-cooled and refrigerated condensers. However, both contaminants were effectively removed by the vapor-phase activated carbon column.

B.5.2 MBOCA Removal

The LT³® system achieved MBOCA removal efficiencies ranging from 79.8 to 99.3 percent, with MBOCA concentrations in the treated sludge ranging from 3 to 9.6 mg/kg. MBOCA concentrations in untreated sludge ranged

from 43.6 to 860 mg/kg. The decrease in MBOCA concentration after treatment was accompanied by an increase in the measured concentration of AC-MBOCA (see Figures B-1 and B-2), a known metabolite of MBOCA. These results indicate that the removal of MBOCA is probably due partially to thermal desorption and partially to its conversion to AC-MBOCA. However, the presence of co-eluting compounds may have interfered with the quantitation of AC-MBOCA. The concentration of DAC-MBOCA, another metabolite of MBOCA, decreased after treatment for most samples analyzed, probably due to removal mechanisms similar to those described for MBOCA.

MBOCA has a high tendency to sorb onto clay particles, as indicated by its large adsorption coefficient of 1,500 (Versar, 1983). This tendency may have affected the LT³ system's ability to completely remove MBOCA from the sludge. MBOCA has a sublimation point of 240.8 to 251.6 °F, which is well below the treatment temperature of above 500 °F. However, MBOCA was not completely removed during treatment, probably because of its high tendency to be sorbed onto soil particles. MBOCA concentrations in the fabric filter dust were significantly higher than MBOCA concentrations in the treated sludge, which supports this hypothesis. MBOCA concentrations in fabric filter dust ranged from 6.3 to 75 mg/kg. In addition, MBOCA was detected in liquid condensate at concentrations ranging from 100 to 257 micrograms per liter (µg/L). No MBOCA was detected in the exhaust gas from the refrigerated condenser.

In fabric filter dust, the concentration of AC-MBOCA is significantly higher than the concentration of DAC-MBOCA. Apparently, MBOCA and DAC-MBOCA are converted to AC-MBOCA during heating. However, AC-MBOCA associated with small particles is not effectively desorbed but remains attached to the small particles, which are carried away in the sweep gas and are removed in the fabric filter.

B.5.3 SVOC Removal

The LT³ system generally decreased the concentration of SVOCs in treated sludge. 4-Methylphenol and bis(2-ethylhexyl)phthalate were identified as critical analytes for the LT³ system SITE demonstration. The concentrations of 3- and 4-methylphenol ranged from 3,100 to 20,000 µg/kg in the untreated sludge. After treatment, 3- and 4-methylphenol concentrations ranged from 540 to 4,000 µg/kg (see Figure B-3), representing removal efficiencies between 57.0 and 97.4 percent. The concentration of 3- and 4-methylphenol in the fabric filter dust ranged from 1,200 to 5,100 µg/kg. Liquid condensate contained 3- and 4-methylphenol at concentrations ranging from 7,900 to 25,000 µg/L. However, no 3- or 4-methylphenol was detected in the exhaust gas exiting the refrigerated condenser. Because of its low boiling point (about 395 °F),

3- and 4-methylphenol is readily desorbed and removed from the sludge, but it condenses and remains in the liquid condensate from the refrigerated condenser.

Bis(2-ethylhexyl)phthalate was present in untreated sludge at concentrations ranging from 1,100 to 7,900 µg/kg. After treatment, the concentration of bis(2-ethylhexyl)phthalate was reduced to below the detection limit, which was less than 820 µg/kg for most samples. The concentration of bis(2-ethylhexyl)phthalate in fabric filter dust ranged from 650 to 3,600 µg/kg. Due to its high boiling point (723.2 °F), bis(2-ethylhexyl)phthalate is not likely to be desorbed during heating in the LT³ system, because the sludge treatment temperature ranged from 500 to 530 °F. Therefore, the decreased concentration of bis(2-ethylhexyl)phthalate was probably due to thermal decomposition during heating. The decomposition scenario is supported by the sampling results of the liquid condensate and the exhaust gas from the refrigerated condenser. The concentration of bis(2-ethylhexyl)phthalate in the condensate was below the detection limit of 3,000 µg/L. Similarly, the concentration of bis(2-ethylhexyl) phthalate in the exhaust gas (before granular activated carbon treatment) was below the detection limit of 28 ppbv.

Although the concentrations of most SVOCs decreased with treatment, the concentration of two SVOCs increased with treatment. These two SVOCs are phenol and chrysene. The increase in the phenol concentration after treatment (see Figure B-4) is most likely due to chemical transformations during heating. The increase in phenol concentration is most likely due to the dehalogenation of 1,2-dichlorobenzene, a reaction that has been reported to take place at elevated temperatures and alkaline pH conditions (Larock, 1989). 1,2-Dichlorobenzene was present in the untreated sludge at concentrations ranging from 1,400 to 110,000 µg/kg. After treatment, the concentration of 1,2-dichlorobenzene was reduced to below method detection limits. The pH of the untreated sludge was alkaline, ranging from 10.9 to 11.2, as a result of lime being added to the lagoon sludge as a conditioning agent before dewatering.

Chrysene, which was not present in untreated sludge, was detected in treated sludge and fabric filter dust. However, chrysene could not form under the treatment conditions because of the extremely high temperature (1,472 °F) required for its synthesis (Merck Index, 1989). A minor leak of heat transfer fluid, which contained triphenylene, may have caused the apparent increase in chrysene concentration. Triphenylene and chrysene produce the same response in the gas chromatography/mass spectroscopy (GC/MS) technique used. Triphenylene has a boiling point of 797 °F; therefore it was not effectively removed and remained in the treated sludge and fabric filter dust.

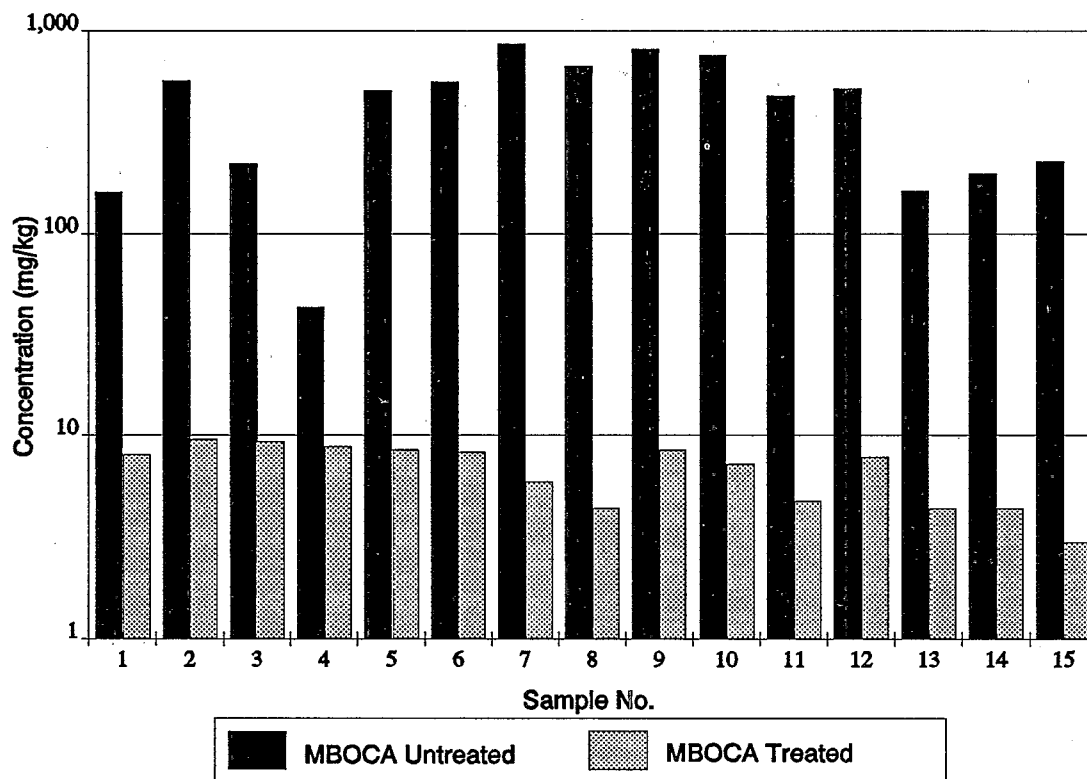


Figure B-1 MBOCA Concentrations in Untreated and Treated Sludge

B.5.4 The Fate of Chloride in the LT³® System

The dehalogenation scenario discussed above is supported by other demonstration results, which indicate that treatment reduced the EOX concentration in sludge but increased the chloride concentration. Figure B-5 shows the reduced concentration of EOX after treatment. However, the EOX concentration in the fabric filter dust was higher than in the untreated sludge. This increase suggests that EOX associated with small particles are not effectively removed. Instead, they remain attached to the small particles, which are carried away in the sweep gas and are removed in the fabric filter or carried through to the condensers. The concentration of TOX in the condensate ranged from 25 to 73 mg/L, which was significantly higher than the 0.3 mg/L TOX concentration in the city water.

Figure B-6 shows that the chloride concentration in sludge increased after treatment, probably as a result of chloride mineralization from dehalogenation reactions. The concentration of chloride in fabric filter dust was also higher than in the untreated sludge. The concentration of chloride in the liquid condensate ranged from 7.5 to 92.4 mg/L.

The formation of HCl during dehalogenation reactions may have caused the reduction in the pH of treated sludge. The pH of untreated sludge ranged from 10.9 to 11.2. The pH of treated sludge ranged from 9.1 to 9.6. However, the pH of the liquid condensate stream was alkaline, ranging

from 10.1 to 10.2. Alkaline pH could have resulted from lime particles being carried away in the off-gas stream before becoming dissolved in the condensate. The concentration of HCl in the exhaust gas from the refrigerated condenser was below the detection limit of 0.034 milligrams per day standard cubic meter (mg/dscm).

B.5.5 The Formation and Distribution of Dioxins and Furans

Dioxins and furans were detected in process residuals. Samples were analyzed for polychlorinated dibenzo(p)dioxins (CDD) and polychlorinated dibenzofurans (CDF). Analytes included 2,3,7,8-tetrachlorodibenzo(p)dioxin (2,3,7,8-TCDD) and the following congeners:

Dioxins

tetrachloro dibenzo(p)dioxins (TCDD)
 pentachloro dibenzo(p)dioxins (PeCDD)
 hexachloro dibenzo(p)dioxins (HxCDD)
 heptachloro dibenzo(p)dioxins (HpCDD)
 octachloro dibenzo(p)dioxins (OCDD)

Furans

tetrachloro dibenzofurans (TCDF)
 pentachloro dibenzofurans (PeCDF)
 hexachloro dibenzofurans (HxCDF)

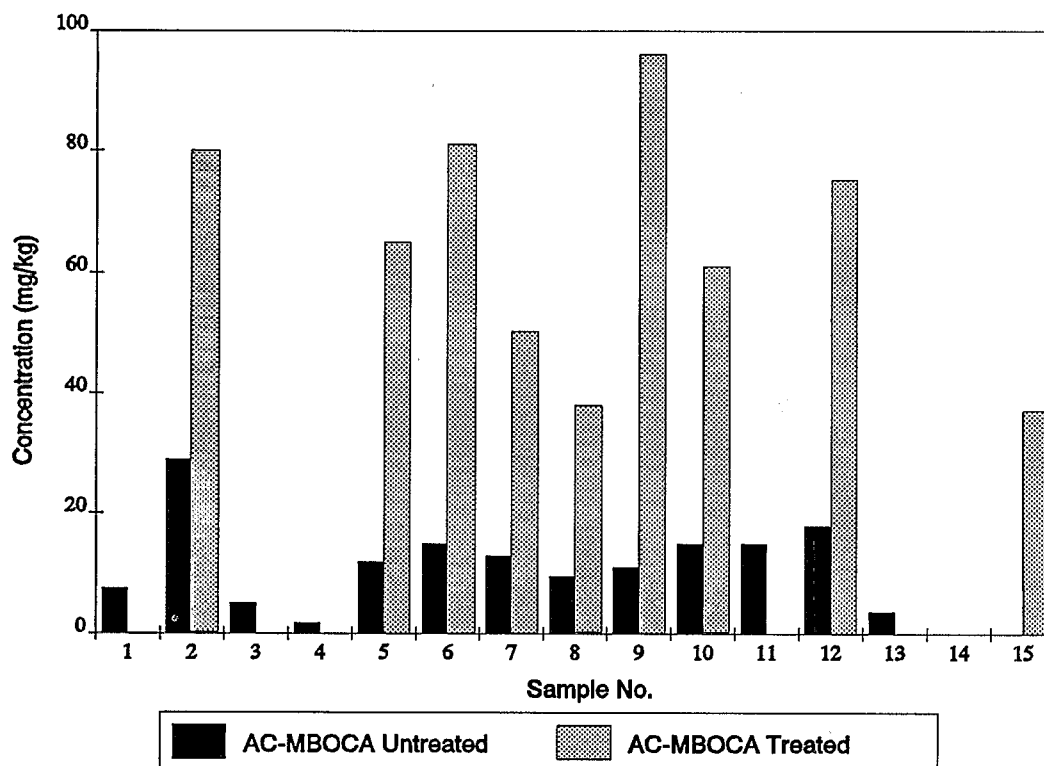


Figure B-2 AC-MBOCA Concentrations in Untreated and Treated Sludge

heptachloro dibenzofurnas (HpCDF)
octachloro dibenzofurans (OCDF)

The formation of dioxins and furans is encouraged by sludge treatment conditions such as elevated temperature (greater than 500 °F), the presence of chemical precursors, alkaline pH, and a high concentration of free chloride (EPA, 1980). The following potential dioxin precursors were present in untreated and treated sludge samples: 1,2-dichlorobenzene; 4-chloroaniline; o-chloroaniline; aniline; phenol; 4,6-dinitro-2-methylphenol; 2,4-dibromophenol; 2-chlorophenol; 4-bromophenol; and 2,4-dibromophenol. As stated above, alkaline pH resulted from lime being added to the sludge. High concentrations of free chloride resulted from adding ferric chloride to the sludge as a conditioning agent before dewatering.

CDDs and CDFs were formed when sludge was treated in the LT³ system. OCDD was the only congener found in one sample of untreated sludge, at a level near the detection limit [0.63 parts per billion (ppb) versus a detection limit of 0.54 ppb]. Table B-2 shows the arithmetic mean concentrations of CDDs and CDFs in samples from each location. Mean values were calculated by assigning zero to all results reported as nondetectable (ND). As a result, these mean values may underestimate CDD and CDF concentrations.

Fabric filter dust consistently contained higher concentrations of CDD and CDF than treated sludge, and the dust was the only solid matrix containing measurable amounts of 2,3,7,8-TCDD. No 2,3,7,8-TCDD was detected in liquid condensate, but five of the 10 congeners were found at measurable concentrations. TCDD and TCDF predominated, with lower concentrations of PeCDD, PeCDF, and HxCDF. As with the treated soil samples, tetra and penta congeners were more prevalent.

The liquid condensate data suggest that TCDD and TCDF, and possibly PeCDD, PeCDF, and HxCDF, increased measurably with each successive run (see Table B-3). The condensers were not cleaned between runs, and a small amount of particulate matter may have accumulated within the condensers. CDDs and CDFs are strongly adsorptive, lipophilic, and only slightly water-soluble (EPA, 1980). The increasing concentrations of congeners may be attributed to the release of CDDs and CDFs from particulate matter within the condenser.

Vapor-phase activated carbon reduced all CDDs and CDFs in the off-gas to less than 0.1 nanograms per dry standard cubic meter (ng/dscm). The removal efficiency varied with analyte, from 20 percent for HpCDD, to 100 percent (or to nondetectable levels) for PeCDF and HxCDD.

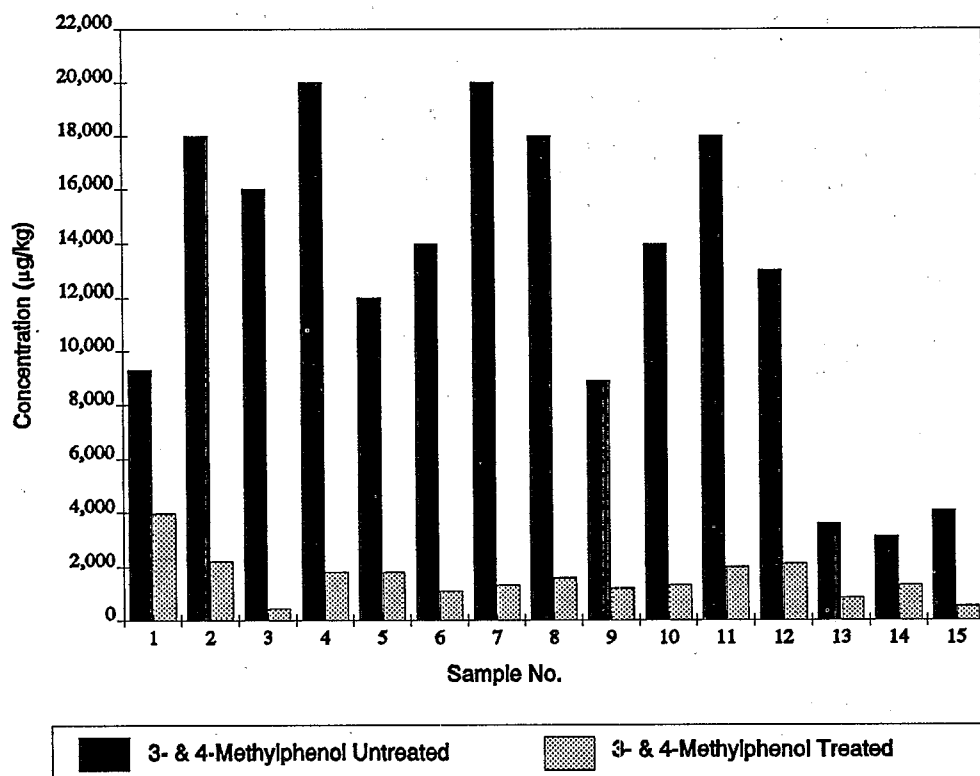


Figure B-3 3- and 4-Methylphenol Concentrations in Untreated and Treated Sludge

B.5.6 The Fate of Metals in the LT³® System

Untreated and treated sludge samples had similar metal concentrations, which was expected because the LT³® technology is not designed to remove metals. However, metal concentrations in fabric filter dust were, in general, greater than the concentration in untreated and treated sludge. The results also showed that TCLP metal concentrations were below detection limits.

B.5.7 Stack Emissions

During the SITE demonstration, the total nonmethane hydrocarbon concentration (TNMHC) in stack gas was determined by separate analyses of samples collected in SUMMA canisters. Analytical results showed that TNMHC was 6.7 parts per million by volume (ppmv) during the first run, 7.6 ppmv during the second run, and 11 ppmv during the last run. Because a new vapor-phase activated carbon unit was used during the SITE demonstration, the results suggest that breakthrough occurred after a relatively short period of time.

Similar observations were made during routine remedial operations at the ADC site. As part of the LT³® system, a continuous emissions monitoring (CEM) system was used to monitor the total hydrocarbon concentration (THC). The CEM system occasionally recorded THCs as high as 100 ppmv. To rectify the problem, Weston replaced the vapor-

phase carbon unit regularly. However, CEM results indicated that THC was below 10 ppmv for only about the first 12 hours of operation of the new vapor-phase carbon unit. After 12 hours, THC was significantly higher.

TNMHC includes both VOCs and SVOCs. VOC emissions from the stack were predominately composed of propylene and chloromethane. SVOC stack emissions did not contain any predominant contaminants, and testing indicated that all compounds were present in concentrations at or below instrument detection limits.

The particulate concentration in the stack gas ranged from less than 8.5×10^{-4} to 6.7×10^{-3} grains per dry standard cubic meter (gr/dscm) and the particulate emissions ranged from less than 1.2×10^{-4} to 9.2×10^{-4} pounds per hour (lb/hr). The chloride concentration in the stack gas was below the detection limit, which had an average value of 2.8×10^{-2} mg/dscm.

In addition, during both the SITE demonstration and remedial operations at the site, unusual levels of fugitive dust emissions from the treated sludge pile area were occasionally observed. During remedial operations, dust levels ranging from 0.16 to 0.99 milligrams per cubic meter (mg/m³) were recorded downwind of the treated sludge pile and in the control trailer located near the treated sludge pile.

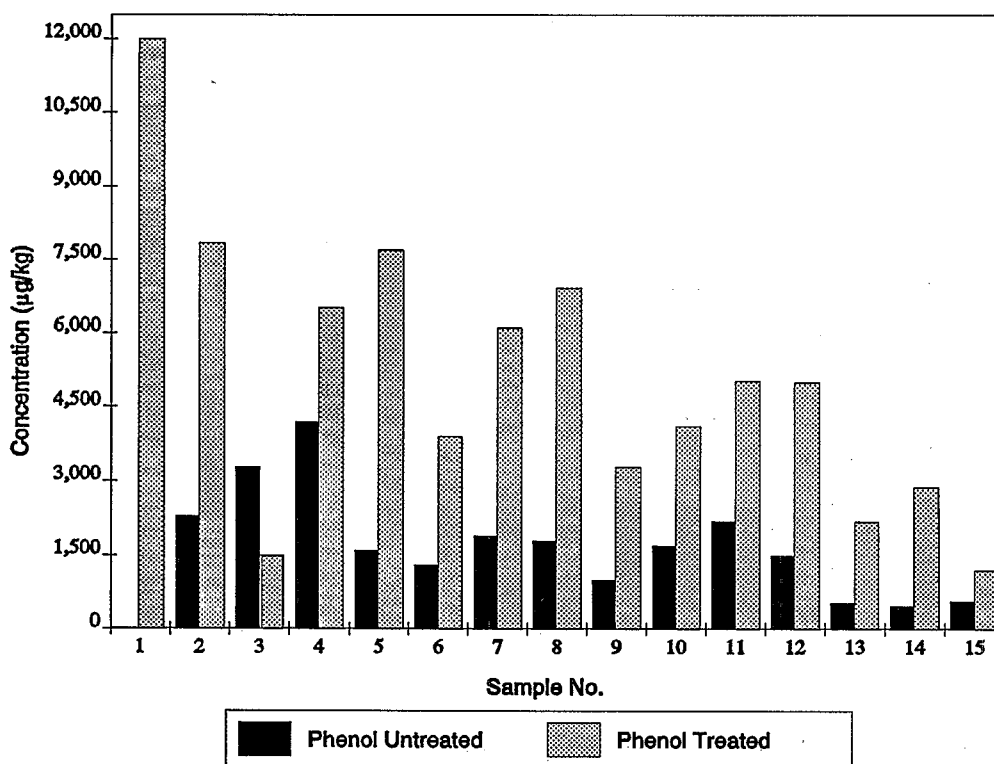


Figure B-4 Phenol Concentrations in Untreated and Treated Sludge

B.5.8 Physical Properties of Sludge

Untreated sludge consisted of wet, nonhomogeneous clumps of soil. Processed sludge consisted of dry, homogeneous, fine particles. Because of the decrease in moisture content, the processed sludge had a tendency to generate fugitive dust.

The following physical properties of the sludge were determined: (1) particle size distribution, (2) soil classification, (3) available surface area, (4) moisture content, (5) density, and (6) CBR. Each of these properties is discussed below.

Particle Size Distribution - The arithmetic mean diameters of untreated sludge and fabric filter dust were found to be 765 microns (μm) and 34.12 μm , respectively. The size of the fabric filter dust particles is important for the operation of the fabric filter, which is part of the LT³⁰ system. Also, the size of the fabric filter dust is important to determine health risks associated with the inhalation of the fabric filter dust during operations.

Soil Classification - According to the American Society of Testing and Materials (ASTM) soil classification system, untreated sludge was classified in the A-7-6 soil group. Typical characteristics of material in this group are plastic clay soil with 75 percent or more of the particles smaller than 75 μm in diameter, a minimum liquid limit of

41 percent, and a plasticity index above 11. Materials in this group usually have a high-volume change between wet and dry states.

Available Surface Area - The available surface area of the untreated sludge ranged from 49.1 to 52.3 square meters per gram (m^2/g). These values are comparable to the surface area of kaolinite, a clay material that has a reported available surface area of 25 m^2/g (Stumm and Morgan, 1981).

Moisture Content - The moisture content of the untreated sludge (after dewatering) ranged from 41 to 44 percent. The moisture content of the treated sludge (after conditioning) ranged from 7.5 to 23 percent.

Density - Treated sludge had higher maximum dry densities than untreated sludge. Although no large changes were observed, analytical results suggest that thermal

processing changed the sludge characteristics. In other case studies, the density of the soil decreased after treatment (Weston, 1986).

CBR - To determine the stability of the treated sludge, CBR values were determined as a function of dry density at 10, 25, and 56 blows per layer of sludge sample. The results indicated that CBR values increase as a function of dry density. Treated sludge lacks moisture and is likely to

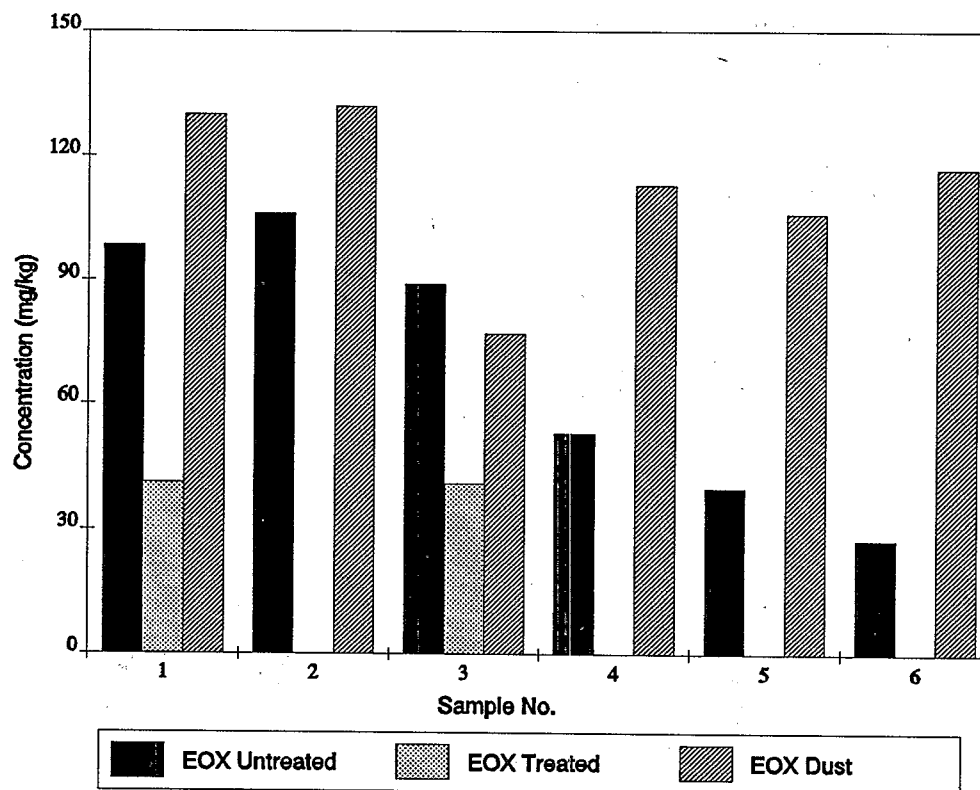


Figure B-5 EOX Concentrations in Untreated and Treated Sludge and in Fabric Filter Dust

exhibit some instability. To obtain material with significant bearing capacity and moderate stability, water needs to be added and the moistened material needs to be compacted to increase the material's density and stability. The level of compaction required can be determined from the CBR value.

B.5.9 Toxicological Properties of Sludge

Toxicity tests were conducted on untreated and treated sludge and sludge leachate samples. Sludge was tested using the earthworm (*Eisenia foetida*) as the test organism. Leachate was tested using the fathead minnow (*Pimephales promelas*) and the water flea (*Ceriodaphnia dubia*) as the test organisms.

Four replicate tests of each sludge sample were conducted with 10 worms per replicate. No dilutions were conducted, and test results represented 100 percent test soil. All the worms in the untreated and treated sludge died within 48 hours. Therefore, a median lethal concentration (LC50) could not be calculated from the data to determine if untreated sludge was more toxic.

The mortality of the earth worms in untreated and treated sludge samples was attributed to the alkaline pH of untreated and treated sludge. The pH of untreated sludge ranged from 10.9 to 11.2. The pH of treated sludge ranged from 9.1 to 9.6. Subsequent to the SITE demonstration,

additional toxicity tests were conducted with untreated and treated sludge at controlled pH and at different dilutions. The sludge samples were diluted using artificial soil at 15, 25, 40, 60, and 100 percent. The pH was adjusted using acidified artificial soil and HCl. The resulting pH of untreated and treated sludge samples ranged from 7.4 to 8.7 at all dilutions ranging from 15 to 40 percent; at 60 and 100 percent dilutions, the pH ranged from 8.3 to 9.6. The 7-day LC50 was 56.3 percent for untreated sludge and 76.3 percent for treated sludge. The 14-day LC50 was 49.1 percent for untreated sludge and 75.2 percent for treated sludge. Therefore, at controlled pH, untreated sludge was more toxic than treated sludge.

The results of the leachate toxicity study also suggest that the LT³® technology reduces the toxicity of treated materials. For the fathead minnows, toxicity was reduced from a LC50 of about 40 percent in the untreated sludge leachate sample to no toxicity in the treated sludge leachate sample. For *Ceriodaphnia dubia*, toxicity was also reduced. Only 15 percent of the test organisms exposed to 6.25 percent leachate solution from untreated sludge survived. When the test organisms were exposed to a solution of 100 percent leachate from treated sludge, 85 percent survived.

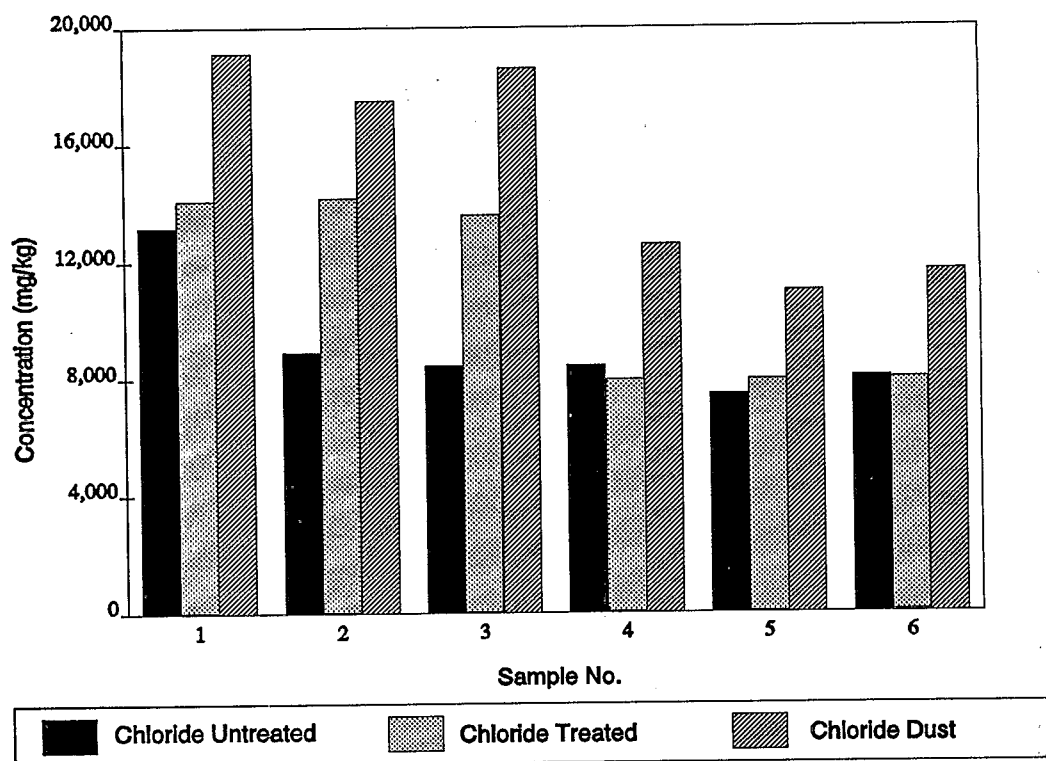


Figure B-6 Chloride Concentrations in Untreated and Treated Sludge and in Fabric Filter Dust

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Table B-2 Arithmetic Mean Concentrations of CDDs and CDFs

Parameter	Sampling Location					
	Untreated Sludge	Treated Sludge	Filter Dust	Liquid Condensate	Exhaust Gas from Refrigerated Condenser	Stack Gas
	ng/kg (ppb)	ng/kg (ppb)	ng/kg (ppb)	ng/L (ppt)	ng/dscm	ng/dscm
2,3,7,8-TCDD	0	0	0.10	0	0.010	0.0010
TCDD	0	0.987	6.54	119.0	0.137	0.0087
TCDF	0	2.42	19.80	697.0	0.178	0.066
PeCDD	0	0.534	5.98	60.0	0.20	0.0089
PeCDF	0	0.066	2.49	47.7	0.14	0
HxCDD	0	0	0.81	0	0.0020	0
HxCDF	0	0	0.50	2.8	0.0004	0.0003
HpCDD	0	0	1.38	0	0.023	0.017
HpCDF	0	0	0.14	0	0.005	0.0012
OCDD	0.21	0	3.20	0	0.121	0.025
OCDF	0	0	0.04	0	0.0067	0.0024

All CDDs and CDFs not detected are assigned a value of 0.

Detection limits in untreated sludge ranged from 0.04 to 0.80 nanograms per gram (ng/g). Detection limits in treated sludge ranged from 0.07 to 1.6 ng/g. Detection limits in fabric filter dust ranged from 0.14 to 9.6 ng/g. Detection limits in the liquid condensate ranged from 1.4 to 17 ng/L.

ng = nanogram

ppt = parts per trillion

Table B-3 Liquid Condensate Concentrations (ppt) Averaged by Run ^a

Parameter ^b	Run 1	Run 2	Run 3
TCDD	11	67	280
TCDF	0.92	490	1600
PeCDD	0	0	180
PeCDF	0	23	120
HxCDF	0	0	8.4

^a = CDDs and CDFs not detected were assigned a value of zero.

^b = HxCDD, HpCDD, HpCDF, OCDD, and OCDF were not detected in liquid condensate samples.

Appendix C Case Studies

This appendix summarizes case studies on the use of the Low Temperature Thermal Treatment (LT³) system. These case studies were written and provided by Roy F. Weston, Inc. (Weston). During the development of the LT³ system, Weston conducted tests at the bench- and pilot-scale and collected treatability data for the following contaminants: coal tar, drill cuttings (oil-based mud), leaded and unleaded gasoline, No. 2 diesel fuel, JP4 jet fuel, petroleum hydrocarbons, halogenated and nonhalogenated solvents, volatile organic compounds (VOC), semivolatile organic compounds (SVOC), and polynuclear aromatic hydrocarbons (PAH). Weston also completed a full-scale remediation using the LT³ system. The information available for these case studies ranged from detailed analytical data to relatively little information on system performance and cost. Results from the following five case studies are summarized in this appendix:

Case Study	Site and Location
C-1	Confidential Site, Springfield, Illinois
C-2	Tinker Air Force Base, Oklahoma City, Oklahoma
C-3	Letterkenny Army Depot, Chambersburg, Pennsylvania
C-4	Environmental Technology Laboratory, Lionville, Pennsylvania
C-5	Bench-Scale LT ³ Test, Colorado Springs, Colorado

Case Study C-1

Project: LT³ for Petroleum Contaminated Soil

Client: Confidential

Site: Confidential, Springfield, Illinois

Project Description

While renovating an existing building, several leaking underground storage tanks, previously holding No. 2 fuel oil and gasoline, were discovered. Weston was awarded the

contract to process the contaminated soil in the LT³ system. Approximately 1,000 cubic yards of material were excavated and processed. The objective was to render the soil suitable for on-site backfill and eliminate the need for transportation and off-site disposal in a special waste landfill.

Initial concentrations of contaminants were less than 1,000 parts per million (ppm). Stringent cleanup objectives were established by the Illinois EPA for benzene, toluene, ethylbenzene, xylene, and naphthalene. In addition, clean-up objectives for 15 separate PAHs were established at below the detection limit of 330 parts per billion (ppb).

The Illinois EPA also established stringent air emission limitations that included the following:

- Carbon monoxide (CO) less than 100 ppm
- Total hydrocarbons less than 100 ppm
- No visible dust emissions
- Development of detailed test and safety plans
- Environmental permitting including air, operating, and landfill permits for residual material not suitable for processing (concrete, scrap metal, oversize rock)
- Excavation and tank removal
- Mobilization of the LT³ system
- Operating of the LT³ system including process sampling
- Clean soil storage in covered stockpile
- Analysis of soil to confirm that it is clean
- Site closure

Results

One thousand cubic yards of contaminated soil were successfully processed, and all cleanup objectives were met. Table C-1 summarizes analytical results. Processed soil was approved by the Illinois EPA for on-site backfill. Stack emissions were in compliance with all state and federal regulations. Fugitive emissions of dust and organic vapors were well controlled, with no complaints from residents located as close as 100 yards away from the LT³® system.

Case Study C-2

Project: LT³® Processing of Soils Contaminated with Chlorinated Solvents and JP4 Jet Fuel

Client: U.S. Army Toxic and Hazardous Materials Agency (USATHAMA)

Site: Tinker Air Force Base, Oklahoma City, Oklahoma

Project Description

In a continuing effort to identify and evaluate new and innovative technologies for remediation of Department of Defense (DOD) sites, USATHAMA wanted to perform a full-scale demonstration of the LT³® system. The LT³® system had already been proven effective in the pilot-scale during a field demonstration at Letterkenny Army Depot. The objective of the test would be to determine optimum operating conditions and maximum feed rates for feed soil contaminated with a wide variety of compounds, including chlorinated solvents, semivolatile organics, and JP4 aviation fuel (all common contaminants at DOD installations). Following a comprehensive search of remedial investigation reports, Tinker Air Force Base (Tinker AFB) was selected as the site for the full-scale demonstration. Tinker AFB was selected because of the wide variety of contaminants present and the plastic clay soil matrix which provided a "worst case" test regarding material handling and contaminant removal.

Weston was awarded the task of performing the demonstration project at Tinker AFB. Weston excavated the existing clay and asphalt cap from the previously closed landfill. A total of approximately 3,000 cubic yards of contaminated soil was excavated for treatment during the demonstration program. Concentrations of trichloroethene (TCE) in the contaminated soil were as high as 6,100 ppm. Other significant contaminants included chlorinated organics (for example, dichlorobenzene) and JP4 aviation fuel.

Weston Scope of Work

- Preparation of all advance plans, including the following:

- Detailed Test Plan
- Sampling and Analysis Plan
- All environmental permitting including a RCRA RD&D Permit from U.S. EPA, Region 6
- Health and Safety Plan

- Site preparation and waste excavation
- Mobilization and operation of the LT³® system
- Analysis of soil samples in on-site laboratory
- LT³® system demobilization, decontamination, and site closure

Results

- The LT³® system reduced the concentrations of all target contaminants below the goal cleanup levels and in most cases to less than detection limits.
- The above excellent performance was accomplished while operating at processing rates as high as 20,000 lb/hr, which was 33 percent higher than the design feed rate.
- As a result of this program, estimated costs for LT³® treatment have been significantly reduced due to the ability to successfully operate at significantly increased soil feed rates.

Case Study C-3

Project: LT³® for VOC-Contaminated Soil

Client: USATHAMA

Site: Letterkenny Army Depot, Chambersburg, Pennsylvania

Project Description

Contamination of soils from past operations involving VOCs has become one of the preeminent environmental concerns at several U.S. Army installations. TCE is the most frequently found contaminant; however, other VOCs such as dichloroethene, tetrachloroethene, and xylene have also been found. If allowed to remain in the soil, these contaminants can migrate to underlying ground water.

USATHAMA contracted with Weston to develop an innovative solution to this problem. The contract called for the demonstration of a new technology on a pilot scale at a site contaminated with VOCs.

Table C-1 Results of Full-Scale Cleanup of No.2 Fuel Oil and Gasoline-Contaminated Soil ^{a, b}

Contaminant	Boiling Point (°F)	Feed Soil Concentration (ppb)	Processed Soil Concentration (ppb)	Contaminant Removal Efficiency (%)	Concentration in TCLP Leachate (ppb)
Benzene	176	1,000	5.2	99.48	Not Analyzed
Toluene	231	24,000	5.2	99.98	Not Analyzed
Xylenes	291	110,000	<1.0	>99.999	Not Analyzed
Ethylbenzene	277	20,000	4.8	99.98	Not Analyzed
Napthalene	424	4,900	<330	>93.3	Not Analyzed
Carcinogenic Priority PAHs					
Benzo(a)-anthracene	850	<6,000	<330	<94.5	16J
Benzo(a)pyrene	923	<6,000	<330	<94.5	4J
Benzo(b)-fluoranthene	896	<6,000	<330	<94.5	N/D
Chrysene	875	<6,000	590	<90.2	N/D
Dibenzo(a,h)-anthracene	975	<6,000	<330	<94.5	N/D
Noncarcinogenic Priority PAHs					
Acenaphthene	534	890	<330	<62.9	1J
Acenaphthalene	518	1,200	<330	<72.5	0.13J
Anthracene	644	2,700	<330	>87.8	3J
Benzo(g,h,i)-perylene	995	<6,000	<330	<94.5	N/D
Benzo(k)-fluoranthene	896	<6,000	450	<92.5	N/D
Fluoranthene	707	<6,000	<330	<94.5	N/D
Fluorene	560	4,900	<330	>93.3	N/D
Ideno(1,2,3-c,d)-pyrene	950	<6,000	<330	<94.5	N/D
Phenanthrene	644	2,400	430	82.1	3J
Pyrene	759	<6,000	<330	<94.5	N/D

^a = Processed soil temperature was 350 °F.

^b = Processed soil residence time was 70 minutes.

J = Present at less than detection limit.

N/D = Not detected; detection limit = 20 ppb.

USATHAMA selected a site at the Letterkenny Army Depot in Chambersburg, Pennsylvania. Weston responded with the first LT³® system, much as it exists today. The system incorporated a thermal process 10 feet in length. Previous experience was limited to laboratory work with a unit only 3 feet in length.

Weston Scope of Work

- Design of the pilot system
- Preparation of test and safety plans
- Environmental permitting
- Equipment selection
- Installation, start-up, and test operation
- Demobilization and site closure
- Identification of full-scale design criteria
- Preparation of a technical report including economics and auxiliary pollution control equipment specifications

Results

More than 15,000 pounds of contaminated soils were processed in 28 operating days. Table C-2 summarizes the analytical results. A removal efficiency of more than 99.99 percent was demonstrated in the soil, and no VOCs were detected in the stack of the afterburner, indicating a destruction and removal efficiency (DRE) of 100 percent for the system.

Stack emissions were in compliance with all federal and state regulations including VOCs, HCl, CO, and particulates.

Regulatory authorities allowed the disposal of processed soil on site as backfill.

Case Study C-4

Project: LT³® Laboratory Testing of Contaminated Soil

Client: Various Industrial and Federal Clients

Site: Environmental Technology Laboratory in Lionville, Pennsylvania

Project Description

Initially to prove the concept and now as a tool for determining feasibility and predicting LT³® performance,

Weston has established a laboratory complete with a thermal processor, sample storage and preparation facilities, and analytical capabilities. Clients with environmental problems that might be addressed with the LT³® system can send a sample of the material to be processed to the laboratory where testing will determine the feasibility and predict the performance of the full-scale system.

Testing prior to mobilization of the full-scale system will avoid the problems of trying to apply the system to compounds and soils for which it is not suited. Process rates can be determined and approximations of cleanup capabilities can be made. Weston has tested a broad spectrum of materials, but each contaminant behaves differently in association with other compounds and with differing soil types making testing of prime importance.

Weston Scope of Work

- Sample collection (if required)
- Sample preparation
- Initial feed soil analysis
- Preparation of a test and safety plan
- Test operation
- Data collection and analysis
- Return of sample material to client
- Final report including predictions of process rates and cleanup capabilities

Results

A wide range of contaminants in varying types of soils and other host matrices have been successfully tested, including VOCs, petroleum hydrocarbons, coal tars, chlorinated solvents, a wide range of carcinogenic and noncarcinogenic PAHs, and many SVOCs, such as xylene and hexachlorobenzene. In addition Weston has:

- Proven concept feasibility for specific applications
- Developed standard testing and safety plans
- Established the capability to predict process rates and levels of contaminant reduction

Weston has performance parameters for the generic waste streams and specific compounds shown in Tables C-3, C-4 and C-5.

Table C-2 Results of Pilot-Scale Demonstration on VOC-Contaminated Soil^{a, b}

Contaminant	Boiling Point (°F)	Feed Soil Concentration (ppb)	Processed Soil Concentration (ppb)	Contaminant Removal Efficiency (%)	Concentration in TCLP Leachate (ppb)
Benzene	141	586,106	730	99.88	Not Analyzed
Trichloroethene	189	2,678,536	1,800	99.93	Not Analyzed
Tetrachloroethene	250	1,422,031	1,400	99.90	Not Analyzed
Xylene	293	27,197,367	550	99.998	Not Analyzed
Other VOCs	N/A	39,127	BDL	N/A	Not Analyzed
Total VOCs	N/A	31,923,167	4,480	99.99	Not Analyzed

^a = Processed soil temperature was 320 °F.

^b = Processed soil residence time was 60 minutes.

N/A = Not Applicable.

BDL = Below detection limit.

Case Study C-5

Project: Bench-Scale LT³® Test for Chlorinated Benzene Contaminated Soil

Client: Confidential

Location: Colorado Springs, Colorado

Bench-scale studies were conducted at Colorado Springs, Colorado, on soil contaminated with chlorinated benzene. The soil was treated at 400 °F for a residence time of 44 minutes. The total concentration of contaminants was 530 mg/kg. Of that amount, 523 mg/kg was 1,4-dichlorobenzene, and the rest consisted of other contaminants. Table C-6 summarizes the results. Removal efficiencies greater than 99.9 percent were achieved.

Table C-3 Results of Engineering Technology Laboratory^{a, b}

Contaminant	Boiling Point (°F)	Feed Soil Concentration (ppb)	Processed Soil Concentration (ppb)	Contaminant Removal Efficiency (%)	Concentration in TCLP Leachate (ppb)
Methylene Chloride	104	120,000	22	99.98	<14
Acetone	134	12,000	93	99.2	<473
n-Butanol	243	32,000	340	98.9	<1,200
1,2-Dichloroethane	183	120	<5	>95.8	<5
1,2-Dichloropropane	356	4,000	<5	>99.9	<5
Isopropanol	180	7,900	<100	>98.7	<1,700
Methanol	148	30,000	<6,000	>80.0	<230
Cyclohexane	176	230	<10	>95.7	<10

^a = Processed soil temperature was 250 °F.

^b = Processed soil residence time was 45 minutes.

Table C-4 Results of Bench-Scale LT³® Test on Coal Tar-Contaminated Soil^{a, b}

Contaminant	Boiling Point (°F)	Feed Soil Concentration (ppb)	Processed Soil Concentration (ppb)	Contaminant Removal Efficiency (%)	Concentration in TCLP Leachate (ppb)
Benzene	176	<150	<5.0	>96.7	N/D
Toluene	231	<150	<5.0	>96.7	N/D
Ethylbenzene	277	78,000	<5.0	>99.994	N/D
Methyl Chloride	106	14,000	<5.0	>99.96	N/D
Napthalene	424	1,200,000	1,200	99.9	N/D
Carcinogenic Priority PAHs					
Benzo(a)-anthracene	850	100,000	2,100	97.9	N/D
Benzo(a)pyrene	923	82,000	1,600	98.0	N/D
Benzo(b)-fluoranthene	896	45,000	1,700	96.2	N/D
Chrysene	875	96,000	4,400	95.4	N/D
Dibenzo(a,h)-anthracene	975	9,600	<660	>93.1	N/D
Noncarcinogenic Priority PAHs					
Acenaphthene	534	28,000	<660	>97.6	N/D
Acenaphthalene	518	28,000	<660	>97.6	N/D
Anthracene	644	160,000	<660	>99.6	N/D
Benzo(g,h,i)-perylene	995	38,000	790	97.9	N/D
Benzo(k)-fluoranthene	896	46,000	1,800	96.1	N/D
Fluoranthene	707	192,000	6,500	96.6	N/D
Fluorene	560	222,000	<660	>99.7	N/D
Ideno(1,2,3-c,d)-pyrene	950	31,000	670	97.8	N/D
Phenanthrene	644	580,000	14,000	97.6	N/D
Pyrene	759	275,000	3,100	98.9	N/D

^a = Processed soil temperature was 400 °F.

^b = Processed soil residence time was 50 minutes.

N/D = Not detected; detection limit = 150 ppb.

Table C-5 Results of Bench-Scale LT³® Testing on Petroleum Hydrocarbon-Contaminated Soil^{a, b}

Contaminant	Boiling Point (°F)	Feed Soil Concentration	Processed Soil Concentration	Contaminant Removal Eff. (%)	Concentration in TCLP Leachate (ppb)
Oil and Grease (By IR)	N/A	100,000 ppm	170 ppm	99.82	N/A
Napthalene	424	23,000 ppb	<330 ppb	>98.57	1J
Carcinogenic Priority PAHs					
Benzo(a)-anthracene	850	66,000 ppb	<330 ppb	>99.50	N/D
Benzo(a)pyrene	923	110,000 ppb	<330 ppb	>99.70	N/D
Benzo(b)-fluoranthene	896	90,000 ppb	<330 ppb	>99.63	N/D
Chrysene	875	80,000 ppb	<330 ppb	>99.59	N/D
Dibenzo(a,h)-anthracene	975	19,000 ppb	<330 ppb	>98.26	N/D
Noncarcinogenic Priority PAHs					
Acenaphthene	534	28,000 ppb	<330 ppb	>98.82	N/D
Acenaphthalene	518	20,000 ppb	<330 ppb	>98.35	2J
Anthracene	644	49,000 ppb	<330 ppb	>99.32	1J
Benzo(g,h,i)-perylene	995	19,000 ppb	<330 ppb	>98.26	N/D
Benzo(k)-fluoranthene	896	59,000 ppb	<330 ppb	>99.44	N/D
Fluoranthene	707	57,000 ppb	<330 ppb	>99.42	N/D
Fluorene	560	55,000 ppb	390 ppb	99.29	7J
Ideno(1,2,3-c,d)-pyrene	950	65,000 ppb	<330 ppb	>99.49	N/D
Phenanthrene	644	52,000 ppb	20 ppb J	99.96	N/D
Pyrene	759	50,000 ppb	<330 ppb	>99.34	N/D
Volatile Organic Compounds					
1,1,1-Trichloroethane	165	2,600 ppb	<250 ppb	>90.38	N/D
Other Parameters					
Moisture	212	21.80%	0.01%	99.95	N/A

^a = Processed soil temperature was 450 °F.

^b = Processed soil residence time was 30 minutes.

N/A = Not Applicable

J = Present at less than detection limit.

N/D = Not detected; detection limit = 20 ppb.

Table C-6 Results of Bench-Scale LT[®] Testing on Chlorinated Benzene-Contaminated Soil^{a, b}

Contaminant	Boiling Point (°F)	Feed Soil Concentration (ppb)	Processed Soil Concentration (ppb)	Contaminant Removal Efficiency (%)	Concentration in TCLP Leachate (ppb)
Benzene	176	106	0.01	99.991	N/D
Monochlorobenzene	270	318	0.03	99.991	N/D
1,3-Dichlorobenzene	343	1,219	0.35	99.97	N/D
1,4-Dichlorobenzene	345	524,859	6.25	99.999	0.0064
1,2-Dichlorobenzene	357	1,431	0.85	99.94	0.0048
1,2,4-Trichlorobenzene	416	477	0.22	99.95	0.0011
1,2,3-Trichlorobenzene	424	636	0.06	99.99	N/D
1,2,4,5-Tetrachlorobenzene	475	530	0.03	99.994	N/D
1,2,3,4-Tetrachlorobenzene	489	424	0.05	99.99	N/D
Totals	N/A	530,000	7.85	99.999	N/A

^a = Processed soil temperature was 400 °F.

^b = Processed soil residence time was 44 minutes.

N/D = Not detected

N/A = Not Applicable

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