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Low Temperature Thermal Aeration (LTTA) Process
Canonie Environmental Services, Inc.

Applications Analysis Report

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

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Notice

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Foreword

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

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for reducing risks from threats to human health and the environment. The focus of the Laboratory's research program is on methods for the prevention and control of pollution to air, land water and subsurface resources; protection of water quality in public water systems ; remediation of contaminated sites and groundwater; and prevention and control of indoor air pollution. The goal of this research effort is to catalyze development and implementation of innovative, cost-effective environmental technologies; develop scientific and engineering information needed by EPA to support regulatory and policy decisions; and provide technical support and information transfer to ensure effective implementation of environmental regulations and strategies.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Abstract

This report presents an evaluation of the Low Temperature Thermal Aeration (LTTA®) system's ability to remove volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), and pesticides from soil. This evaluation is based on treatment performance and cost data from the Superfund Innovative Technology Evaluation (SITE) demonstration and five case studies. This report also discusses the applicability of the LTTA® system based on compliance with regulatory requirements, implementability, short-term impact, and long-term effectiveness. The factors influencing the technology's performance in meeting these criteria are also discussed.

The LTTA® system thermally desorbs organic compounds from contaminated soil without heating the soil to combustion temperatures. The LTTA® system consists of three main operations: soil treatment, emissions control, and water treatment. End products include treated soil, spent activated carbon, and treated stack gas. The transportable system consists of six major components assembled on nine flat-bed trailers and five auxiliary support trailers.

The LTTA® system was demonstrated under the SITE program at a confidential abandoned pesticide mixing facility in western **Arizona** During the demonstration, the LTTA® system treated site soils contaminated primarily with seven pesticides: toxaphene; 4,4'-dichlorodiphenyltrichloroethane (DDT); 4,4'-dichlorodiphenyldichloroethane (DDD); 4,4'-dichlorodiphenyldichloroethene (DDE); dieldrin; endosulfan I; and endrin. Additionally, Canonie Environmental Services Corporation conducted several pilot-scale tests and full-scale operations to obtain treatment data for soils contaminated with petroleum hydrocarbons, VOCs. SVOCs, and organochlorine and organophosphorus pesticides.

Based on the results of the SITE demonstration and other case studies, the following conclusions can be drawn. The LTTA® system: (1) can process a wide variety of soils with differing moisture and contaminant concentrations; (2) can remove VOCs from soil to below detection limits; (3) can substantially decrease SVOC concentrations in soil; (4) can remove pesticides from soil to below or near detection limits (removal efficiencies range from 82.4 to greater than 99.9 percent); and (5) did not produce dioxins and furans during the SITE demonstration. Remediation costs, including all activities from site preparation through demobilization, are estimated to range from approximately $133 to $209 per ton of soil, depending predominantly on moisture content, contaminant concentrations in the soil, and regulatory requirements.

Contents

Section	Page
Notice	ii
Foreword	iii
Abstract	iv
Acronyms, Abbreviations, and Symbols	viii
Conversion Factors for U.S. Customary and Metric Units	ix
Acknowledgements	x
Executive Summary	1
1.0 Introduction	4
1.1 **The** SITE Program	4
1.2 SITE Demonstration Reports..	4
1.2.1 Technology Evaluation Report	5
1.2.2 Applications Analysis Report	5
1.3 Technology Description	5
1.3.1 Principal Treatment Operations	5
1.3.2 Innovative Features of the LTTA® System	9
1.3.3 LTTA® System Limitations	9
1.4 Key Contacts	9
2.0 Technology Applications Analysis	10
2.1 Basis for Applications Analysis	10
2.2 Treatment Effectiveness for Toxicity Reduction..	10
2.2.1 Pesticide Removal	10
2.2.2 VOC Removal	10
2.2.3 SVOC Removal	12
2.2.4 Formation of Thermal Transformation Byproducts	12
2.2.3 Stack Emissions	13
2.3 Compliance with Applicable or Relevant and Appropriate Requirements	13
2.3.1 CERCLA	13
2.3.2 RCRA	14
2.3.3 CAA	14
2.3.4 OSHA	14
2.3.5 State Cleanup Requirements	15
2.4 Implementability	15
2.4.1 Mobilization	15
2.4.2 Operating and Maintenance Requirements	16
2.4.3 Reliability	17
2.4.4 Personnel Requirements	17
2.4.5 Demobilization	17

2.5 Short-Term Impact 18
2.5.1 Operational Hazards 18
2.5.2 Potential Community Exposures 18
2.6 Long-Term Effectiveness 18
2.6.1 Permanence of Treatment 18
2.6.2 Residuals Handling 18
2.7 Factors Influencing Performance 19
2.7.1 Waste Characteristics 19
2.7.2 Operating Parameters 20
2.7.3 Climatic Conditions 20

3.0 Economic Analysis 21

3.1 Site-Specific Factors Affecting Costs 21
3.2 Basis of the Economic Analysis 21
3.2.1 Assumptions about the LTTA® Technology and Capital Cost 21
3.2.2 Assumptions about the Soil and Site Conditions 21
3.2.3 Assumptions about the LTTA® System Operation 24
3.3 Cost Categories 24
3.3.1 Site Preparation 24
3.3.2 Permitting and Regulatory 24
3.3.3 Equipment 25
3.3.4 Sstartup 25
3.3.5 Labor 26
3.3.6 Consumable Materia s 26
3.3.7 Utility 26
3.3.8 Effluent Monitoring 27
3.3.9 Residual Waste Shipping, Handling, and Transportation 27
3.3.10 Analytical 27
3.3.11 Equipment Repair and Replacement 27
3.3.12 Demobilization 27

4.0 References 29

Appendices

A Vendor's Claim for the Technology

B Site Demonstration Results

C Case Studies

Figures

Figure **Page**

1 LTTA® System How Diagram - Soil 6

2 LITA System Flow Diagram-Air and Water. 7

3 LTTA® System Layout 8

Tables

Table **Page**

1 Treatment Condition s for Site Demonstration andCase Studies 11

2 Range of General Operating Parameters.. 20

3 Cost to Process 10,000 tons of Soil at Various Processing Rates 22

4 Summary of Variable Costs Per Ton of Soil Processed at Various Processing Rates 23

Acronyms, Abbreviations, and Symbols

µg/kg	Micrograms per kilogram
µg/dscm	Micrograms per dry standard cubic meter
ADEQ	Arizona Department of Environmental Quality
ARAR	Applicable or relevant and appropriate requirement
CAA	Clean Air Act
Canonie	Canonie Environmental Services Corporation
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cfm	Cubic feet per minute
CFR	Code of Federal Regulations
DDD	4,4'-Dichlorodiphenyldichloroethane
DDE	4,4'-Dichlorodiphenyldichloroethene
DDT	4,4'-Dichlorodiphenyldichloroethane
EPA	U.S. Environmental Protection Agency
°F	Degrees Fahrenheit
GAC	Granular activated carbon
gpm	Gallon per minute
lbs	Pounds
lb/hr	Pound per hour
LTTA	Low Temperature Thermal Aeration
mg/kg	Milligrams per kilogram
ORD	Office of Research and Development
OSHA	Occupational Safety and Health Administration
OSWER	Office of Solid Waste and Emergency Response
QA	Quality assurance
QC	Quality control
RCRA	Resource Conservation and Recovery Act
RREL	Risk Reduction Engineering Laboratory
SITE	Superfund Innovative Technology Evaluation
SARA	Superfund Amendments and Reauthorization Act
SVOC	Semivolatile organic compound
tons/hr	Tons per hour
VOC	Volatile organic compound

Conversion Factors for U.S. Customary and Metric Units

Length:	inches	x	2.54	=	centimeters
	feet	x	0.3048	=	meters
Volume:	gallons	x	3.785	=	liters
	cubic yards	x	0.7646	=	cubic meters
Weight:	pounds	x	0.4536	=	kilograms
	tons	x	0.9072	=	metric tons
	kilograms	x	1,000	=	metric tons
Temperature	5/9	x	(^{0}Fahrenheit - 32)	=	^{o}Celsius

Acknowledgements

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This report was prepared for the EPA SITE program by James Peck, Scott Engle, Roger Argus, Daniel Auker, Diana Olson, and Karen Kirby of PRC Environmental Management, Inc. Technical input was provided by Chuck Sueper of Twin City Testing, Javed Bhatty of Construction Technology Laboratories, and Don Burrows of Radian Corporation. The report was reviewed and edited by Robert Foster, Dr. Ken Partymiller, Dr. Chriso Petropoulou, Butch Fries, and Jeff Swano of PRC.

Executive Summary

Introduction

This report assesses the applications of the Low Temperature Thermal Aeration (LTTA) system developed by Canonie Environmental Services Corporation (Canonie). A demonstration was conducted under the U.S. Environmental Protection **Agency** (EPA) Superfund Innovative Technology Evaluation (SITE) program in September 1992, at an abandoned pesticide mixing facility in western Arizona. This evaluation of the LTTA system is based on the results of the SITE demonstration, subsequent remediation of the Arizona site, and five other case studies performed by Canonie for several private and governmental clients. The five case studies used in this report include remedial activities at the McKin Superfund site (Maine), the Cannons Bridgewater Superfund site (Massachusetts), the Ottati and Goss Superfund site (New Hampshire), the South Keamy site (New Jersey), and the former Spencer Kellogg facility (New Jersey).

The LTTA system thermally desorbs organic compounds from contaminated soil without heating the soil to combustion temperatures. The system consists of three main operations: soil treatment, emissions control, and water treatment. End products include treated soil, spent granular activated carbon (GAC), and treated stack gas. The transportable system has six major equipment components assembled on flat-bed trailers.

The SITE demonstration and the case studies utilized a full-scale LTTA system. A major advantage of demonstrating a full-scale system is that the demonstration results are mom likely to be representative of future operations at similar sites than the results from smaller pilot-scale or prototype units. Also, the nature of operational problems encountered during the full-scale system demonstration should be indicative of potential problems at other sites.

Technology Applications

The LTTA system has demonstrated its effectiveness at treating soils contaminated with volatile organic compounds (VOCs), pesticides, and petroleum compounds by treating over 90,000 tons of soil at six different sites. Limited data suggest that the LTTA system is an effective technology for removing several semivolatile organic compounds (SVOCs) as well. The LTTA system can treat up to 50 tons per hour of contaminated soil, making it particularly applicable to sites requiring extensive remediation or an expedited cleanup schedule. Based on the findings of the SITE demonstration and other case studies, the following conclusions can be drawn regarding applications of the LTTA system:

- Pilot- or full-scale LTTA systems have effectively treated soil contaminated with the following wastes: petroleum hydrocarbons, VOCs, SVOCs, and organochlorine and organophosphorus pesticides. Based on available data, reported VOC and pesticide removal efficiencies are generally greater than SVOC removal efficiencies.

- Contaminant removal in the LTTA system is primarily through thermal desorption, with thermal transformation and degradation as possible secondary mechanisms.

- The LTTA system is most appropriate for wastes with moisture content less than 20 percent. To enhance the efficiency of the LTTA system, soils with greater moisture content may require dewatering.

- Screening or crushing oversized material (greater than 2 inches in size), or clay shredding may be required for some applications.

- Treatment residuals consist of spent GAC. The ready availability of facilities throughout the country to treat and recycle spent GAC increases the long-term effectiveness of the LTTA system. Reuse of the GAC makes it a temporary waste, with full recycling potential.

- Based on a treatment volume of 10,000 tons, treatment costs are $209, $144, and $133 per ton, for processing rates of 20.35, and 50 tons per hour.

No operational problems were encountered during the SITE demonstration. Canonie reports that it is not unusual for system maintenance to require up to 2 hours of downtime per week of operation.

Treatability and pilot studies are highly recommended before implementing full-scale applications. Because results may vary greatly with different soil types and contaminant characteristics, the LTTA system's performance is best predicted with preliminary testing and process monitoring during full-scale proof-of-process operations.

Data Sources

This section summarizes the LTTA system's performance during the SITE demonstration and during five case studies.

The LTTA system SITE demonstration was conducted as part of full-scale remedial operations at an Arizona pesticide mixing facility. Site soils were contaminated with pesticides primarily during mixing and loading/unloading operations. The pesticides present were predominantly toxaphene, 4,4'-dichlorodiphenyltrichloroethane(DDT), 4,4'-dichlorodiphenyldichloroethene (DDE), and 4,4'-dichlorodiphenyldichloroethane (DDD) it h lessrr concentrations of dieldrin, endosulfan I, and endrin. The demonstration consisted of three 8-hour replicate tests. During the tests, contaminated soil was heated to approximately 730 degrees Fahrenheit (°F) for a residence time of approximately 10 minutes. Soil was processed at an average rate of 34 tons per hour (tons/hr). Approximately 5 1,000 tons of soil will be treated upon completion of remedial activities. Key findings from the SITE demonstration include the following:

The LTTA system removed pesticides other than DDE to near or below method detection limits in soil. All pesticides were removed to below cleanup requirements.

Th e LTT A system achieved pesticide removal efficiencies ranging from 81.9 to greater than 99.9 percent. Only three pesticides were present at quantifiable concentrations in the treated soil: DDT (0.77 to 3.1 micrograms per kilogram [µg/kg]), DDE (100 to 1,500 µg/kg), and endrin aldehyde (0.07 to 11 µg/kg). None of the other target pesticides were detected.

The LTTA system's ability to remove VOCs and SVOCs present in the soil at the Arizona site was not quantifiable with any degree of certainty due to the extremely low initial concentrations (at or below the detection limit). However, data from other full-scale non-SITE soil remediation projects conducted using the LTTA system indicate that VOCs and SVOCs can be removed by the LTTA system.

Polychlorinated dibenzo-p-dioxins (dioxins) and polychlorinated dibenzofurans (furans) were not formed in the LTTA system. No quantifiable levels of dioxins or furans were detected in the treated soil, scrubber liquor, or GAC samples. Extremely low levels of dioxins and furans were detected in the stack gas.

Chlorine and organic halides appeared to concentrate in the scrubber blowdown, where organic halide masses were several times greater than other process effluent streams. Additionally, the treated soil contained significant levels of chloride.

All five case studies involved full-scale applications of the LTTA process at sites contaminated with petroleum hydrocarbons, VOCs, and SVOCs. These case studies include the following:

Approximately 11,500 cubic yards of oil- and VOC-contaminated silt and coarse sand were treated at the McKin Superfund site in Gray, Maine. Concentrations of VOCs were reduced from greater than 3,000 milligrams per kilogram (mg/kg) to an average of less than 0.05 mg/kg. A real-time continuous emissions monitoring system was installed to document emission compliance during soil treatment operations. All specified performance standards were met for the treated soils and the emissions during remedial activities.

About 11,300 tons of soil and wetland sediments contaminated with VOCs were treated at the Cannons Bridgewater Superfund Site in Bridgewater, Massachusetts. The soils were treated at a processing rate of between 42 and 48 tons/hr. All treated soil samples met the specified cleanup standards.

More than 4,500 cubic yards of soil contaminated with VOCs were treated at the Ottati and Goss Superfund site in Kingston, New Hampshire. All treated soils met the discharge limitation0 of 1 .O mg/kg total VOCs and 0.1 mg/kg for l,2-dichloroethane, trichloroethene, and tetrachloroethene.

Approximately 16,000 tons of soils contaminated with VOCs and SVOCs were treated at a site in South Kearny, New Jersey. Total VOC concentrations were reduced fromgreater than 300mg/kg to 0.51 mg/kg of detectable

compounds. All polynuclear aromatic hydrocarbons were reduced to a total detectable concentration of 12 mg/kg.

A total of 6,500 tons of soil contaminated with VOCs and SVOCs were treated at the former Spencer Kellogg Facility in Newark, New Jersey. Total VOC concentrations were reduced from greater than 5,000 mg/kg to total detectable concentrations of 0.45 mg/kg. All compounds were removed to below specified cleanup levels.

Canonie's claims for the technology are presented in Appendix A. The results of the SITE demonstration are discussed in Appendix B. Appendix C describes each case study in greater detail.

Section 1
Introduction

This section provides information on the Superfund Innovative Technology Evaluation (SITE) program, discusses the purpose of this Applications Analysis Report, and describes the Low Temperature Thermal Aeration (LTTA) system developed by Canonie Environmental Services Corporation. For additional information about the SITE program and Canonie's technology, key contacts are listed at the end of this section.

1.1 The SITE Program

The SITE program is 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. International in scope, the SITE program is administered by the U.S. Environmental Protection Agency (EPA) Office of Research and Development's (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 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 either 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 wastes, applicable types of wastes 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 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 at 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), report preparation, and technology transfer.

Each SITE demonstration evaluates the performance of a technology in treating a particular waste type 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 the technology will be equally effective at other sites. Data obtained from the SITE demonstration may have to be extrapolated and combined with other information regarding the technology to estimate the operating range and limits of the technology.

1.2 SITE Demonstration Report

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.

1.2.1 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 particular waste type at the demonstration site. The report describes, 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.

1.2.2 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 waste types. Prior to a SITE demonstration, the amount of data available for an innovative technology may vary widely. Data may be limited to laboratory tests on synthetic wastes or may include 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 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 and presents estimated costs 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.

1.3 Technology Description

The LTTA is a thermal treatment system that desorbs organic compounds from soil at temperatures of 300 to 800 "F. The full-scale transportable system consists of six major components assembled on nine flat-bed trailers. Additional components include two soil conveyors, a power generator, a control trailer, and additional support facilities. The entire system and support areas require approximately 10,000 square feet of operating space.

1.3.1 Principal Treatment Operations

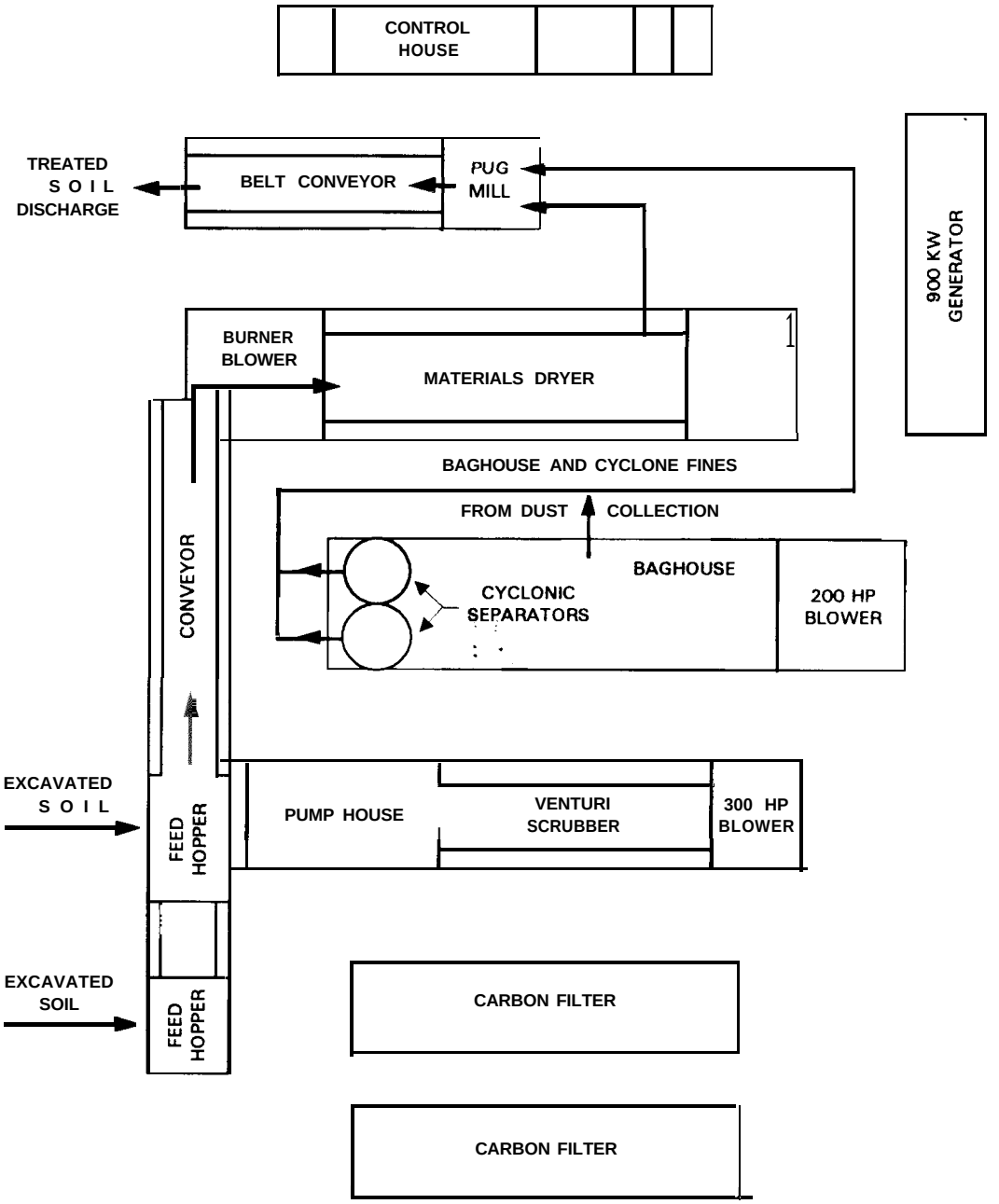
The operations discussed in this section are based on material provided by Canonie (Canonie 1992a). The LTTA system has three main material flow paths: soil, air, and water. The six major components of the system are as follows:

1. Materials dryer
2. Pug mill mixer
3. Cyclone separators (2)
4. Baghouse
5. Venturi scrubber and liquid-phase carbon filter
6. Vapor-phase activated carbon beds (2)

These components are shown in Figures 1 and 2; the system layout is shown in Figure 3. The following paragraphs describe the system as it was implemented at the Arizona pesticide site.

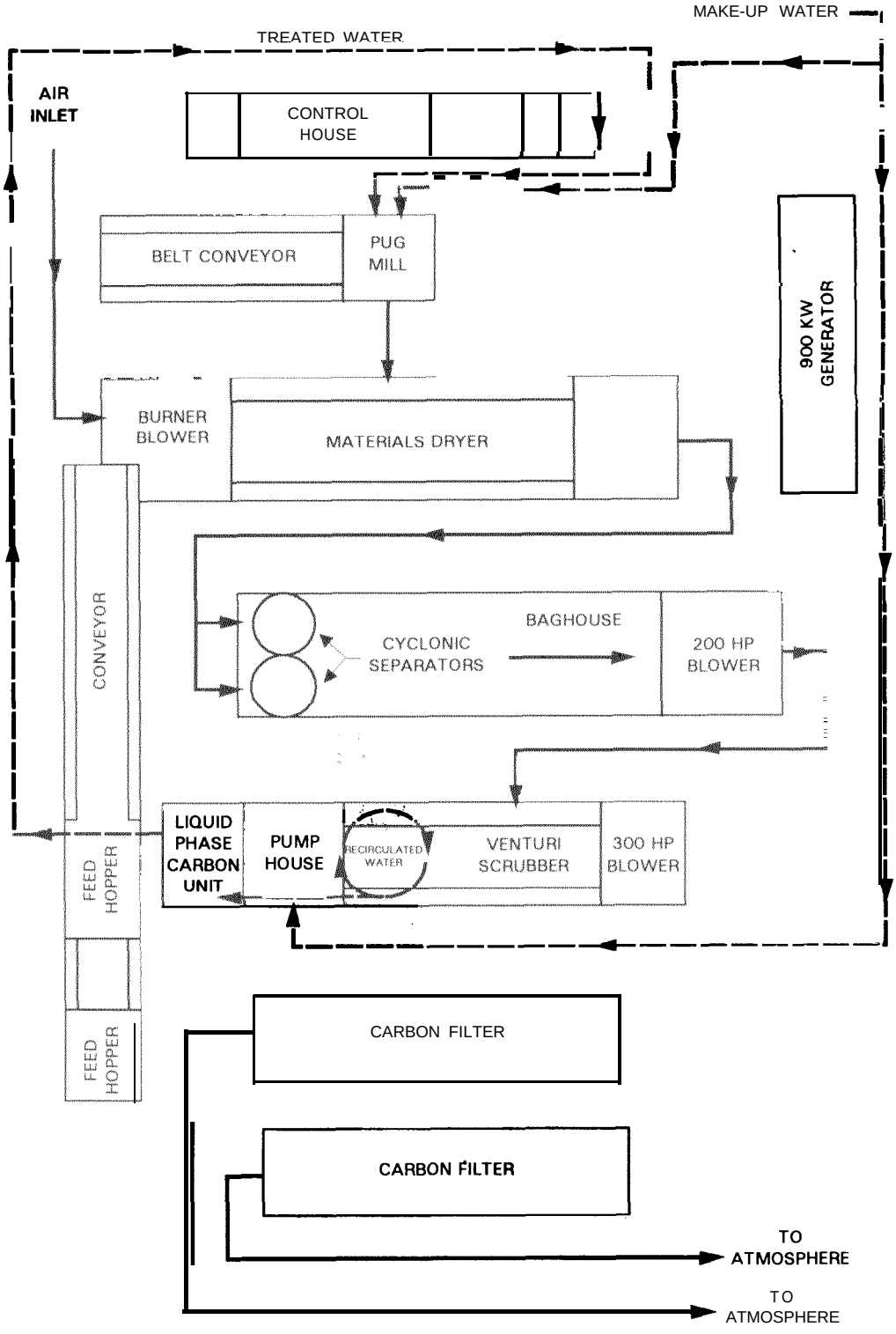
Contaminated soil is fed into the system from feed hoppers by conveyors. If screening is required, then a portable screen may be utilized prior to feeding the soil into the hoppers. Other pretreatment procedures, such as soil dewatering, may be employed, if necessary. The feed hoppers or conveyors supply soil to the elevated end of a rotating materials dryer that heats the soil as high as 800 °F by a concurrent flow of hot air stream. The air stream is heated by a propane or fuel oil burner. Longitudinal flights inside the dryer promote mixing by showering the soils thus increasing the heat and mass transfer between the contaminated soil and hot air. Organic constituents in the soil are desorbed and vaporized in the dryer. Vaporized organic compounds and airborne soil particles are directed to the cyclone separators. The dry, hot soils are discharged via a chute at the lower end of the materials dryer into an enclosed pug mill mixer. Water is introduced to the pug mill to mitigate dust generation during handling.

The initial step in dryer emissions treatment is performed by a pair of cyclone separators with a maximum operating rate of 30,000 cubic feet per minute (cfm). The direction and linear flow rate of the exhaust gas from the materials dryer is modified so that large particles drop out of the air stream. The particles are collected at the base of the conical section of the separators and transferred by screw auger to the pug mill. In the pug mill, the particles are quenched along with the treated soils. The exhaust gas stream from the cyclone separators is directed to the baghouse.



Not to Scale
Source: Canonie 1992

Figure 1. LTTA System Flow Diagram - Soil



Not to Scale
Source: Canonie 1992

Figure 2. LTTA System Flow Diagram - Air and Water

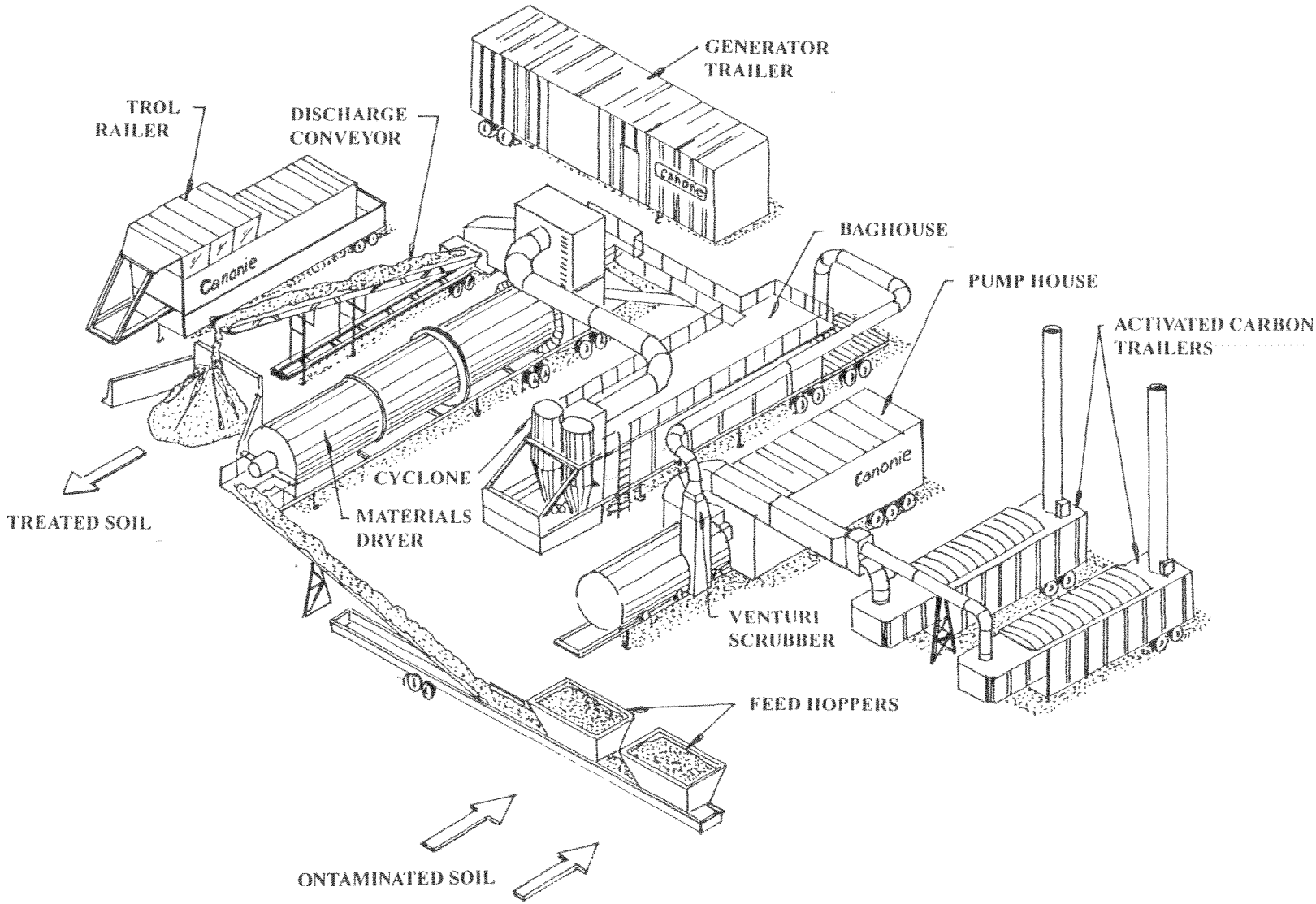


Figure 3. LTTA® System Layout

The baghouse consists of a structure housing a bank of fine mesh filter bags that remove suspended particulate matter from the gas stream. The baghouse is rated at a maximum capacity of 31,000 cfm, and has particulate emissions of less than 0.04 grains per dry standard cubic foot. Entrapped particles are removed from the filter bags, collected, and transferred by screw auger to the pug mill for mixing and quenching with treated soils. The exhaust from the baghouse is then directed to the venturi scrubber.

The venturi scrubber operates by injecting approximately 220 gallons per minute (gpm) of water at low pressure into the throat of a venturi through which the gas stream passes at a velocity of 150 to 500 feet per second. The scrubber removes approximately 95 percent of the particles larger than 0.2 microns in size, neutralizes acid gases, and removes water-soluble components from the air stream.

Sodium hydroxide is pumped continuously, or as required, into the recirculating scrubber water to maintain the system pH above 7.0. The water is removed from the gas stream through a dual de-entrainment section, where it is collected in a bottom sump. The scrubber water is then filtered through micron-sized particulate filters and a liquid-phase carbon filter to remove any residual particles and organic compounds.

The treated water and any additional make-up water are transferred to the pug mill for soil quenching. No wastewater is generated in the process. Water exiting the liquid-phase carbon filter is analyzed twice per week to ensure contaminant removal and to evaluate carbon filter loading.

The gas stream exiting the venturi scrubber receives final treatment in two vapor-phase granular activated carbon (GAC) beds. The beds am contained within two 35-foot by 8-foot trailers connected in parallel. Gas is directed to the bottom of each trailer to an open plenum covered by a wire mesh supporting the GAC. An induced draft fan draws gas through the GAC and exhausts it through a 40-foot stack.

GAC samples are taken routinely to determine if carbon loading is approaching breakthrough conditions, at which time the GAC requires replacement. The spent carbon is transported to an off-site carbon regeneration facility for treatment and reuse. At the Arizona pesticide site, the carbon beds were changed after treatment of approximately 20,000 tons of soil.

1.3.2 Innovative Features of the LTTA System

The unique features of the LTTA system include its large material throughput capacity and minimal residuals. The reported case studies show processing capacities of up to 50 tons per hour, allowing large volumes of waste soils to be treated in a comparatively short period of time. Residues are limited to spent carbon material, which is easily transported to regeneration facilities.

1.3.3 LTTA System Limitations

Canonie reports that the LTTA system can process a wide variety of soils with differing moisture and contaminant concentrations. However, the technology is best suited for soils with a moisture content of less than 20 percent. Wastes with a moisture content greater than 20 percent may require dewatering. Pretreatment screening or crushing of oversized material (greater than 2 inches in size) or clay shredding may also be required for some applications. When the LTTA system is used to treat soils with high concentrations of petroleum hydrocarbons, the air pollution control system may include a thermal oxidizer or afterburner to destroy organic compounds and a quench tower to cool the air stream. Treatment must be evaluated for each site based on contaminant concentrations and cleanup objectives.

1.4 *Key Contacts*

Additional information on the LTTA technology and the SITE program can be obtained from the following sources:

The LTTA Process

Mr. Chetan Trivedi
Canonie Environmental Services Corporation
800 Canonie Drive
Porter, Indiana 46304
(219) 926-8651

The SITE Program

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

Section 2
Technology Application Analysis

This section addresses the applicability of the LTTA system to soils contaminated with pesticides, VOCs, SVOCs, and petroleum hydrocarbons based on the SITE demonstration results and five case studies involving past performance of the LTTA system. Appendix A presents Canonie's claims regarding the system's applicability and performance.

The applicability of the LTTA system was evaluated according to technical criteria used for selecting remedial actions at Superfund sites: (1) treatment effectiveness for toxicity reduction, (2) compliance with regulatory requirements, (3) implementability, (4) short-term impact, and (5) long-term effectiveness. It should be noted that these criteria can also be applied to Resource Conservation and Recovery Act (RCRA), underground storage tank, or other corrective action decisions. This section also describes factors influencing the technology's performance in meeting these criteria.

2.1 *Basis for Applications Analysis*

The evaluation of the LTTA system's applicability is based on the results of the SITE demonstration (Appendix B) and reported results from five case studies (Appendix C). Treatment conditions for the SITE demonstration and the case studies are summarized in Table 1. Only the treatment data from the SITE demonstration has been subjected to EPA's QA/QC process and is of known quality. Data from the case studies are based on information provided by Canonie for the SITE evaluation as well as on site closure reports submitted by Canonie to the EPA for Superfund cleanups.

Although data have been generated on the LTTA system's effectiveness in treating various contaminated soil types under differing operating conditions, results of applications of the LTTA system may vary with different soil matrices and contaminant characteristics. Contaminants may also behave differently in association with other compounds and with differing soil types. Therefore, the technology's performance is best predicted with preliminaty bench-scale testing to determine whether the technology can meet treatment objectives. Treatability studies ate recommended before mobilizing the full-scale system.

2.2 Treatement Effectiveness for Toxicity Reduction

The LITA system's effectiveness for toxicity reduction was evaluated based on (1) pesticide removal, (2) VOC removal, (3) SVOC removal, (4) formation of thermal transformation byproducts, and (5) stack emissions.

2.2.1 Pesticide Removal

During the SITE demonstration, the LTTA system removed pesticides with an efficiency ranging from 8 1.9 to greater than 99.9 percent. The LTTA removed toxaphene with efficiencies ranging from greater than 99.4 percent to greater than 99.9 percent. DDT was removed with an efficiency of 99.8 percent to greater than 99.9 percent. DDD was removed with efficiencies ranging from greater than 98.8 percent to greater than 99.9 percent. DDE was removed with efficiencies ranging from 81.9 percent to 97.8 percent. This lower efficiency may be the result of DDE formation as a product of thermal transformation of DDT and DDD.

The LTTA system also removed dieldrin with efficiencies ranging from 98.6 percent to greater than 99.8 percent. Endosulfan I was removed at an efficiency ranging from greater than 99.8 to greater than 99.9 percent. Endrin was removed at efficiencies ranging from greater than 99.6 percent to greater than 99.9 percent. Endrin aldehyde was removed with efficiencies ranging from greater than 92.4 percent to greater than 99.9 percent.

2.2.2 VOC Removal

At the case study sites, the LTTA system removed most VOCs present in untreated soils to below method detection limits. Specific compounds treated included benzene, 1,2-dichlorobenzene, trans-1,2-dichloroethene, ethylbenzene, toluene, trichloroethene, **1,1, 1** -trichloroethane, xylenes, tetrachloroethane, and tetrachloroethene. During the SITE demonstration, no VOCs were present in the contaminated soil and thus removal efficiency could not be evaluated.

Table 1. Treatment Conditions for the SITE Demonstration and Case Studies

Study	Scale	Site	Client	Treatment Conditions	Soil Type	Soil Treated	Contaminants
SITE Demonstration	Full-Scale	Arizona, confidential location	Confidential	Temperature: 720-750 'F Residence Time: 9-12 min Processing Rate: 34 tons/hr Soil Moisture: 4.5-5.6%	clayey loam	51,000 tons	Pesticides
Case Study 1	Full-Scale	McKin Superfund Site; Gray, Maine	McKin Steering Committee	Temperature: 300-350 °F Residence Time: 4-8 min Processing Rate: 35-45 tons/hr Soil Moisture: 15%	Silt and coarse sand	11,500 cubic yards	VOCs and oil
Case Study 2	Full-Scale	Canons Bridgewater Superfund Site; Bridgewater, Massachusetts	Cannons Bridgewater Superfund Settling Parties	Temperature: 450-500 °F Residence Time: 4-8 min Processing Rate: 42-48 tons/hr Soil Moisture: 16-28%	Wetland sediments and soils-unclassified	11,330 tons	VOCs
Case Study 3	Full-Scale	Ottati and Goss Superfund Site; Kingston, New Hampshire	Ottati and Goss Settling Party Committee	Temperature: 350-400 °F Residence Time: 4-8 min Processing Rate: 35-45 tons/hr Soil Moisture: 5-10%	Sediments and soils - unclassified	4,700 cubic yards	VOCs
Case Study 4	Full-Scale	South Kearny, New Jersey	TP Industrial, Inc.	Temperature: 550 °F Residence Time: 6-9 min Processing Rate: 50 tons/hr Soil Moisture: 5-10%	Silty clays sandy fill	16,000 tons	VOCs and SVOCs
Case Study 5	Full-Scale	Former Spencer Kellogg Facility; Newark, New Jersey	Textron, Inc.	Temperature: 700-750 °F Residence Time: 9-12 min Processing Rate: 15 tonsihr Soil Moisture: 12-20%	Silty sand	6,500 tons	VOCs and SVOCs

'F Degrees fahrenheit
min Minute
tons/hr Tons per hour
% Percent
VOCs Volatile organic compounds
SVOCs Semivolatile organic compounds

Results from the first case study (conducted at the McKin Superfund site in Gray, Maine) showed effective removal of benzene, 1,2-dichlorobenzene, trans-1,2-dichloroethene, ethylbenzene, tetrachloroethene, toluene, l,l,l-trichloroethane, trichloroethene, and xylenes. The concentration of VOCs in untreated soil ranged from 2,700 µg/kg for benzene to 3,310,000 µg/kg for trichloroethene. The concentration of trichloroethene in treated soil was 40 µg/kg, resulting in a removal efficiency greater than 99.9 percent. Reported concentrations for all other VOCs in treated soil were below method detection limits.

Results from the second LTTA case study (conducted at the Cannons Bridgewater Superfund site in Bridgewater, Massachusetts) showed that benzene was effectively removed from contaminated soil. Removal efficiencies greater than 99 percent were reportedly achieved. Other VOCs present were not evaluated for removal efficiency. The concentrations of VOCs in untreated soil had a maximum value of 5,300 µg/kg. The concentrations of VOCs in treated soil were below the method detection limit of 25 µg/kg.

The third case study (conducted at the Ottati and Goss Superfund site in Kingston, New Hampshire) involved treatment of soils contaminated with 1, 1,l -trichloroethane, trichloroethene, tetrachloroethene, toluene, ethylbenzene, and xylenes. The total concentration of VOCs in untreated soil ranged from 4,900 to 3,000,000 µg/kg. In the treated soils, all VOCs were reduced to non-detectable levels except for toluene (with a residual level of 110 µg/kg) and xylenes (with a residual level of 140 µg/kg). Removal efficiencies exceeding 99 percent were achieved for all VOC compounds.

The fourth case study (conducted at the South Keamy site in South Kearny, New Jersey) involved treatment of soils contaminated with 1 ,2-dichloroethene, 1, 1,l -trichloroethane, trichloroethene, tetrachloroethene, l,2-dichlorobenzene, toluene, ethylbenzene, and xylenes. The concentration of VOCs in untreated soil ranged from 550 to 190,000 µg/kg, while the concentration of VOCs in treated soil ranged from 380 µg/kg to nondetectable levels. The concentration of total VOCs before treatment was measured at 308,200 µg/kg and after treatment at 510 µg/kg; this indicated a removal efficiency exceeding 99 percent for all VOCs.

The fifth case study (conducted at the former Spencer Kellogg facility in Newark, New Jersey) reported concentrations of ethylbenzene, toluene, and xylenes in untreated soils at 1,400,000 µg/kg, 3,000,000 µg/kg, and 3,700,000 µg/kg, respectively. Concentrations of ethylbenzene and toluene were reduced to nondetectable levels (at detection limit of 50 µg/kg). Concentrations of xylenes were reduced to 250 µg/kg, and total VOCs were reduced from 5,420,000 µg/kg to 450 µg/kg. Removal efficiency exceeded 99 percent for these contaminants.

2.2.3 SVOC Removal

In general, the LTTA system reduces the concentration of SVOCs. However, information from the SITE demonstration and case studies is limited by the low concentration of SVOCs in untreated soils. The available information does show significant reductions of SVOCs in treated soils, although SVOC removal does not appear to be as effective as VOC removal.

Since SVOCs were not detected in the untreated soil samples at the Arizona pesticide site, their removal efficiency could not be evaluated for the SITE demonstration.

For case studies 2,4, and 5, SVOC removal ranged from 51 percent to 94 percent for the reported chemicals. SVOCs for which data are available included acenaphthene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, bis(2-ethylhexyl)phthalate, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno (1,2,3_cd) pyrene, naphthalene, phenanthrene, butylbenzylphthalate, isophorone, and pyrene. At the South Kearny, New Jersey site, pyrene was present in untreated soils at a concentration of 15,000 µg/kg; chemical removal efficiency for pyrene in this case was 93 percent. However, a slightly greater efficiency of 94 percent was reported for pyrene at the former Spencer Kellogg facility (Case Study 5), where its initial concentration was 4,700 µg/kg.

2.2.4 Formation of Thermal Transformation Byproducts

Chemical characteristics of contaminants in the waste feed determine the types of byproducts formed during treatment. Of special concern are the dioxins and furans that may form during the heating process in thermal treatment systems. The conditions necessary for formation include (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. Analytical results from the LTTA system SITE demonstration showed that the following potential chemical precursors for the formation of dioxins were present in untreated and treated soil samples and in the scrubber liquor: phenol, benzoic acid, benzene, furancarboxaldehyde, 2-methylphenol, 4-methylphenol, phenanthrene, and benzaldehyde. However, it does not appear than dioxins or furans were formed in the LTTA system. While very low levels of several dioxins and furans were detected in the feed soil, no dioxins or furans were detected in the treated soil or LTTA process streams. Trace amounts of several dioxins and furans were detected in the stack emissions, but at extremely low levels.

Several VOCs and SVOCs were found in the LTTA system process streams that were not present in the feed soils. These compounds were predominantly found in the scrubber liquor and GAC, with some compounds being found in the treated soil

and stack emissions. The most notable compounds were acetone, acetonitrile, acrylonitrile, chloromethane, benzene, toluene, xylene, benzoic acid, chlorobenzene, and phenol. The acid and alcohol group compounds may have been formed due to pesticide oxidation. Simpler byproducts, such as acetone and chloromethane, may have been formed by toxaphene degradation.

Chlorine and organic halides appear to concentrate in the scrubber blowdown, where organic halide masses are several times greater than other process effluent streams. Additionally, the treated soil contained significant levels of chloride. The detected chloride is most likely due to the dechlorination of the pesticides present in the feed soil.

2.2.5 Stack Emissions

Generally, stack gas emissions from the LTTA system contain very low concentrations of thermal transformation products of the primary waste constituents. Most of these byproducts are removed in the scrubber liquor, the liquid-phase GAC column, or the vapor-phase GAC beds. Experience from pilot studies or other studies performed prior to full-scale operation can be used to identify contaminants which may not be fully removed by the system filters. This information can be used to establish system operating parameters for minimizing contaminant emissions and to establish monitoring guidelines for determining when the GAC needs replacing.

During the SITE demonstration, monitoring for dusts, pesticides, and VOCs was performed during the pilot phase and the first week of operations. Personnel and perimeter monitors were used to determine whether airborne material levels exceeded established permissible exposure limits and air permit requirements. Weekly air monitoring was performed during full-scale operations to confirm that emissions remained in compliance. Regular maintenance checks of the LTTA process were performed to minimize fugitive dust emissions from treatment operations.

During the SITE demonstration, chlorides were detected in the stack gas at an average concentration of 273 micrograms per dry standard cubic meter (µg/dscm). In addition, ten volatile contaminants were reported at quantifiable levels; the highest was benzene at 2,320 µg/dscm. Particulate emissions averaged 0.041 grams per dscm. Additionally, very low concentrations of dioxins and furans were detected in the stack gas; the highest detected concentration was 0.0479 nanograms per dscm.

For Case Study 1 (McKin), Canonie conducted polynuclear aromatic hydrocarbon analysis of the carbon bed exhaust stream. None of the target analytical compounds were present above method detection limits.

For Case Study 2 (Cannons Bridgewater), three stack sampling runs were performed to quantify and characterize the atmospheric emissions of VOCs from the LTTA system. A computer dispersion model was used to determine worst-case ground level concentrations. The maximum in-stack detection was of toluene at 2,508 micrograms per cubic meter in the third run. The average total emission rate for quantified VOCs in the three test runs was 0.20 pounds per hour (lb/hr). For all three runs, the quantified individual VOC worst-case ground level concentrations from the stack emissions were below the allowable ambient limits, except for benzene in the third run.

2.3 *Compliance with Applicable or Relevant and Appropriate Rquirements*

This section discusses specific environmental regulations that may be pertinent to the operation of the LTTA system, including the transport, treatment, storage, and disposal of wastes and treatment residuals.

Applicable or relevant and appropriate requirements (ARARs) may include (1) the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) at National Priorities List sites; (2) RCRA; (3) the Clean Air Act (CAA); (4) applicable Occupational Safety and Health Administration (OSHA) regulations; and (5) state-specific guidelines. Site-specific soil cleanup requirements were established by the Arizona Department of Environmental Quality (ADEQ) for the Arizona pesticide site. The four general ARARs and the ADEQ guidelines are discussed below. Specific ARARs should be identified for each site where the LTTA technology may be used.

2.3.1 CERCLA

CERCLA, as amended by the Superfund Amendments and Reauthorization Act (SARA), provides for federal authority to respond to releases of hazardous substances, pollutants, or contaminants to air, water, and land at National Priorities List sites. 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 encourage highly reliable remedial actions that provide long-term protection. Such actions permanently and significantly reduce the volume, toxicity, or mobility of hazardous substances, pollutants, or contaminants. The LTTA system permanently reduces the toxicity of the feed wastes; thus only a small volume of residuals may require additional treatment or long-term management.

Federal cleanup standards also require that remedies selected at CERCLA sites comply with federal and state ARARs. ARARs for a remedial action may be waived under the following 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 impractical to meet the ARAR; (4) the performance standard 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).

2.3.2 RCRA

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 Code of Federal Regulations (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 generated by the LTTA system include GAC and solid waste that may be hazardous under RCRA:

* GAC - Activated carbon beds and liquid carbon filters are transported to a carbon regeneration facility which removes the adsorbed organic contaminants and makes the activated carbon available for reuse.

* Personal protective equipment - Disposable protective equipment is generally incinerated or landtilled.

For both CERCLA actions and RCRA corrective actions, treatment residuals generated by the LTTA system are subject to land disposal restrictions if the residuals are hazardous. If untreated soils contain dioxin or furan thermal precursors, dioxins or furans may be present in low concentrations in treatment residuals from the LTTA system and other thermal desorption systems. Under 40 CFR Section 268.31, FO20-F023 and FO26-FO28, dioxin- and furan-containing wastes are prohibited from land disposal unless the treatment standard of 1 part per billion for each dioxin and furan isomer is met.

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 groundwater, 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 requirements are similar to those under CERCLA, and as proposed, allow treatment units such as the LTTA system to operate as temporary treatment units without full permits. RCRA permits were not required at any of the six sites where LTTA was utilized.

2.3.3 CAA

The Clean Air Act requires that treatment, storage, and disposal facilities comply with primary and secondary ambient air quality standards. Gas and particulate emissions from the LTTA system are monitored with portable photoionization detectors, gas collection samplers, and particulate monitors during routine system operation. If a thermal oxidizer is used with the LTTA system, then a continuous emissions monitoring system is used to monitor the LTTA system emissions. Site-specific emission monitoring procedures, based upon soil contaminants and air samples collected during pilot runs, should be established for each site. Toxic materials were not detected in the analysis of samples collected during the SITE demonstration. A state air pollution permit is required, except at CERCLA sites where only the substantive requirements of a permit must be addressed. Permit limits may be established for total suspended particulates, acid gases, toxic organic compounds, and stack height.

For the SITE demonstration, an air pollution operating permit was issued by the State of Arizona. Air emission limits specified by this permit were as follows:

Compound	Emission Limit (lb/hr)
Carbon monoxide	10
Oxides of nitrogen	2.6
Oxides of sulfur	1.6
Total suspended particulates	7.6
Toxaphene	0.22
Total DDT compounds	0.04
Total methyl parathion	0.02
Total ethyl parathion	0.01

None of the values specified above were exceeded during the demonstration.

2.3.4 OSHA

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 provide 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.

2.3.5 State Cleanup Requirements

The Arizona pesticide site was remediated under supervision of the state by voluntary action of the potentially responsible party. Two significant ARARs were considered: air pollution regulations specified by the county air permit (See Section 2.3.3) and state groundwater protection and health risk standards.

All treated soils at the Arizona pesticide site were required to contain less than 5 mg/kg total pesticides after one pass through the LTTA system, as stated in the remedial action plan. ADEQ established site-specific soil cleanup criteria for toxaphene and DDT based upon a sliding scale which incorporates acceptable daily intake values and results of the site-specific risk assessment (SCS Engineers 1992). The sliding scale values are shown in Appendix B. Treated soils met the specified cleanup criteria if 90 percent of the treated soil sample results accumulated each day fell within the cleanup criteria envelope shown.

Under Case Study 1 (McKin), the LTTA system met all specified performance standards established by the EPA and the Maine Department of Environmental Protection for soils contaminated with VOCs and petroleum products. Feed soils contained VOCs at up to 3,310 mg/kg and polynuclear aromatic hydrocarbon concentrations of up to 1.2 mg/kg. Treated soils contained less than 0.1 mg/kg of trichloroethene; other VOCs (including 1,2-dichlorobenzene, trans-1,2-dichloroethene, tetrachloroethene, and xylenes) were completely removed. Petroleum compounds, primarily polynuclear aromatic hydrocarbons, were removed to less than 0.33 mg/kg, except for phenanthrene which was reduced to concentrations averaging 0.5 1 mg/kg.

For Case Study 2 (Cannons Bridgewater) remedial design excavation levels were established by the New Jersey Department of Environmental Protection for several VOC and SVOC compounds found in soils at concentrations up to 2,000 mg/kg. These levels were set at 0.5 to 1 .O mg/kg for VOCs and 3.0 mg/kg for SVOCs. Confirmation sampling showed that these levels were met for all soils treated with the LTTA process.

2.4 Implementability

The criteria of implementability includes the following factors: mobilization, operation and maintenance requirements, reliability, personnel requirements, and demobilization. The implementability of the LTTA' system is discussed below.

2.4.1 Mobilization

Site characteristics that must be considered before mobilizing the LTTA system include site area, site preparation requirements, and site access.

Site Area

The full-scale LTTA unit used in the SITE demonstration was a transportable system consisting of 14 flat-bed trailers. In addition, a tool storage trailer was located near the system. Three ancillary trailers, located outside the operation exclusion area, were used to house laboratory, decontamination, and on-site office support areas. The entire system required a relatively flat area of about 10,000 square feet.

Site Preparation Requirements

Site preparation is typically needed prior to operating the LTTA system. For the Arizona pesticide site, the following site preparation was needed:

- All trees and brush were removed from the area where the LTTA system and support facilities would be placed.
- An excavation 6 feet below grade was performed. The ground surface was graded flat over an approximate lO,OOO-square-foot area. The installed LTTA system was located 5 feet below grade. This preparation was specific to the Arizona project and generally is not required for the LTTA system.
- A 20-foot high berm was constructed around three sides of the LTTA system operations area to provide both a visual and audio barrier between site operations and an adjacent recreational facility. This preparation step was specific to the Arizona project only.
- A lo-foot high chain-link fence with insert slats was placed along the top perimeter of the berm to restrict unauthorized access and to provide an additional visual barrier. This preparation step, specific to the Arizona project, was at the client's request. It is generally not included in LTTA remediation projects.
- Earthen ramps were constructed on the east and west sides of the site, to provide access for excavation and transportation equipment.
- Utilities (electric, telephone, water) for support trailers were connected outside the exclusion zone. Water supply for system operation and support services was obtained from a nearby irrigation system.

* Health and safety zones were established to accommodate both on-site operating and off-site support personnel.

Site Access

Site access requirements for the LTTA system are minimal. The site must be accessible to trailer trucks delivering the LTTA equipment, and the bed of the access road must be able to support these vehicles. Since the LTTA unit trailers are oversized, some highway restrictions may apply. Permits from state and local authorities may be required.

2.4.2 Operating and Maintenance Requirements

Operating and maintenance requirements for the LTTA system include utilities for support trailers, as well as services and supplies. The LTTA system is equipped with a generator which powers the system. These requirements are discussed below.

Utilities

Operating the LTTA system requires the following utilities?

* Electrical power -- The LTTA system requires 460-volt, three-phase, 200-ampere electrical service. Transformers in the LTTA system reduce the electrical service to 240-volt, three-phase and 120-volt, single-phase service to operate the LTTA system and control circuits, respectively. The LTTA system includes a transportable diesel generator, allowing operation in areas that are remote from established utility service lines.

* Process water -- Process water is primarily needed for quenching treated material, for the venturi scrubber, and for decontamination purposes. The LTTA system requires 20 to 100 gpm of process water during operation. Treated scrubber water is reused for wetting treated soil. The recovered scrubber water must be augmented with a steady outside supply. For the SITE demonstration, a pump was utilized to obtain water from a nearby irrigation system.

Services and Supplies

A number of readily obtainable services and supplies are required to operate the LTTA system. Major services may include (I) heavy equipment rigging, (2) replacement services for spent GAC, (3) sanitary and decontamination wastewater disposal, and (4) laboratory analyses to monitor the system's performance. The laboratory analyses can be preformed on site using Canonie's laboratory. During all the LTTA projects studied for this report, the mobile laboratory was approved by the appropriate regulatory agencies for on-site analyses.

During the SITE demonstration, treated soil samples were collected hourly, cornposited into two 4-hour samples, and analyzed at Canonie's on-site laboratory to determine acceptable system performance before soils were backfilled in the excavations. Post-excavation samples were also analyzed at the on-site laboratory.

During the SITE demonstration and the subsequent remediation, subcontractors or off-site facilities furnished the remaining required services. Rigging of the LTTA system during mobilization was facilitated by LTTA personnel and local labor sources.

Canonie utilized Westates Carbon Company to provide activated carbon and to accept spent carbon. Each of the vapor-phase activated carbon beds hold approximately 50,000 pounds (lbs) of carbon. Approximately 20,000 tons of soil were treated before the liquid and vapor-phase GAC required replacement.

All wastewater is directed through the liquid-phase GAC column before being reused in the pug mill. There is no discharge from the LTTA system.

Supplies required for the remedial activities included (1) sodium hydroxide to maintain the scrubber water at an alkaline pH, (2) absorbing cloth and oil-dry material, (3) lubricating fluids and oils, (4) diesel fuel, (5) propane, (6) plastic sheeting, (7) fiber drums, (8) GAC for the vapor-phase beds and the liquid phase column, and (9) disposable personal protection equipment.

Absorbing cloth and oil-dry material were kept on site to contain accidental fluid spills.

About 860 gallons of diesel fuel per day is required to operate heavy. equipment and the diesel generator. Diesel fuel was supplied daily by a local retailer and stored on site in two aboveground l,000-gallon storage tanks. During 5 days of operations involving SITE demonstration activities, 2,568 gallons of diesel were required for the generator and 1,752 gallons of diesel were required for equipment operation.

Propane gas is required for the burner that heats the soils within the materials dryer. Approximately 7.5 gallons of propane per ton of treated soil were consumed during the demonstration. Propane was supplied through a local vendor. The LTTA system's on-site bulk tank capacity is 5,700 gallons.

The two vapor-phase activated carbon beds (50,000 pounds each) receive minor organic contaminant loading since much of the airborne contaminants are removed in the venturi scrubber.

The GAC replacement frequency depends on site-specific contaminant concentrations. Samples of the carbon bed are collected and analyzed routinely to evaluate carbon loading and preempt breakthrough. As stated elsewhere, the carbon beds used during the SITE demonstration were changed after treating approximately 20,000 tons of soil.

One liquid-phase GAC column was used to treat scrubber liquor exiting the venturi scrubber. For the SITE demonstration, the liquid-phase GAC was replaced at the same time as the vapor-phase GAC, after treating approximately 20,000 tons of soil.

In general, each on-site worker will require two full sets of disposable personal protective equipment per work day. Site-specific requirements will vary. One to two 55-gallon drums were needed each shift to store used personal protective equipment.

2.4.3 Reliability

No operational difficulties were encountered during the SITE demonstration. This section summarizes operational problems reported by Canonie during remedial activities at the Arizona pesticide site.

Operational problems generally result from mechanical difficulties with equipment in the LTTA system. Canonie reports that operations are routinely stopped once or twice a week for up to 2 hours to repair minor mechanical breakdowns. During remedial activities at the Arizona pesticide site, a main bearing on the materials dryer broke down, requiring a 3-day shutdown for replacement.

Startup operations at the Arizona site lasted about 3 weeks. Many modifications have been made to the LTTA system to reduce startup time and improve sustained operational performance. For example, an automated screening device was added to separate materials larger than 2 inches in diameter before they enter the materials dryer. The consistent performance of this device and the relatively low potential for clogging by treated soils, due to system design, eliminated many of the materials handling problems common to soil treatment systems.

For Case Study 3 (Ottati and Goss), the cleanup goal was 1.0 mg/kg total VOCs. Four separate locations were treated, with feed concentrations of total VOCs greater than 2,000 mg/kg in some locations. Of 4,712 cubic yards of soil treated by the LTTA" system, only 470 cubic yards failed confirmatory testing and required reprocessing.

2.4.4 Personnel Requirements

Operation of the LTTA system generally requires six to eight people per shift. However, personnel requirements depend largely upon the type of services provided by Canonie for a particular project, size of the site, and the specifications of the client and regulatory agencies. During the SITE demonstration 14 staff members were involved with LTTA' operations, excavation operations, and on-site laboratory operations. Staff for LTTA operations include a control room supervisor, a field operations supervisor, a site health and safety officer, and one to five equipment operators.

The control room operator monitors all LTTA operations: feed rate, burner temperature, drum vacuum, baghouse temperature, treated soil scale loadings, and venturi scrubber flow rate and pressure drop. The control room operator is also responsible for ensuring a steady flow of soil from the feed hopper into the LTTA system. Up to three equipment operators service the input and output plant operations. A feed loader and a,tailings loader work with the control room operator to maintain a constant flow of soil into and out of the system.

The field operations supervisor monitors all the operations from outside the control room. In addition, up to two site workers were required at the Arizona pesticide site to provide water supplies, keep the operations area clean, and perform routine maintenance.

Soil excavation, soil replacement, and other on-site support operations are ongoing during processing. At the Arizona pesticide site three heavy equipment operators handled soils with a deep mixer, front-end loader, backhoe, and grader.

Additional on-site staff were needed for support operations at the Arizona pesticide site. Up to four laboratory staff were present during operations (two technicians and two chemists), and one administrative assistant. Laboratory operations may be conducted in shifts, with one chemist and one technician on site for each shift. Generally, a laboratory staff including one chemist and one technician are required. However, the laboratory staff requirements are mainly dependent upon the services provided by Canonie and on the specifications of the client and regulatory agencies.

2.4.5 Demobilization

This section summarizes demobilization activities associated with the LTTA system based on the field operations plan for the Arizona pesticide site.

Decontamination and demobilization activities begin once remedial activities have been completed. Decontamination of the LTTA system includes brushing and pressure-washing all leased equipment prior to its return. The exterior of all LTTA plant equipment will likewise be brushed and pressure-washed. The interiors of the trailer's are pressure-washed or scrubbed and mopped, as appropriate.

A composite sample of the baghouse bags is analyzed to determine if the bags are suitable for reuse. If the bag material contains concentrations of contaminants above specified cleanup levels, the bags are disposed of at a suitable facility.

The materials dryer is aerated for a short time after all soil processing is complete, to expel residual levels of organic compounds. After cooling, the materials dryer is moved to the decontamination pads for exterior cleaning. The outside of the dryer is pressure-washed. Wash water from the decontamination cleaning is either (1) processed on site through the liquid-phase carbon column until contaminant concentrations in the water are below drinking water maximum contaminant levels or (2) drummed for off-site disposal.

A decontamination inspection is conducted and documentation completed by the site safety officer on all system components before the LTTA system exits the decontamination zone.

2.5 *Short- Term Impact*

Potential short-term concerns of the LTTA technology include operational hazards **and** potential community exposures.

2.5.1 Operational Hazards

Operational hazards to the on-site personnel associated with the LTTA system can be grouped in two categories: (1) general site hazards and (2) potential chemical hazards. General site hazards include the following:

- Heavy equipment hazards
- Occupational noise exposure
- Potential slip, trip, or fall hazards
- Potential for contact with underground or overhead mechanical and electrical hazards
- Open trench and excavation hazards
- Airborne dust hazards
- Confined space entry hazards
- Fire and heat exposure
- High pressure control line injuries

Potential chemical hazards involve inhaling, absorbing, and ingesting constituents of concern in contaminated material. The potential for exposure is high during excavation and handling of contaminated soils. At the Arizona pesticide site, primary constituents of concern included toxaphene, DDT, DDD, DDE, methyl and ethyl parathion, and endosulfan I.

All personnel working at the site had a minimum of 40 hours of health and safety training, and were under routine medical surveillance. Remedial activities were conducted using Level C personal protective equipment. Compliance with all 40 CFR 1910.120 health and safety requirements was maintained by Canonie staff.

2.5.2 Potential Community Exposures

Potential community health hazards from the operation of the LTTA system include exposure to (1) stack gas emissions, (2) fugitive dust emissions, and (3) noise.from the system and from earth moving equipment. Daily, real-time air monitoring confirmed compliance with all fugitive emission guidelines for dust and pesticides. The berm and fence were constructed primarily to create a visual barrier for the neighboring golf course visitors. However, they helped reduce the noise levels as well. Noise level surveys surrounding the site and nearby residences confirmed that noise levels from the operations were at background levels.

2.6 *Long-Term Effectiveness*

Long-term effectiveness of the LTTA system was assessed based on the permanence of the treatment and the handling of process residuals. These items are discussed below.

2.6.1 Permanence of Treatment

The LTTA system desorbs and separates contaminants from contaminated soils. However, the treatment residuals on which the separated contaminants are collected are not destroyed on site and require off-site treatment and disposal.

Approximately 350 tons of treated soils were produced every 10 hours of LTTA system operation at the Arizona pesticide site during the SITE demonstration. Treated material from each processing period was transported separately to a clean staging area to await analytical results. If analytical results indicated that the required level of treatment had not been achieved for greater than 10 percent of the hourly grab samples, the material from that processing period was reprocessed.

2.6.2 Residuals Handling

The final stage of gas stream treatment takes place in the vapor-phase activated carbon beds. The beds remove the remaining VOCs from the gas stream before it exits the LTTA system stacks. Routine sampling of the carbon bed determines carbon loading and the approach of breakthrough conditions. If breakthrough is approaching, the carbon is transported off site for regeneration and is replaced with virgin carbon. The long-term cost effectiveness of the LTTA system is influenced by the method used to treat or dispose of the residuals sorbed to the GAC in the vapor-phase beds and the liquid-phase column. During the Arizona pesticide site remediation, spent carbon from

these components was sent to nearby carbon regeneration facilities, which desorbed and incinerated the contaminants in a tiered furnace operation.

A portion of the venturi scrubber liquor containing condensed VOCs and water-soluble air stream components is continuously blown down from the recirculating line and treated by the liquid-phase GAC column. The treated water is transferred to the pug mill for reuse in soil quenching. Water analyses are conducted twice each week to ensure that all contaminants are removed in the liquid-phase carbon filter and breakthrough conditions do not exist. The liquid-phase GAC is replaced on a schedule determined by the concentration and identity of site-specific contaminants.

At the Arizona pesticide site, the liquid-phase carbon filter and the vapor-phase activated carbon beds were changed after approximately every 20,000 tons of treated soil. This generates approximately 60,000 pounds of carbon each time the filter and beds are changed.

2.7 Factors Influencing Performance

This section discusses several factors that may influence the LTTA system's performance, including waste characteristics, operating parameters, and climate.

2.7.1 Waste Characteristics

The most important waste characteristics affecting the LTTA" system's performance include the size of the contaminated materials, its moisture content, particle size distribution and available surface area, pH, and contaminant properties such as coefficient of adsorption and boiling point. These characteristics are discussed below.

The LTTA system operates best when the waste feed material consists of small, uniformly sized particles, preferably less than 2 inches in diameter. Mechanical failure and reduction in desorption efficiency may result from large rocks or oversized debris in the feed material. During the SITE demonstration, oversized material in the untreated soil was removed with an automated screen before the soils entered the LTTA system. The oversized material can be crushed through size reduction devices, and then processed through the LTTA system, if required.

Moisture Content

The LTTA system is most efficient when treating wastes with a moisture content less than 20 percent. Waste with a high moisture content requires additional thermal energy to remove the water while maintaining the treatment temperature, thereby increasing operating costs. To enhance the efficiency of the LTTA system, wastes with an excessively high moisture content must be dewatered. Soils at the Arizona pesticide site contained approximately 8 percent moisture and did not require dewatering.

Particle Size Distribution and Available Surface Area

The waste feed's particle size distribution and available surface area are important factors that affect the performance of the LTTA system. Contaminants tend to concentrate on smaller soil particles, because soils composed of small particles have a larger surface area with more sites available for contaminant sorption.

During the SITE demonstration, 37 percent of the soil particles were less than 74 microns (clays), about 43 percent were between 74 and 425 microns (fine to medium sands), and approximately 20 percent were greater than 425 microns. The clay content of the soils was fairly low, at less than 10 percent by weight.

Alkalinity

The alkalinity of the waste feed may also affect the performance of the LTTA system. Waste feed alkalinity can impact the net surface charge of the soil particles, which is, in turn, related to contaminant sorption. In addition, soil alkalinity determines the type and extent of chemical reactions that occur during thermal treatment in the LTTA system. The soil at the Arizona pesticide site was slightly alkaline and had a measured pH of 7.6.

For many contaminants, acid vapors are produced as products of thermal transformation in the LTTA system. Under these circumstances, sodium hydroxide is added to the scrubber liquor to neutralize the acid vapors in the gas stream.

Contaminant Properties

Physical and chemical properties of the contaminants also influence the performance of the LTTA system. Two properties of primary concern are the coefficient of adsorption and the boiling point. The coefficient of adsorption measures the relative affinity of a compound to adsorbing surfaces. Contaminants with a high coefficient of adsorption will require more thermal energy to desorb than contaminants with a low coefficient of adsorption. Contaminants with a low boiling point will desorb more readily than contaminants with a high boiling point. Both the coefficient of adsorption and boiling point should be taken into consideration when assessing the LTTA system's ability to remove a particular contaminant.

2.7.2 Operating Parameters

Operating parameters affecting contaminant removal efficiency are normally optimized during pilot testing or proof-of-process testing. Soil feed rate and soil temperature were optimized during full scale proof-of-process testing at the Arizona pesticide site, before the SITE demonstration. Typical values for these and other system operating parameters are shown in Table 2.

Contaminated Soil Feed Rate

The feed material flow rate is the main variable in controlling the residence time of soils in the LTTA system. At a selected propane flow rate, the residence time determines the soil treatment temperature. This temperature impacts the efficiency of contaminant removal and the potential for chemical transformations during heating. The LTTA system can process contaminated material at a rate of up to 50 tons/hr. During the SITE demonstration, soil was treated at a rate of 34 tons/hr, which resulted in a residence time of 9 to 12 minutes. The rotational speed of the dryer and the dryer angle were kept constant during the demonstration.

Dryer and Heated Air Temperature

Heat generated by a propane burner provides the thermal energy needed to maintain the desired temperature in the materials dryer. The resulting air and soil temperature affects the rate and degree of contaminant volatilization, desorption, and formation of thermal degradation byproducts. At elevated temperatures, contaminants may react to form dioxins and furans, or other products of incomplete combustion. For the SITE demonstration, the LTTA materials dryer maintained a soil temperature between 720 °F and 750 °F to volatilize organic compounds from the contaminated soil.

2.7.3 Climatic Conditions

The SITE demonstration of the LTTA system was conducted under dry, warm weather conditions with light winds. Freezing or wet conditions may cause difficulties in the operation and maintenance of the LTTA system. Strong winds may increase fugitive dust from the excavation and soil transportation process.

Table 2. Range of General Operating Parameters

Component	Parameter	Approximate Value
Materials Dryer	Temperature	600 to 800 °F
	Feed Material Flow Rate	20 to 50 tons/hr
	Rotational Speed	1 to 8 rpm
	Dryer Angle	l-7 degrees
	Residence Time	6to15min
Cyclonic Separators	Inlet Velocity	4,800 ft/min
Baghouse	Air/Cloth Ratio	5
	Cleaning Frequency	Every 5 to 30 set
Venturi Scrubber	Gas Velocity	150 to 500 ft/sec
	Operational Gas Flow Rate	20,000 to 30,000 cfm
	Pressure Differential	6 to 25 inches of water
	Water Flow Rate	100 to 220 gpm
	Water Blowdown Rate	2 to 80 gpm
Vapor-Phase Activated Carbon Beds	Empty Bed Velocity	55 ft/min
	Empty Bed Contact Time	0.07 min

°F Degrees Fahrenheit
tons/hr Tons per hour
rpm Revolutions per minute
min Minute
ft/min Feet per minute
set Second
ft/sec Feet per second
cfm Cubic feet per minute
gpm Gallons per minute

Section 3
Economic Analysis

This section presents an analysis of cost data associated with operating the LTTA system. Costs have been placed in 12 categories applicable to typical clean up activities at Superfund and RCRA sites. Site-specific factors affecting costs, the basis of the economic analysis, and each of the 12 cost categories as they apply to the LTTA technology are discussed in this section.

Data were compiled in 1992 during remedial operations at the Arizona pesticide site. This cost analysis presents the costs associated with treating 10,000 tons of soil contaminated with a range of pesticides including toxaphene, DDT and its derivatives, endosulfan, and methyl parathion at total concentrations up to 120 mg/kg. This analysis then compares the costs of treating soils at different soil processing rates.

This economic analysis reveals that operating costs are most affected by soil moisture content, soil composition, and the nature and concentration levels of contaminants in the soil. These factors significantly impact the soil processing rate. Soil processing rates directly affect the variable costs of the LTTA system by determining the duration of system operation during any given remediation activity.

3.1 *Site-Specific Factors Affecting Costs*

Site-specific wastes and features affect the costs involved with this soil treatment technology. Waste-related factors affecting costs include waste volume, waste type and concentration, soil moisture content, treatment goals, and the affinity of the contaminants for soil particles. Site-specific features that significantly affect costs include site area, accessibility, geographical location, and soil composition. Soil contaminated with compounds showing a high affinity for soil particles may require reprocessing, particularly fine-grained soils consisting of greater than 50 percent silts or clays. Reprocessing significantly reduces the overall soil processing rate.

3.2 *Basis of the Economic Analysis*

Table 3 presents processing costs associated with each cost category. These costs are estimated to be within 50 percent above and 30 percent below the actual costs. The table presents a breakdown of fixed and variable costs for processing 10,000 tons of soil at rates of 20, 35, and 50 tons/hr. Variable costs are calculated according to a weekly rate and therefore depend on the time required to process a given amount of contaminated soil. Table 4 summarizes variable costs per ton of soil processed. Fixed costs remain constant regardless of soil processing rates and length of time that the LTTA system is in operation.

3.2.1 Assumptions About the LTTA Technology and Capital Costs

This economic analysis assumes that Canonie will operate the LTTA system for on-site treatment of soils contaminated with VOCs, SVOCs, or pesticides. The LTTA system, consisting of nine system and five support semitrailers, will be delivered to the site by a subcontracting transportation company and assembled by Canonie. In addition to the LTTA system, it is assumed that excavation and earth-moving equipment will be required at all remediation sites as detailed in Section 3.3.3. Neither depreciation nor salvage value is applied to the costs presented in this analysis.

3.2.2 Assumptions About the Soil and Site Conditions

This analysis assumes that the soil is contaminated with VOCs, SVOCs, or pesticides, is fairly homogenous, and contains less than 50 percent silts or clays. It is further assumed that the amount of oversized material in the soil will not significantly impact excavation activities and that any oversized materials can be disposed of at an ordinary Class III industrial landfill following testing.

The amount and type of contaminants and the cleanup goals will affect the soil processing rate. Soil with a moisture content greater than 20 percent will normally require dewatering. This cost analysis assumes dewatering will be accomplished by lower production rate required to drive off the excess moisture in the dryer drum. Dewatering will reduce the effective contaminated soil processing rate in proportion to the amount of moisture that must be removed from the feed soils.

Table 3. Cost to Process **10,000** Tons of Soil at Various Processing Rates

Cost Category	Processing **Rate**		
	20 tons/hr	**35 tons/hr**	**50 tons/hr**
Site Preparation	$26,250	$26,250	$26,250
Permitting/Regulatory	$22,000	$22,000	$22,000
Equipment	$439,450	$258,500	$180,950
Startup	$264,810	$264,810	$264,810
Labor	$398,820	$234,600	$335,140
Consumable Materials	$387,260	$227,800	$159,460
Utilities	0	0	0
Effluent Monitoring	$52.,000	$52,000	$52,000
Residual Waste Shipping, Handling, and Transportation	$28,900	$17,000	$11,900
Analytical	$204,000	$120,000	$84,000
Equipment Repair and Replacement	$122,400	$72,000	$50,400
Site Demobilization	$141,840	$141,840	$141,840
Total	**$2,087,730**	**$1,436,800**	**$1,328,750**
Cost/Ton	**$209**	**$144**	**$133**

Table 4. Summary of Variable Costs Per Ton of Soil Processed at Various Processing Rates

Cost Category	Processing Rate		
	20 tons/hr	35 tons/hr	50 tons/hr
EQUIPMENT			
LTTA System Capital Equipment Cost	$33.33	$19.05	$13.33
Earth Moving and Excavation Equipment	$5.67	$3.24	52.27
Miscellaneous Equipment	$4.08	$2.33	$1.63
Total Equipment Cost Per Ton	$43.08	$24.62	$17.23
LABQR			
Excavation and Earth-Moving Equipment Operators	$9.85	$5.63	$3.94
LTTA staff	$15.67	$6.95	$6.27
Analytical and Support Staff	$6.30	$4.79	$3.35
Site Supervisor	$5.20	$2.97	$2.08
Total Labor Cost Per Ton	$39.10	$22.34	$16.34
CONSUMABLE MATERIALS			
Propane	$6.67	$3.81	$2.67
Diesel Fuel	$2.42	$1.38	$0.97
Carbon	$25.64	$14.65	$10.26
Personal Protection Equipment	$2.33	$1.33	$0.93
Disposal Drums	$0.92	$0.52	$0.37
Total Consumable Materials Cost Per Ton	537.98	$21.69	$15.20
UTILITIES			
RESIDUAL WASTE, SHIPPING, HANDLING, AND TRANSPORTATION	92.83	$1.62	51.13
ANALYTICAL	$20.00	$11.43	se.00
EQUIPMENT REPAIR AND REPLACEMENT	$12.00	$6.86	54.80
TOTAL VARIABLE COST PER TON OF SOIL TREATED	$154.99	$88.56	$62.70

Site preparation costs assume that electric and telephone utilities and a sanitary sewer are available at or nearby the site and that a ready source of water is available on site, such as existing water lines, an irrigation canal, well, or aqueduct. It further assumes that no costs are associated with preparing, fencing or otherwise improving the remediation site, except as needed for assembly and operation of the LTTA system.

3.2.3 Assumptions about the LTTA System Operation

Accounting for down time due to equipment repair or replacement, daily startup and shutdown, and other factors, the LTTA system is assumed to operate approximately 30 hours per week. At this rate, 10,000 tons of soil can be processed in 10 weeks, not including site preparation, mobilization, startup, demobilization, and site restoration. At a processing rate of 20 tons/hr, 17 weeks would be needed to process the same amount of soil. At a processing rate of 50 tons/hr, 7 weeks would be needed to process the material. The 20-ton/hr and 50-ton/hr processing rate costs are extrapolated from data based on a 35-ton/hr processing rate, assuming no significant changes in the weekly operating costs of the LTTA system at different processing rates. It is also assumed that no soil dewatering will be required.

When in full operation as implemented at the Arizona pesticide site, the LTTA system may require a crew of up to 13 staff members. This includes a control room operator, an overall field operations supervisor, three to five equipment operators, one to two laboratory technicians one to two laboratory chemists, an administrative assistant, and a site supervisor who also serves as the health and safety officer. All staff **are** assumed to work 40 hours per week.

Because the full-scale LTTA system is the only model available, no equipment cost alternatives are presented here. This analysis presents fixed and variable costs for operating the full-scale LTTA system.

Other assumptions used for this analysis include the following:

* The site is located approximately 2,000 miles from the Canonie main office in Porter, Indiana.
* Only an air permit is necessary for LTTA system operations.
* GAC is regenerated and reused off site.
* The only residual waste produced during remedial operations are disposal drums for personal protective equipment and a small amount of laboratory waste.
* The administrative assistant will perform all administrative tasks associated with system operation; other staff, such as the health and safety officer, will participate on an as-needed basis.
* No major site improvements are required.
* Treated soil will be backfilled on site.

3.3 *Cost Categories*

Cost dam associated with the LTTA technology have been assigned to the 12 categories discussed below.

3.3.1 Site Preparation

Site preparation costs are based upon the space and logistical requirements of operating the LTTA system. A 10,000-square-foot site must be leveled to provide adequate area for the LTTA system and its support trailers. Additional leveling may be required for soil staging. Fencing materials around the LTTA' unit are assumed in the cost estimate. It is assumed that site preparation can be accomplished in 1 week. The total (fixed) cost for site preparation is $26,250.

This cost estimate assumes that no road building or other major improvements to the remediation or processing areas are necessary. Electric and telephone hook-ups, at a cost of $1,000 and $250 respectively (Means 1992b), will be necessary. A source of water is assumed to be available and a sanitary sewer located on or very near the site. Total utility hook-up costs are $1,250.

Equipment used during site preparation includes the excavation and earth-moving equipment and miscellaneous equipment used throughout the remediation process at a total cost of $5,850, in addition to a 25,000-lb grader at $2,300 per week for one week (Means 1992a) for site leveling. In addition to the site supervisor and administrative assistant, up to four medium equipment operators will be required, at a total cost of $12,440 (see Section 3.3.5). Three hundred feet of 8-foot, slatted, wire mesh fence on 4-by-4 wooden posts are assumed in the cost estimate to provide a visual screening, at a cost of $4,410 (Means 1992b). Total equipment costs for site preparation are $25,000.

3.3.2 Permitting and Regulatory

Permitting and regulatory costs for the LTTA system are based upon the costs of obtaining an air permit and are estimated to be approximately $22,000 (Canonie Permitting costs will vary depending on the site-specific regulatory requirements.

No other regulated effluents are produced by the LTTA system. Treated soil is backfilled on site. Wastewater is produced in small quantities during demobilization and decontamination; however, this water is recycled through the venturi scrubber and processed by a liquid-phase GAC column until it exceeds drinking water standards and can be discharged to a sanitary sewer. All soil and water sampling and analysis costs are included in analytical costs.

3.3.3 Equipment

Equipment costs to remediate soil using the LTTA system are based on (1) LTTA system equipment capital cost, (2) earth-moving and excavation equipment cost, and (3) miscellaneous equipment cost. For the purpose of this economic analysis, operating costs are incorporated into the weekly rental rate of equipment for excavation and miscellaneous equipment costs. Equipment operating costs are based on standard hourly operating cost assuming 30 hours of operation per week. operating costs of the LTTA system are itemized in overall variable costs. The total cost of equipment is $25,850 per week.

Rental of the LTTA system is billed to the client and includes a total of 14 trailers. Nine trailers are used for the LTTA equipment itself, while the remaining five trailers are used for operations, an on-site laboratory, personnel equipment, health and safety equipment, and miscellaneous related equipment.' The cost of the laboratory trailer is itemized separately under analytical costs. LTTA equipment costs are extrapolated from figures provided by Canonie and should be used only as a benchmark, since the actual capital equipment billing rate will vary from site to site. .The capital equipment cost for the LTTA system is approximately $20,000 per week.

Earth-moving and excavation equipment costs assume that a minimum amount of equipment is needed to excavate contaminated soil, deliver it to the LTTA processing area, load the contaminated soil into the processing unit, return the processed soil to the excavation area, and backfill the clean soil. Three pieces of heavy equipment are assumed to be necessary to complete these tasks; a crawler-mounted diesel hydraulic backhoe at $1,700 per week (Means, 1992a), and two standard 40 to 45 horsepower, wheeled loaders with a minimum 5/8cubic-yard capacity, at $850 per week each (Means, 1992a). The total cost of earth-moving and excavation equipment is $3,400 per week.

Miscellaneous equipment costs include (1) two portable toilets at $26 per week each; (2) a 40-cubic-yard dumpster at $345 per week; (3) an 18-foot, 3,000-pound, 2-wheel-drive all-terrain forklift for moving equipment and supplies at $564 per week; (4) two, 3/4-ton, 2-wheel-drive pickup trucks at $235 per week each; (5) a 2,000-gallon water truck for dust suppression at $900 per week; and (6) a submersible electric pump capable of delivering at least 85 gpm at $116 per week (Means, 1992a). The total weekly rate for miscellaneous equipment is $2,447 per week.

3.3.4 startup

Startup costs are fixed costs which includes mobilization, assembly, and shakedown. A fixed cost figure can be given because startup should take the same amount of time at each site once standard site preparation is complete. All costs associated with startup are included in the fixed price, including variable costs such as labor, equipment, and consumable materials (see the applicable section for specific rates and costs). Unusual requirements at any given site will affect startup costs. The total startup cost is approximately $264,810.

Mobilization costs include all costs associated with transporting equipment to the site. It is assumed that mobilization will take 1 week. The total cost of delivering the 14 trailers to the site is $34,510 ($2,465 per trailer) (AAA Coast to Coast Trucking 1993). This assumes that the trailers will travel approximately 2,000 miles to the site; the actual cost depends on the distance from the remediation site to the Canonie office in Porter, Indiana. It is assumed that all other equipment will be delivered to the site by or picked up from local suppliers at no charge. The only on-site personnel required during mobilization are the site supervisor and administrative assistant, each working a standard 40-hour week, for a cost of $3,560. The total mobilization cost is approximately $38,070.

Assembly of the LTTA system is assumed to take 3 weeks. All normal equipment costs apply for a cost of $77,550. In addition to the LTTA operator, site supervisor, and administrative assistant, one equipment operator and six technical support staff are assumed in the set up of the system, for a cost of $62,180 (see Section 3.3.5). All staff are assumed to work 40-hour weeks. Due to the nature of the work, employees will not be exposed to contaminated soil and, therefore, will not wear personal protection equipment. The total assembly cost is approximately $139,730.

During shakedown, the LTTA system operates for 1 week at a much lower soil processing rate. During shakedown, contaminated soil is processed through the LTTA system to perform proof-of-process testing. All normal operating costs for equipment, labor, consumable materials, utilities, analytical, and equipment repair apply. The total shakedown cost is approximately $85,010.

3.3.5 Labor

Labor costs fall into four categories: (1) excavation and earth-moving equipment operators, (2) LTTA staff, (3) analytical and support staff, and (4) the site supervisor. All staff are assumed to work 8-hour shifts, 5 days per week for the course of site remediation. Labor wage rates include overhead and hinge benefits. All staff wage rates are based on standard level-of-effort cost accounting (James M. Montgomery 1992). No overtime is included in this economic analysis. Per diem is assumed to be $500 per week for each staff member. The total cost of labor during LTTA system operation is approximately $23,460 per week.

Three equipment operators are assumed necessary to operate the earth-moving and excavation equipment. It is assumed that these operators can also operate the forklift and water truck, as needed. The labor wage rate for a heavy equipment operator is $36.75 per hour or $1,470 per week (Means 1992a). The total cost rate for excavation and earth-moving equipment operators is $5,910 per week. The LTTA staff are responsible for the actual operation and maintenance of the LTTA system. The LTTA staff are as follows: (1) control room operator at $1,820 per week, (2) field operations supervisor at $2,620 per week, and two laborers at $1,480 per week. The total cost of labor for LTTA staff is $9,400 per week.

Analytical and support staff labor are needed while the LTTA system is in operation. A minimum of three employees make up the analytical and support staff: (1) one laboratory technician at $1,180 per week, (2) one laboratory chemist at $1,410 per week, and (3) one administrative assistant at $940 per week. It is assumed that the administrative assistant can perform all administrative tasks of the soil remediation project with other staff, such as the health and safety officer, participating as needed during their normal shift. The total labor costs for analytical and support staff are $5,030 per week.

The site supervisor oversees all operations associated with the site remediation at $2,620 per week. The site supervisor's total labor wage rate is $3,120 per week.

3.3.6 Consumable Materials

Consumable materials costs fall into two major categories: (1) materials consumed in the LTTA process (propane, diesel, and GAC), and (2) materials related to personal protective equipment and the necessary waste disposal drums. For this cost analysis, fuel and operating costs for excavation, earth-moving, and miscellaneous equipment have been accounted for in the weekly equipment rate (Section 3.3.3). Similarly, analytical supply costs are included in the analytical rate. The total consumable materials rate is $22,780 per week.

When in operation, the LTTA is powered by a generator trailer. Monitoring of fuel use during the LTTA SITE demonstration indicates that the generator uses approximately 1.25 gallons of diesel fuel per ton of soil processed, or 1,310 gallons per week at 35 tons/hr Diesel cost per gallon, delivered on site, is assumed to be $1.10 per gallon (Supreme Gil Company 1992). The diesel fuel costs are approximately $1,440 per week.

Based on figures generated during the LTTA SITE demonstration, approximately 7.5 gallons of propane is consumed per ton of soil treated, or about 7,980 gallons per week at 35 tons/hr. This cost analysis assumes a cost of $0.50 per gallon for propane, for a total propane cost of approximately $4,000 per week.

A major component of the consumable materials cost is GAC regeneration. Based upon the data collected during processing at a 35-ton/hr rate, it is assumed that the GAC used in the vapor-phase and liquid-phase carbon adsorption units (approximately 50,000 lbs) must be regenerated every 3 months. Type and concentration of contaminants, soil processing rates, and soil water content will affect GAC regeneration. The cost of regenerating the 50,000 lbs of GAC is approximately $200,000. Prorated on a per-week basis, the consumable materials cost for GAC regeneration is $15,385 per week.

Due to the potential for exposure to contaminants from airborne particulates, all employees working outdoors at the site will be required to wear personal protective equipment. It is assumed that each employee working outdoors will use a minimum of level D protection. In addition, equipment operators and the field operation supervisor are expected to require respirators for level C protection. Costs for personal protective equipment are estimated at $25 .00 per day for standard level D protection and $45.00 per day for level C protection. Four staff will require level D and four staff will require level C protection each day, for a total of $280 per day or $1,400 per week.

All used disposable personal protective equipment must be drummed and disposed of as hazardous waste. It is assumed that two open-top, 55-gallon, steel or fiber drums will be required for hazardous waste disposal per day ($56 each) for the estimated personal protection equipment consumed. The total cost for disposal drums is $550 per week.

3.3.7 Utility

A diesel generator supplies all power for LTTA system operations and is incorporated into capital equipment costs. Although electrical, water, and telephone utilities are in use, the weekly consumption rates for these utilities are negligible in

terms of the overall LTTA system operating costs. Therefore, for this economic analysis, the utility rate is assumed to be $0 per week.

3.3.8 Effluent Monitoring

Effluent monitoring costs are given as a fixed cost, based upon the assumption that only one air permit is required to operate the LTTA system. A one-time stack gas sampling must be performed and reported by an outside contractor to verify compliance with the air permit. The monitoring of feed and treated soil, ambient air testing, liquid-phase aud vapor-phase carbon unit testing, and final demobilization and decontamination water testing are not permit-related and are thus itemized under analytical costs. The cost of this sampling and subsequent analysis is approximately $52,000 (Canonie 1992c).

3.3.9 Residual Waste Shipping, Handling, and Transportation

It is assumed that residual waste shipping, handling, and transportation consists only of the disposal of drummed personal protective equipment and a small amount of laboratory hazardous waste. No other residual waste is produced. Treated soil is backfilled on site. A small amount of wastewater is produced during demobilization and decontamination; however, this water can be treated by the liquid-phase GAC column until it meets or exceeds drinking water standards. The water is then discharged to a sanitary sewer. It is assumed that oversized material such as rocks and concreteis tested and disposed of at a standard Class III industrial landfill. If the oversized material exceeds cleanup standards, it can be pulverized and processed through the LTTA system; however, it is assumed that this will not be necessary. The pick-up, transportation, and disposal cost for a 100-lb drum is approximately $170 (Means 1992b). The total cost rate for residual waste shipping, handling and transportation is $1,700 per week.

3.3.10 **Analytical**

Analytical costs include the rental of the LTTA system laboratory trailer and all related supplies, consumables, equipment rental, and outside verification testing associated with normal LTTA system operations. Feed soil and treated soil are each analyzed on site twice per day. Samples of each are sent weekly to an outside laboratory for verification testing. Water and carbon from the liquid-phase and vapor-phase carbon units are analyzed on site once per week. Demobilization and decontamination wastewater is also analyzed on site and verified by an independent laboratory.

According to Canonie estimates for the Arizona pesticide site, analytical costs are approximately 60 percent of LTTA capital equipment costs (Canonie 1992c). Based on the weekly LTTA capital equipment cost of $20,000 (see Section 3.3.3), the analytical cost is $12,000 per week.

3.3.11 Equipment Repair and Replacement

Standard maintenance of LTTA machinery requires about 2 hours per week. This includes inspection and replacement of baghouse filters and pumps as well as other routine maintenance. Repairs are made on an as-needed basis.

Based on Canonie estimates at the Arizona pesticide site, equipment repair and maintenance is about 36 percent of the LTTA system capital equipment cost (Canonie 1992c). Based on the LTTA capital equipment rate of $20,000 per week, the total equipment repair and replacement rate is $7,200 per week.

3.3.12 Demobilization

It is assumed that all necessary site demobilization activities can be completed in ten 8-hour shifts. Five days are required for LTTA system shutdown, cleanup and disassembly; the additional five days are required for site cleanup and restoration. With the exception of site-specific cleanup and restoration costs, site demobilization costs will be fairly consistent. Total site demobilization cost is approximately $141,840.

Shutdown, cleanup, and disassembly of the LTTA system, including decontamination, cau be performed at $25,850 with equipment already on site; however, six additional laborers are assumed necessary in addition to the regular staff, for a total labor cost of $34,840 (see Section 3.3.5). During this time, up to 12 workers will be wearing level D personal protective equipment, necessitating purchase and disposal of three 55-gallon drums per day. This results in a total consumable materials cost of $3,000 and a total residual waste shipping, handling and disposal costs of $1,670. Disconnecting electric and telephone utilities will cost approximately $1,000 (Means 1992b). Analytical costs will be double the normal rate of $12,000 (see Section 3.3.10) due to the volume of wastewater produced during decontamination of equipment and because verification testing must be done by an outside laboratory. Finally, the 14 LTTA trailers must be returned to the Canonie office in Porter, Indiana. This cost, $34,510, is the same as trucking costs during mobilization. The total shutdown, cleanup, and disassembly cost is $124,870.

Site cleanup and restoration is fairly minimal because the processed soil is backfilled throughout the remediation process. It is assumed that cleanup and restoration can be accomplished using the on-site excavation and earth-moving equipment with the addition of a grader, for a total equipment cost of $5,695 If . extensive soil dewatering was necessary, the increased volume of processed soil caused by the addition of sand to the feed material could hinder site cleanup and restoration, but for the purposes of this cost analysis, no additional costs are included. During cleanup and restoration only three excavation and earth-moving equipment operators, site supervisor, and administrative assistant will be involved, for a total labor cost of $10,470. Five employees will be wearing personal protective equipment during this period; the resulting total consumable materials cost is $625. Personal protective equipment disposal cost is $180. The total cost of site cleanup and restoration is approximately $16,970.

Section 4
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Appendix A
Vendor's Claims for the Technology

1.0 Introduction

Low Temperature Thermal Aeration (LTTA) is a remedial technology developed by Canonie Environmental Services Corp. (Canonie) for treating soil containing volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), organochlorine pesticides (OCPs), organophosphorus pesticides (OPPs), and other extractable organic compounds. The LTTA" system separates these hazardous constituents from excavated soil and allows the treated soil to be backfilled on-site without restriction. The LTTA technology was developed by Canonie using full-scale equipment during the remediation of the McKin Superfund Site in Gray, Maine. More than 11,000 cubic yards (yd^3) of soils impacted with chlorinated VOCs and petroleum hydrocarbons were successfully remediated at this Superfund Site. After the successful completion of the McKin Superfund Site soil remediation, Canonie employed a new transportable LTTA system to cost effectively treat the soil at the following five sites:

1 The Ottati & Goss Superfund Site in Kingston, New Hampshire;

2. The South Keamy Site in New Jersey;

3. The Cannons/Bridgewater Superfund Site in Massachusetts;

4. The Former Spencer Kellogg Facility in Newark, New Jersey;

5. A Pesticide Site in Arizona.

At each of these sites, compliance with soil cleanup criteria was verified by analyzing the treated soil on-site or off-site. Table 1 presents a summary of the contaminants successfully removed from soil using the full-scale LTTA system and the removal efficiencies achieved. Typical pre- and post-treatment soil characterization results for contaminants at the above mentioned sites are presented in Tables 2 through 6.

1.1 *LTTA Advantages*

The LTTA system provides the following advantages over many other treatment systems:

1 LTTA is a full-scale, proven technology which has treated more than 90,000 tons of contaminated soils at Superfund and non-Superfund Sites.

2. Unlike incineration systems, during treatment of OCPs, LTTA does not generate dioxins or dibenzofurans.

3. LTTA provides a very cost effective solution for remediation of soils impacted with chlorinated VOCs OCPs, and OPPs. The cost of remediation using incineration is generally an order of magnitude higher than that using LTTA.

4. LTTA provides permanent treatment, allows backfill of treated soil on-site, and eliminates future liabilities to the potentially responsible party.

5. No wastewater or waste streams other than personnel protective equipment and activated carbon (for regeneration) are generated by LTTA that require off-site disposal. This eliminates the need for permits like NPDES.

6. The LTTA system can remediate a site in a much shorter time than those technologies which utilize indirect heat transfer mechanism, for example a thermal screw system. Soil processing rates of up to 55 tons per hour (tph) have been achieved in the past by LTTA. Soil treatment systems utilizing thermal screws have been known to obtain processing rates of 2 to 3 tph.

7. LTTA is a trailer mounted system and can be transported from site-to-site.

8. LTTA has a flexible system configuration and can utilize an thermal oxidizer in lieu of the carbon adsorption system. This flexibility enables LTTA to treat soils contaminated with petroleum hydrocarbons and allows destruction of the contaminants of concern.

Table A-I. Demonstrated Full-Scale LTTA Chemical Removal Efficiencies

Compound (b)	Pretreatment Concentration (mg/kg)	Post-Treatment Concentration (mg/kg)	Removal Efficiency	Site (a)
Volatile Organk Compounds				
Benzene	5.3	ND (<0.025)	>99%	Cannons
1 ,2-Dichlorobenzene	320	ND (<0.02)	>99%	McKin
trans-1,1-Dichloroethene	300	ND (<0.02)	>99%	McKin
Ethylbenzene	1.409	ND (<0.05)	>99%	Newark
Tetrachloroethene	1,200	ND (<0.025)	>99%	Ottati &Goss
Toluene	3,000	ND (<0.05)	>99%	Newark
Trichioroethene	460	ND (<0.025)	>99%	Ottati & Goss
1 ,1,1-Trihloroethane	470	ND (<0.025)	>99%.	Ottati & Goss
Xylenes	3,700	0.25	>99%	Newark
Total VOCs	5,420	0.45	>99%	Newark
Organochlorine Pesticides				
p,p'-DDD	206	ND (<0.01)	>99%	Arizona
pep'-DDE	46	0.94	99%	Arizona
p.p'-DDT	321	ND (<0.04)	>99%	Arizona
Toxaphene	1.540	ND (<0.5)	>99%	Arizona
Organophosphorus Pesticides				
Ethyl Parathion	116	ND (<0.07)	>99%	Arizona
Methyl Parathion	0.76	ND (<0.059)	>92%	Arizona
Merphos	195	ND (<0.004)	>99%	Arizona
Mevinphos	20.4	ND (<0.002)	>99%	Arizona
Total Petroleum Hydrocarbons	2,000	ND (<50)	>99%	Cannons
Semivolatile Organic Compounds				
Acenaphthene	1.1	ND (<0.39)	>65%	Newark
Anthracene	1.1	0.062	94%	Newark
Benzo(a)anthracene	2.2	0.22	90%	Newark
Benzo(a)pyrene	2	0.3	05%	Newark
Benzo(b)fluoranthene	2.1	0.34	84%	Newark
Benzo(g.h.i)perylene	1	0.33	67%	Newark
Benzo(k)fluoranthene	1.6	0.32	80%	Newark
Bis(2-ethylhexyl)phthalate	6.5	1	85%	South Kearny
Chrysene	2.3	0.3	87%	Newark
Dibenzo(a,h)anthracene	0.15	0.05	67%	Newark
Fluoranthene	3.4	0.2	94%	Newark
Fluorene	0.79	ND (<0.39)	>51%	Newark
Indeno(l,2,3cd)pyrene	1	0.24	76%	Newark
Naphthalene	1.2	0.042	96%	Newark
Phenanthrene	3.8	0.23	94%	Newark
Pyrene	4.7	0.26	94%	Newark

ND Not detected. (Detection limit is provided parenthetically.)
(a) Descriptions of the site cleanups are provided in the project description section of this booklet.
(b) This table includes only chemicals treated to date using a full-scale LTTA system. Bench-scale results show that many other chemicals can be cost effectively treated using LTTA

Table A-2. Low Temperature Thermal Aeration Process Representative Soil Analysis Results McKin Superfund Site Gray, Maine

	Concentration (mg/kg)	
Chemical Constituent	Pretreatment Soil	Post-Treatment Soil
Volatile Organic Compounds		
Benzene	2.7	ND (<1)
1,2-Dichlorobenzene	320	ND (<0.02)
trans-1,2-Dichloroethene	300	ND (<0.02)
Ethylbenzene	130	ND (<l)
Tetrachloroethene	120	ND (<0.02)
Toluene	62	ND (<l)
1 ,1 ,1-Trichloroethane	19	ND (<0.02)
Trichloroethene	3,310	0.04
Xylenes	840	ND (<1)
Semivolatile Organic Compounds		
Anthracene	0.44	ND (<0.33)
Butylbenzylphthalate	0.8	ND (<0.33)
Fluoranthene	1.2	ND (<0.33)
Isophorone	0.79	ND (<0.33)
Naphthalene	0.8	ND (<0.33)
Phenanthrene	1.2	0.51

Notes

1, All concentrations are reported in milligrams per kilogram (mgkg).
2. ND indicates that the chemical constituent was not detected in excess of the stated concentration

Table A-3. Low Temperature Thermal Aeration Process Represetnative Analytical Results
Ottati & Goss Superfund Sites Kingston, New Hampshire

	Location 1		Location 2	
Chemical	**Pretreatment**	**Post-Treatment**	**Pretreatment**	**Post-Treatment**
I,I,I-Trichloroethane	33	**ND (<0.025)**	**120**	**ND (<0.025)**
Trichloroethene	19	**ND (<0.025)**	**6.5**	ND (<0.025)
Tetrachloroethene	12	ND (<0.025)	4.9	ND (<0.025)
Toluene	>470	**ND (<0.025)**	**260**	**ND (<0.025)**
Ethylbenzene	**>380**	**ND (<0.025)**	**>300**	**ND (<O. 025)**
Total Xylenes	>I,IOO	0.14	>900	**ND (<0.025)**

	Location 3		Location 4	
Chemical	**Pretreatment**	**Post-Treatment**	**Pretreatment**	**Post-Treatment**
1,1,1,-Trichloroethane	**27**	**ND (<0.025)**	**470**	**ND (<0.025)**
Trichloroethene	27	**ND (<0.025)**	**460**	**ND (<0.025)**
Tetrachloroethene	**40**	**ND (<0.025)**	**1,200**	**ND (<0.025)**
Toluene	**>87**	**ND (<0.025)**	**3,000**	**0.11**
Ethylbenzene	>50	ND (<0.025)	440	ND (<0.025)
Total Xylenes	>170	ND (<0.025)	180	0.14

Notes

1. All concnetrations are reported in mg/kg.
2. Pretreatment soil samples were anlayzed by gas chromatography/mass spectroscopy (EPA Method 8240)
3. Post-treatment soil samples were analyzed by gas chromatography (EPA Method 8010/8020).
4. ND indicates the chemical compound was not detected in excess of the stated concentration.

Table A-4. Representative LTTA Proof-of-Process Analytical Results South Kearny, New Jersey

Chemical Constituent	Concentration (mg/kg)	
	Pretreatment Soil	Post-Treatment Soil
Volatile Organic Compounds		
1,2-Dichloroethene (total)	0.55	ND.
1,1,1-Trichloroethane	3	ND
Trichloroethene	15	0.15
Tetrachloroethene	190	0.38
1,2-Dichlorobenzene	100	ND
Toluene	5.6	ND
Ethylbenzene	15	ND
Xylenes (total)	5.2	ND
Total VOCs	308	0.51
Semivolatile Organic Compounds		
Acenaphthene	0.7	ND
Anthracene	2.5	ND
Benzo(a)anthracene	5.9	0.94
Benzo(a)pyrene	5.4	0.58
Benzo(b)fluoranthene	5	1.2
Benzo(g,h,i)perylene	3.5	0.63
Benzo(k)fluoranthene	4.9	0.71
Bis(2-ethylhexyl)phthalate	6.5	1
Chrysene	5.9	1.3
Di-n-butylphthalate	1.9	0.84
Fluoranthene	7	1.8
Fluorene	1	ND
Indeno(l,2,3cd)pyrene	3.2	0.55
Naphthalene	2	0.34
Phenanthrene	6.4	1.2
Pyrene	15	1

Notes:

1 All concentrations are reported in mg/kg.
2. ND indicates the chemical compound was not detected. Detection levels varied.

Table A-5. Low Temperature Thermal Aeration Process Representative Treatment Results
Former Spencer Kellogg Facility Newark, New Jersey

Chemical Constituent	Concentration (mg/kg)	
	Pretreatment Soil	Post-Treatment Soil
Volatile Organic Compounds		
Benzene	0.24	0.072
Ethylbenzene	1.4	ND (<0.05)
Toluene	3,000	ND (<0.05)
Xylenes (total)	3,700	0.25
Total VOCs	5,420	0.45
Semivolatile Organic Compounds		
Acenaphthene	1.1	ND (<O.39)
Anthracene	1.1	0.062
Benzo(a)anthracene	2.2	0.22
Benzo(a)pyrene	2	0.3
Benzo(b)fluoranthene	2.1	0.34
Benzo(g,h,i)perylene	1	0.33
Benzo(k)fluoranthene	1.6	0.32
Bis(2-ethylhexyl)phthalate	0.95	0.071
Chrysene	**2.3**	0.3
Dibenzo(a,h)anthracene	**0.15**	0.05
Fluoranthene	**3.4**	0.2
Fluorene	**0.79**	ND (<O.39)
Indeno(l,2,3_cd)pyrene	1	0.24
Naphthalene	**1.2**	0.042
Phenanthrene	3.8	0.23
Pyrene	4.7	0.26

Notes:

ND = Not detected above the detection limit shown.

Table A-6. Low Temperature Thermal Aeration Soil Treatment Results for a Pesticide Site in Arizona

Chemical	Concentrations (mg/kg)	
	Pretreatment	Post-Treatment
Organochlorine Pesticides		
p,p'-DDD	206	ND (<0.01)
p,p'-DDE	48	0.94
p,p'-DDT	321	ND (<0.04)
Toxaphene	1,540	ND (<0.5)
Organophosphorus Pesticides		
Ethyl Parathion	116	ND (<0.07)
Methyl Parathion	0.78	ND (<0.059)
Merphos	195	ND (<0.004)
Mevinphos	20.4	ND (<0.002)

Notes:

ND = Not detected at indicated detection limit.

2.0 Process Description

The LTTA technology is a thermal desorption process. It utilizes hot air to desorb organic contaminants from the contaminated soil into a contained air stream and then treats the air stream extensively before discharging it to the atmosphere.

The LTTA system is trailer mounted and transportable. Approximately 10 system components are mobilized to the site, where ductwork, conveyor, and wiring connections are completed. Administrative trailers, laboratory trailers, and various construction trailers are also mobilized, providing the necessary facilities for workers and management.

Figure 1 depicts the primary components of the LTTA system. A soil flow diagram and an air and water flow diagram for the LTTA process are presented in Figures 2 and 3, respectively.

A description of the LTTA system components and related operations are presented below:

1. Feed Train - Rate-controlled feed hoppers and weighing belt conveyors feed the material to the rotary dryer. The feed/processing rate is measured by the weighing belt conveyor.

2. Rotary Dryer - The soil is transferred from the feed conveyor to the feed end of the rotary dryer. Numerous flights inside the dryer move the soil over the length of the rotary dryer. A propane or fuel oil burner at the feed end of the dryer heats air stream. This hot air stream flows co-currently with the soil in the drum, and dries the soil and volatilizes the organic contaminants from the soil into the hot air stream. The process temperature, soil residence time in the dryer, and the processing rate depend upon the type of soil, the nature of the contaminants, contaminant concentrations, and treatment levels to be achieved.

3. Pug Mill - The cleaned hot soil exits the rotary dryer and flows by gravity into a pug mill mixer. Water is metered into the pub mill to quench hot soil to allow handling of the treated soil without fugitive dust generation. Steam generated during soil quenching is vented into the air treatment system under negative pressure.

4. Cyclones and Baghouse - The air stream vented from the rotary dryer is directed to an extensive air treatment system. The air stream typically contains dust, evaporated organics, and traces of acid vapor. Air is first passed through a cyclone system to remove coarse dust particles, and then it is directed into a baghouse to remove fine dust particles. The dust recovered from the cyclones and the baghouse is transported via a screw conveyor into the pug mixer, where it is quenched together with the processed soil.

5. Venturi Scrubber - The air stream exiting the baghouse is directed into a venturi scrubber for acid vapor removal. In the scrubber, the air stream is intimately mixed with slightly caustic solution. During this mixing, the acid vapors are adsorbed from the air stream into the water stream and neutralized. Also, some of the organics in the air stream are adsorbed into the water stream. After the intimate mixing, a two-stage separator removes the entrained water from the air stream: The pH of the collected water is adjusted and the water is recirculated. A slip stream of the scrubber water **is** blown down continuously, treated with liquid-phase carbon as required and then utilized in the process operation.

6. Carbon Adsorption Beds - The air stream exiting the venturi scrubber is directed to two vapor-phase carbon adsorption units, operating in parallel. The organics remaining in the air stream after scrubbing, are adsorbed onto granular activated carbon. Once the carbon is completely spent, it is transported to an off-site, permitted facility for regeneration. The clean air stream is then discharged to the atmosphere.

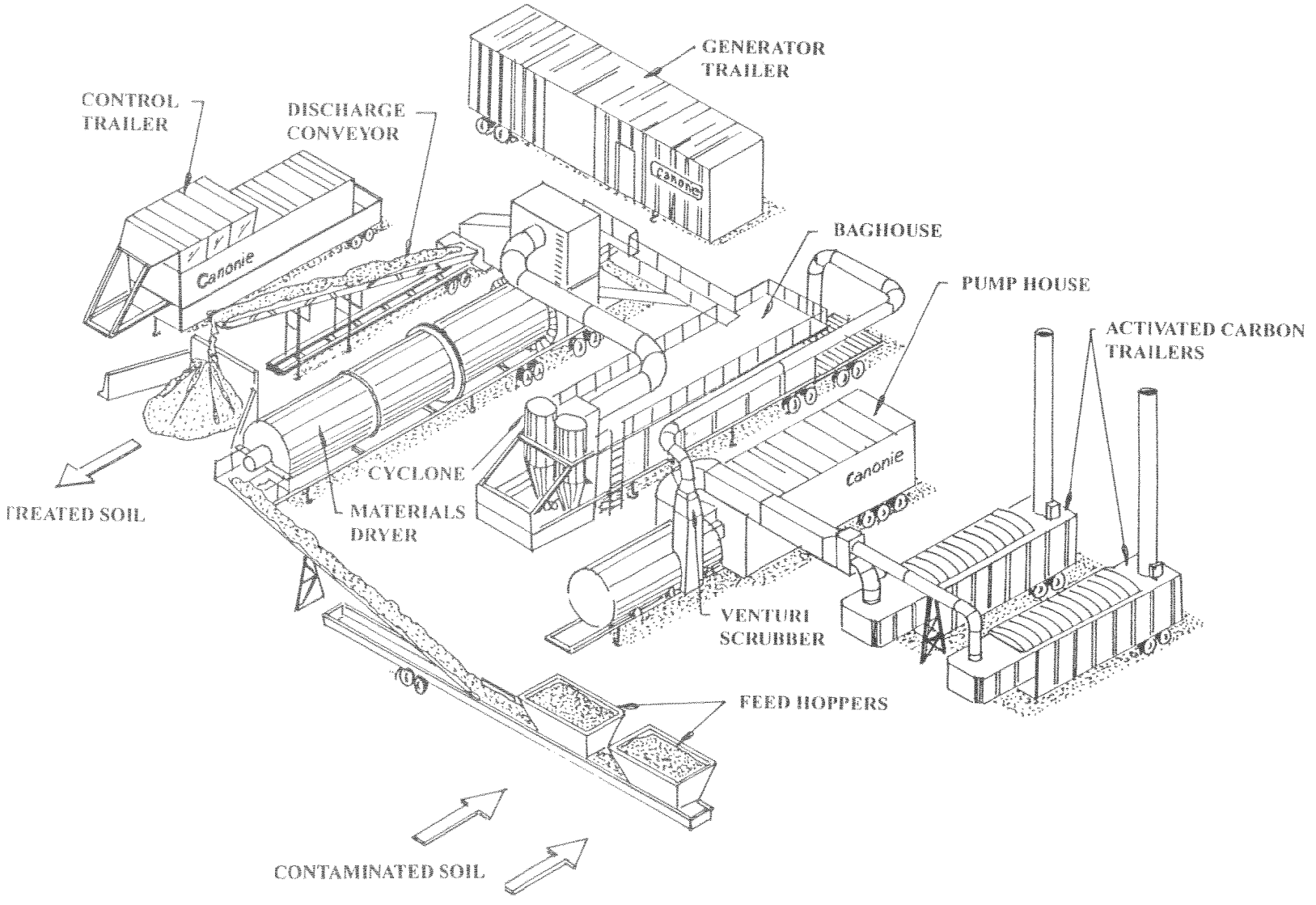
7. Optional Thermal Oxidizer - In some cases (soil contaminated with petroleum hydrocarbons, for example) the vapor-phase carbon adsorption system is replaced with a thermal oxidizer which destroys the vaporized organics present in the process air stream.

3.0 Process Economics

The cost of each particular application depends on the following parameters:

1. Volume of the soil to be treated;
2. Site conditions;
3. Soil type and soil moisture content;
4. Type of the contaminants, their feed concentrations and required final, treated soil concentrations.

As the parameters mentioned above will be unique to each remediation project, a project-specific cost can be developed only after the parameters are defined. However, in general terms, soil remediation costs using LTTA may fall within a range of $90 to $130 per ton of soil processed. This cost may include excavation, soil processing, on-site analyses, air monitoring, permitting, work plan preparation, and on-site coordination with clients and agencies.



Source: Canonie 1992

Figure 1. LTTA® Soil Processing Equipment Layout

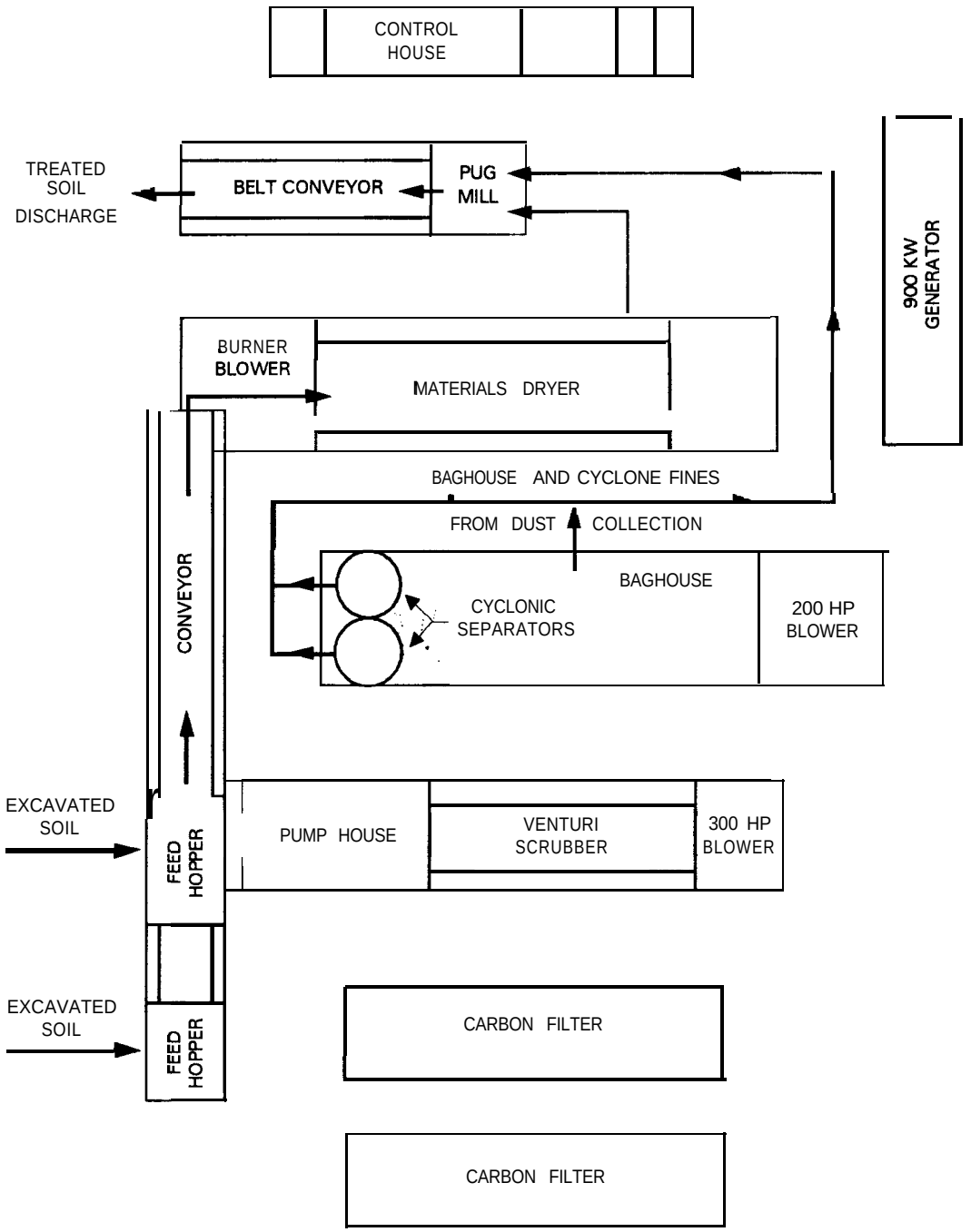


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Figure 2. Soil Flow Diagram

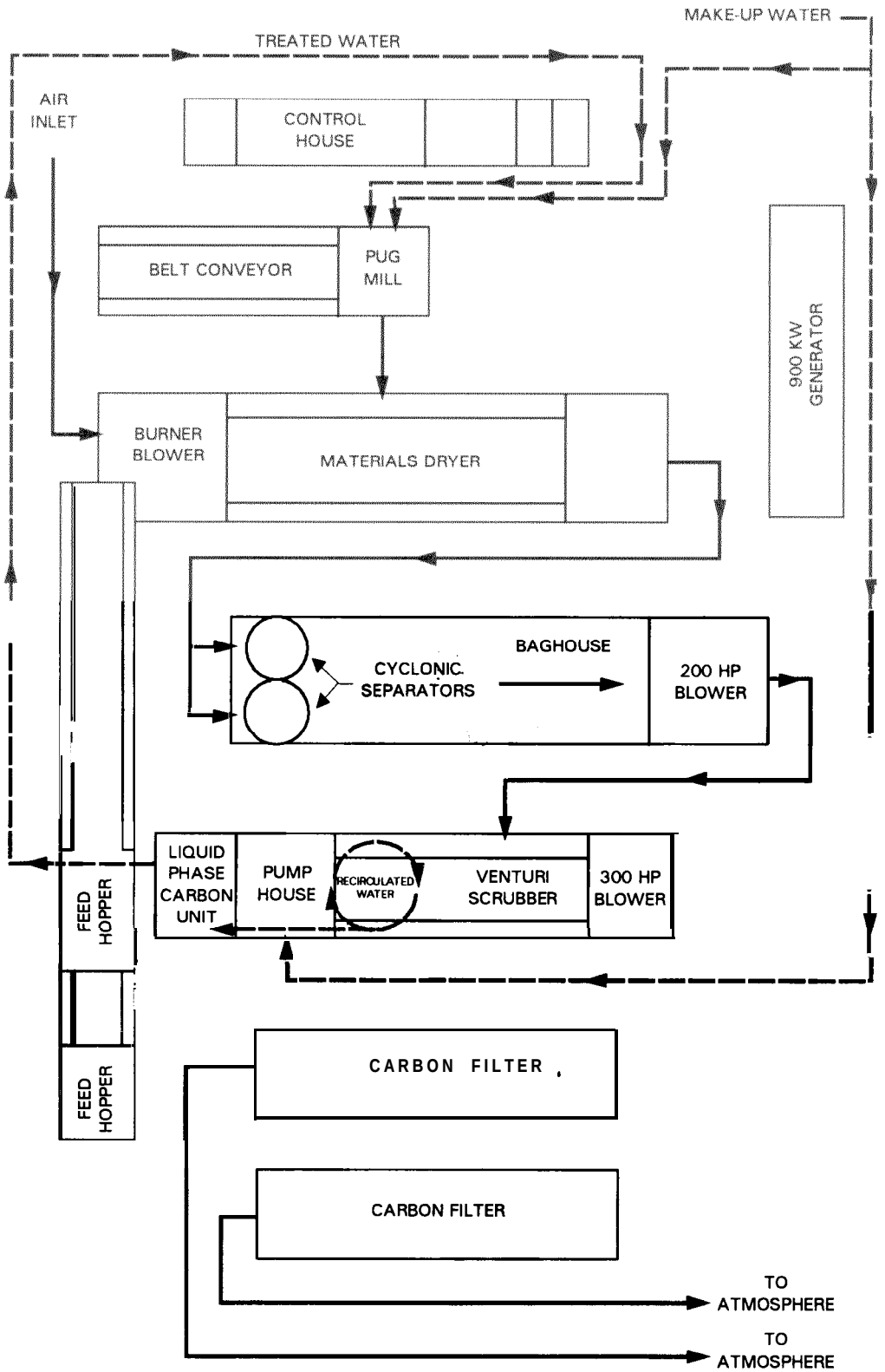

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Figure 3. Air and Water Flow Diagram

Appendix B
Site Demonstration Results

This appendix summarizes the results from the SITE program demonstration of the Canonie LTTA system. A detailed presentation of the SITE demonstration results can be found in the Technology Evaluation Report. The LTTA system was demonstrated using soils which were contaminated with pesticides, primarily toxaphene and DDT and its derivatives, DDD and DDE. The demonstration was conducted as part of full-scale remedial activities **being carried out by Canonie.**

B.l Site Description

The LTTA system was demonstrated at an abandoned pesticide mixing facility in western Arizona, as part of a full-scale remedial effort. The facility actively serviced farms in the surrounding area for over 30 years. Activities at the facility included mixing pesticides, loading and unloading crop dusting aircraft, washing and maintaining aircraft, and disposing of pesticide containers by burning on site. Pesticides stored and mixed on site included toxaphene, DDT, ethyl and methyl parathion, endosulfan, dieldrin, and endrin. The site covers 36 acres including an unpaved runway, an office complex, a mixing area, and an aircraft hanger. An estimated 5 1,000 tons of soil, contaminated with pesticide concentrations of 5 mg/kg or greater, were treated by the LTTA system. Soil with concentrations of less than 5 mg/kg total pesticides and above the required cleanup levels (Figure B- 1) were deep mixed to a depth of 2 feet. Actual concentrations of pesticides in the feed soil during the demonstration were as follows:

Pesticide	Concentration Range
Toxaphene	4.5 - 47 mg/kg
DDT	1.2 - 54 mglkg
DDD	0.027 - 0.86 mg/kg
DDE	3.7 - 15 mg/kg
Dieldrin	<0.001 - 0.20 mg/kg
Endosulfan I	<O.OOl- 1.1 mg/kg
Endrin	0.12 - 2.0 mg/kg
Endrin Aldehyde	(0.002 - 0.65 mg/kg

The geology of the site consists of alluvial basin sediments overlying granitic and extrusive rocks. Surface sediments are generally a clayey loam. Depth to groundwater in the area of the site is approximately 200 feet. Groundwater conditions for the area of the site are typically unconfined, but semiconflned and perched conditions are known to exist. Several water wells, mainly for irrigation, exist in the vicinity of the site.

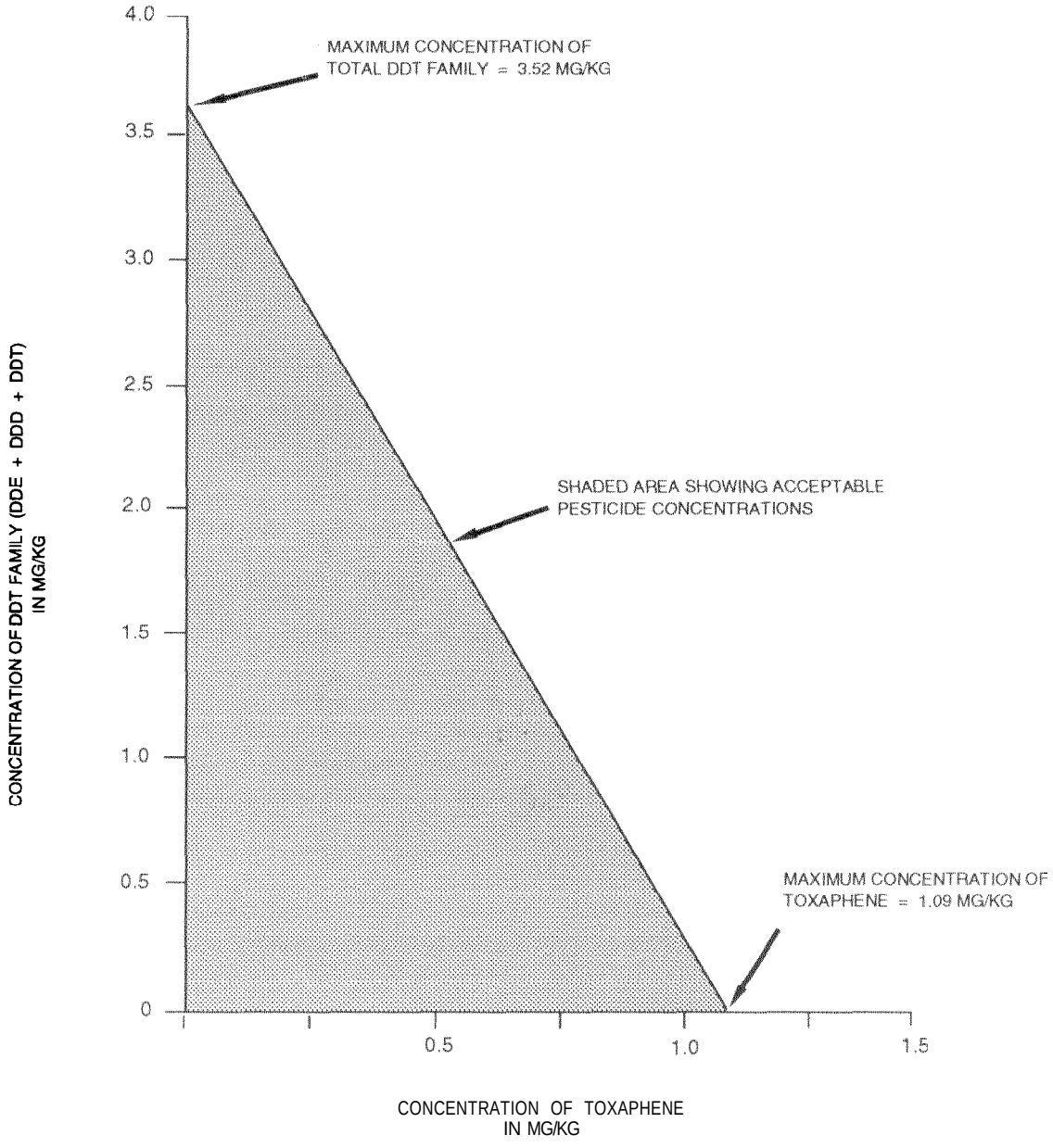
B.2 Demonstration Testing and Sampling Procedures

Prior to initiating demonstration activities, a quality assurance project plan (QAPP) was prepared. The QAPP identifies demonstration objectives and presents a sampling program with associated quality assurance/quality control (QA/QC) procedures that would achieve the established objectives. Two primary objectives and eight secondary objectives were defined in the QAPP and are listed in Table B-l. Measured parameters associated with primary objectives were defined as critical parameters, and measured parameters associated with secondary objectives were defined as noncritical.

The SITE demonstration consisted of three test runs. During all mns, the LTTA system was operated at conditions appropriate for the feed material as determined by Canonie. Each run required approximately 8 hours to complete.

Prior to demonstration sampling, the LTTA system was started according to Canonie's operating procedures. Sampling began when steady-state operating conditions were attained. For each mn, solid and liquid samples were collected every 40 minutes for the 8-hour test period. Stack gas samples were collected once each run. The SITE demonstration did not include continuous emissions monitoring of stack gases.

During the demonstration, samples were collected from seven process points: (1) feed soil, (2) treated soil, (3) scrubber liquor, (4) treated scrubber blowdown, (5) vapor-phase GAC, (6) stack gas emissions, and (7) water supply line. Critical analytical parameters, based upon the primary demonstration objectives, included toxaphene, DDT, DDD, and DDE



SELECTED CLEANUP CONCENTRATION VALUES FOR PESTICIDES

DDT/DDD/DDE (mg/kg)	0.00	0.01	0.83	1.00	2.00	3.00	3.36	3.52
Toxaphene (mgkg)	1.09	1.007	0.83	0.78	0.47	0.16	0.05 [b]	0.00

a Target detection limit for DDT/DDD/DDE
b Target detection limit for toxaphene

Source: SCS Engineers 1990

Figure B-1. Sliding Scale Cleanup Criteria

Table **B-** 1. Demonstration Objectives

PRIMARY OBJECTIVES	SECONDARY OBJECTIVES
1. Assess the ability of the technology to remove toxaphene, DDT, DDD, DDE from contaminated soils.	1. Determine whether the treated soil meets cleanup standards specified by ADEQ after one pass through the system or if the soil must be reprocessed to meet these standards.
2. Determine whether dioxins and furans are formed within the system as products of incomplete combustion (PICs) of pesticides.	2. Assess the ability of the system to remove pesticides other than toxaphene, DDT, DDD, and DDE from the soil. Removal was assessed for five other pesticides found on site: dieldrin, endosulfan I, endrin, and methyl and ethyl parathion.
	3. Determine whether VOC or SVOC reaction products other than dioxins and furans were formed as PICs or as products of a dihydrochlorination within the system.
	4. Determine the fate of pesticides and chlorine in the system to the extent possible.
	5. Document the operating conditions of the L T T A process and identify any potential operational problems.
	6. Characterize soil conditions on site
	7. Develop technology and operating costs that can be used in the Superfund decision-making process.
	8. Measure the effect of the process on the bearing capacity of the soil.

concentrations in the feed soil and treated soil streams, and dioxin and furan concentrations in each of the process streams sampled. Noncritical analytical parameters, which are those associated with secondary objectives, included organochlorine pesticides other than toxaphene, DDT, DDD, and DDE; organophosphorus pesticides: VOCs; SVOCs; total chloride; total organic halides (in liquid samples); and extractable organic halides (in solid samples). Noncritical parameters such as percent moisture, particle size distribution, pH, density and California Bearing Ratio (CBR) were also analyzed to characterize the feed and treated soil. Composite samples of feed soil and treated soil were collected for all critical parameters. Four composite samples were collected from each test run (12 samples total). Each sample was a composite of three grab samples collected at 40-minute intervals. Daily composite samples for determination of noncritical parameters were generated by mixing equal amounts of all 12 grab samples. Samples for analysis of noncritical parameters were composited from four grab samples, which were collected at 2-hour intervals. Samples for VOC analysis were collected as grab samples at 2-hour intervals to minimize contaminant loss resulting from sample compositing.

The vapor-phase GAC samples were collected at the end of the demonstration. These were collected from the bottom foot of one of the vapor-phase activated carbon beds. Samples of scrubber liquor and treated scrubber blowdown were collected once at the beginning and once at the end of each run.

Gas samples were collected from the stack gas using four sampling trains operated simultaneously. Samples for organochlorine pesticides, organophosphorus pesticides, and SVOCs were collected using Modified Method 5 (MM5) sampling trains, according to EPA test methods for evaluating solid wastes (SW-846), Method 0010 (EPA 1986). The organochlorine and organophosphorus pesticide samples were collected from the same MM5 train. Samples for dioxins and furans were collected by an MM5 sampling train configured and operated as described in SW-846, Method 23. Samples for particulate matter, hydrochloric acid (HCl), moisture content, volumetric flow rate, and gas stream temperature were performed according to the boilers and industrial furnaces (BIF) Method 0050 (EPA 1990). Gas samples for VOC analysis were collected by Method TO-14 using SUMMA™ canisters. All sampling trains were leak-checked upon initial assembly and at the end of each run. Sampling personnel used preprinted checklists, calculation forms, and color coding to facilitate the sampling process. In addition, appropriate calibration and inspection records were kept to document that the sampling trains were properly maintained and calibrated.

B.3 Treatment Results

This section summarizes results of the SITE demonstration and presents an evaluation of the LTTA system's effectiveness in treating soils contaminated with pesticides. A summary of results for critical parameters is presented in Table B-2. A detailed presentation of analytical results is provided in the Technology Evaluation Report. The results are based on extensive laboratory analyses under the rigorous QA/QC procedures specified in the QAPP. The following sections discuss (1) the ability of the LTTA system to remove pesticides from soils, (2) formation of products of thermal transformation, (3) compliance with cleanup requirements, (4) fate of pesticides in the system, (5) fate of chlorine in the system, (6) operating conditions, (7) soil properties, and (8) effect on soil bearing capacity.

B.3.1 *The Ability of the LTTA System to Remove* Pesticides *from Soils*

The ability of the technology to remove pesticides from contaminated soils was assessed under both primary and secondary objectives. As a primary objective, the target pesticides included toxaphene, DDT, DDD, and DDE since these are the pesticides for which cleanup levels were established for the site. The removal of other pesticides found on site (dieldrin, endosulfan 1, endrin, methyl parathion, and ethyl parathion) was assessed as a secondary objective.

All composite feed soil samples collected during the demonstration contained high levels of toxaphene, DDT, DDD, and DDE. Measured concentrations of toxaphene in the feed soil ranged from 4,500 to 47,000 µg/kg with an average concentration of 18,300 µg/kg. Feed concentrations for DDT and its metabolites DDD and DDE ranged from 1,200 to 54,000 for DDT, 27 to 860 µg/kg for DDD, and 3,700 to 15,000 µg/kg for DDE. Toxaphene was not detected in any of the treated soil samples above the detection limit of 17 µg/kg (the fourth composite sample of run 3 had a detection limit of 50 µg/kg). Trace amounts of DDT were present in the treated soil samples at an average detected concentration of approximately 1.1 µg/kg. DDD was not detected in any of the treated soil samples above the detection limit of 0.33 µg/kg (the fourth composite sample of run 3 had a detection limit of 0.99 µg/kg). DDE concentrations in the treated soil ranged from 100 to 1,500µg/kg with an average of approximately 680 µg/kg.

Other pesticides were detected in the feed soils at lower concentrations than toxaphene, DDT, DDD, or DDE and were effectively removed by the LTTA system. Dieldrin was present in the feed soil at estimated concentrations ranging from 29 to 200 µg/kg and removed to below the detection limit of 0.33 µg/kg in all treated soil samples, except two samples which had a residual dieldrin concentrations of 0.42 and 0.76 µg/kg. Endosulfan I was present in three of the feed soil samples in the first run at estimated concentrations ranging from 170 to 1,100 µg/kg and was removed to below the detection limit of 0.33 µg/kg (the fourth composite sample of run 3 had a detection limit of 0.99 µg/kg). Endrin and endrin aldehyde were detected in the feed soil sample at average concentrations of 525 µg/kg and 162 µg/kg. Endrin was removed to below the method detection limit of 0.33 µg/kg in all treated soil samples (the fourth composite

Table B-2. Summary of Results for Critical Parameters

Parameter	Average Concentration				
	Feed Soil (µg/kg)	Treated Soil (µg/kg)	Scrubber Liquor (µg/L)	Vapor-Phase GAC (µg/kg)	Stack Gas (ng/dscm)
Toxaphene	18,300	<20	<2.8	<50	<98.6
DDT	18,700	<1.06	0.041	<2.0	8.2
DDD	220	<0.39	<0.031	<l .o	<l.97
DDE	6,980	677	23	79	1,980
2,3,7,8-TCDD	<0.091	<0.15	<0.0016	<0.099	0.00048 [a]
TCDD (total)	<0.091	<0.15	<0.0016	<0.099	0.0062
TCDF (total)	0.1	<0.095	<0.00094	<0.058	0.013
PeCDD (total)	<0.082	<0.72	<0.0016	<0.090	ND
PeCDF (total)	<0.097	<0.86	<0.0011	<0.070	<0.00061
HxCDD (total)	<0.15	<0.18	<0.0028	<0.22	0.0046
HxCDF (total)	<0.095	<0.12	<0.0018	<0.12	0.00062
HpCDD (total)	<0.14	<0.18	<0.0026	<0.21	0.0062[b]
HpCDF (total)	<0.14	<0.15	<0.0021	<0.19	0.0013[b]
OCDD	<0.41	<0.35	<0.0047	<0.53	0.04[b]
OCDF	<0.20	<0.26	<0.0034	<0.40	0.0021[b]

µg/kg Micrograms per kilogram
µg/L Micrograms per liter
ng/dscm Nanograms per dry standard cubic meter
DDT 4,4'-Dichlorodiphenyltrichloroethane
DDE 4,4'-Dichlorodiphenyldichloroethene
DDD 4,4'Dichlorodiphenyldichloroethane
2,3,7,8-TCDD 2,3,7,8,-Tetrachlorinated dibenzo-p-dioxin
TCDD (total) Total tetrachlorinated dibenzo-p-dioxins
TCDF (total) Total tetrachlorinated dibenzofurans
PeCDD (total) Total pentachlorinated dibenzo-p-dioxins
PeCDF (total) Total pentachlorinated dibenzofurans
HxCDD (total) Total hexachlorinated dibenzo-p-dioxins
HxCDF (total) Total hexachlorinated dibenzofurans
HpCDD (total) Total heptachlorinated dibenzo-p-dioxins
HpCDF (total) Total heptachlorinated dibenzofurans
OCDD Octachlorinated dibenzo-p-dioxin
OCDF Octachlorinated dibenzofuran
a 2,3,7,8-TCDD equivalents
b Potential false positive; similar levels were detected in the trip blank sample

sample of run 3 had a detection limit of 0.99 µg/kg). Trace concentrations of endrin aldehyde ranged from <0.66 to 11 µg/kg in treated soil. There were no organophosphorus pesticides in the feed soil at concentrations above detection limits; however, trace quantities of ethyl parathion were detected at concentrations ranging from 1.8 to 4.6 µg/kg.

To numerically quantify the effectiveness of the LTTA at removing pesticides from soil, removal efficiencies were calculated using the following equation:

$$\text{Removal Efficiency} = \frac{(W_i - W_r)}{W_i} \times 100\%$$

where: W_i = Total amount of pesticide fed into the dryer, in pounds (lb.)
W_r = Total amount of pesticide left in the treated soil (lb).

To allow correlation of results, treated soil samples were collected approximately one residence time interval after feed soil samples were collected. Total mass of contaminants was calculated using the concentrations reported as received in the soil and the measured soil feed or discharge rate, as appropriate. Organochlorine pesticide removal efficiencies for each composite sample are listed in Table B-3.

The removal efficiencies indicate the LTTA process is highly effective at removing pesticides from soil. The LTTA removed all detectable toxaphene and DDD from the soils. A trace residue of DDT remained (approximately 1 µg/kg), and a 677 µg/kg residue of DDE remained in the soil. Removal efficiencies for toxaphene ranged from greater than 99.4 percent to greater than 99.9 percent. DDT was removed with an efficiency of 99.8 percent to greater than 99.9 percent. DDD was removed with efficiencies ranging from greater than 98.8 percent to greater than 99.9 percent. DDE was removed with efficiencies ranging from 81.9 percent to 97.8 percent.

The residual DDE concentrations likely resulted when the DDT dehydrochlorinated in the materials dryer, forming DDE as a product of thermal transformation. This increase in DDE concentration in the materials dryer would affect the calculated efficiency at which DDE is removed. Another factor that may have affected the DDE removal efficiency is that DDE probably has a higher coefficient of adsorption than DDT or DDD due to its molecular structure. The ethylene bond in DDE forces the molecule into a planar structure, with pi-electron orbitals on either side of the entire molecule. This bond greatly increases the molecular forces, causing adsorption to the soil. DDT and DDD do not have an ethylene bond and are configured as tetrahedrons with pi-electron orbitals limited to the two benzene groups attached to the ethane group. This configuration of DDT and DDD does not provide the planar structure present in DDE. Therefore, DDT and DDD are not as likely to adsorb to soil particles. The molecular configuration of feed contaminants as well as potential thermal transformation products should be considered in any preliminary estimate of the effectiveness of the LTTA system.

Of nine feed soil samples containing dieldrin, eight of the corresponding treated soil samples did not contain dieldrin above the detection limit. Removal efficiencies for dieldrin ranged from 98.6 to greater than 99.8 percent. Endosulfan I was removed from three feed soil samples with removal efficiencies ranging from greater than 99.8 to greater than 99.9 percent. Endrin was removed to below detection limits with removal efficiencies ranging from greater than 99.6 to greater than 99.9 percent. Trace amounts of endrin aldehyde remained in eight treated soil samples. Endrin aldehyde removal efficiencies ranged from greater than 92.4 to greater than 99.9 percent. Neither ethyl nor methyl parathion were present in the feed soil at concentrations high enough to evaluate the removal efficiency.

B.3.2 *Formation of Products of Thermal Transformation*

A primary objective of the SITE demonstration was to determine whether dioxins or furans are formed in the LTTA system as PICs of pesticides, and a secondary objective was to determine whether reaction products other than dioxins and furans were formed as PICs or as products of dehydrochlorination.

The test data indicate that the LTTA system did not generate measurable amounts of dioxins or furans. The feed soil contained very low levels of various dioxins and furans. Although very low concentrations of dioxins and furans were detected in the stack gas, none of the other solid or liquid process streams contained measurable levels of dioxins or furans.

Several VOC and SVOC compounds detected in the LTTA system's process streams. These compounds may have been formed within the system as products of thermal transformation. The most notable VOCs are acetone and acrylonitrile, which were present in the scrubber liquor; acetone, acrylonitrile, benzene, toluene, and xylenes, which were present in the GAC; and acetonitrile, acrylonitrile, chloromethane, benzene, and toluene, which were present in the stack emissions. The most notable SVOC detections are the benzoic acid and phenol, which were present in the scrubber liquor. The aromatic compounds were presumably formed from the breakdown of DDT, DDD, and DDE. The simpler hydrocarbons and chlorinated compounds, such as methylene chloride, may have been formed from the breakdown of toxaphene and other pesticides. It is suspected that some of the compounds, such as benzoic acid and phenol, are formed from oxidation processes. The presence of VOC and SVOC compounds may be indicative of incomplete combustion of pesticides within the materials dryer.

Table **B-3**. *Pesticide removal Efficiencies for the LTTA® Process*

Compound	Removal Efficiency (Percent)											
	Run 1 Composite Samples				Run 2 Composite Samples				Run 3 Composite Samples			
	1	2	3	4	1	2	3	4	1	2	3	4
Toxaphene	>99.9	>99.8	>99.9	>99.9	>99.6	>99.9	>99.7	>99.9	>99.7	>99.9	>99.8	>99.4
DDT	>99.9	>99.9	>99.9	>99.9	>99.9	>99.9	>99.9	>99.9	>99.9	>99.9	>99.9	998
DDD	>99.9	>99.6	>99.9	>99.8	>99.1	>99.7	>98.8	>99.9	>99.9	>99.8	>99.6	>99.4
DDE	91.3	97.8	93.2	82.4	85.4	93.9	85.3	81.9	93.5	92.1	94.2	94.6
Dieldrin	>99.8	>99.1	>99.2	>99.4	986	>99.5	>99.1	>99.1	>99.7	NC	NC	NC
Endosulfan I	>99.9	NC	>99.8	>99.9	NC	NC	NC	NC	NC	NC	NC	NC
Endosulfan II	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC	NC
Endrin	>99.9	>99.9	>99.9	>99.9	>99.7	>99.9	>99.8	>99.9	>99.9	>99.9	>99.9	>99.6
Endrin Aldehyde	98.4	>98.6	>99.8	946	997	999	992	975	>98.5	NC	>99.9	>92.4

> Greater than
NA Not applicable
NC Not calculated (Compound was not present in the feed soil above the detection limit)
DDT 4,4'-Dichlorodiphenyltrichloroethane
DDD 4,4'-Dichlorodiphenyldichloroethane
DDE 4,4'-Dichlorodiphenyldichloroethene

B.3.3 Compliance with Cleanup Requirements

One of the secondary objectives for the demonstration was to determine whether the treated soil met cleanup standards specified by ADEQ after one pass through the system or if the soil required reprocessing to meet the standards. The ADEQ established site-specific cleanup criteria for toxaphene contamination and the sum of DDT, DDD, DDE contamination. Sliding scale criteria were established with a maximum allowable concentration of 1.09 milligrams per kilogram (mg/kg) of toxaphene with no DDT/DDD/DDE at one end, and a maximum allowable concentration of 3.53 mg/kg of DDT/DDD/DDE with no toxaphene at the other end. Figure B- 1 illustrates the sliding scale criteria established by ADEQ (SCS Engineers 1992).

According to the approved remedial action plan, soil containing greater than 5 mg/kg of total pesticides was to be treated by the LTTA system. Soil that contained less than 5 mg/kg of total pesticides but greater than the cleanup criteria was to be deep-mixed on site (SCS Engineers 1990). An estimated 5 1,000 tons of soil was treated by the LTTA system. The treated soil sample results indicated that the ADEQ cleanup criteria were met after one pass through the system.

B.3.4 Fate of Pesticides in the System

Toxaphene, dieldrin, endosulfan I, and endrin were present in the feed soil, but were either less than or near their detection limits in the other process streams. This indicates that they were either destroyed in the LTTA process or were distributed throughout the process streams at very low levels. DDT and DDD may have degraded into DDE and endrin may have degraded into endrin aldehyde. DDE was concentrated in the scrubber liquor and was also detected in the vapor-phase GAC and, at low levels, in the stack gas.

Toxaphene is apparently destroyed in the process. Toxaphene was present in feed soil samples at an average concentration of 18,300 µg/kg. Toxaphene was not present in the scrubber liquor, as were DDT, DDD, and DDE, yet the water solubility of toxaphene is 50 to 1,000 times greater than the water solubilities of DDT and its metabolites. If present in the exhaust stream, toxaphene would tend to be scrubbed out by the venturi scrubber. Additionally, toxaphene was not detected in the vapor-phase GAC or the stack gas. Toxaphene reportedly decomposes near its boiling point (National Institute of Occupational Safety and Health and Occupational Health and Safety Administration 1981) and dehydrochlorinates at 155°C (311°F) (Gains 1969).

The scrubber liquor contained measurable quantities of DDT, DDD, and DDE. DDT was detected in the scrubber liquor in concentrations ranging from 0.027 to 0.054 µg/L. DDD was detected in concentrations ranging from 0.029 to 0.057 µg/L. However, these concentrations are qualified as estimates due to matrix interferences. DDE was detected in the scrubber liquor in concentrations ranging from 5.9 to 40 µg/L. While DDE is found in the scrubber liquor at 100 to 1,000 times the concentration of DDT, it was present in the feed soil at much lower levels than DDT. Although the water solubility of DDE is a magnitude greater than the water solubility than DDT, the results suggest that DDE is being formed as a product of thermal transformation of DDT in the materials dryer.

Pesticides that were not condensed or stripped in the venturi scrubber would be removed from the exhaust stream by the vapor-phase GAC beds. DDE was present in vapor-phase GAC beds at a concentrations of 79 µg/kg; however, based on the QC results, pesticide data from the GAC samples are likely biased low due to low analytical recoveries of contaminants.

B.3.5 *Fate of Chlorine in the System*

Determining the fate of chlorine in the LTTA system was a secondary objective for the SITE demonstration. Table B-4 provides an approximation of the organic halide and total chloride distribution in the system. Chloride and organic halides appear to concentrate in the scrubber blowdown, where organic halide masses are several times greater than other process effluent streams. Additionally, the treated soil contained significant levels of chloride.

B.3.6 Operating Conditions

Another secondary objective of the demonstration was to document the operating conditions of the LTTA process and identify any potential operational problems. This objective was achieved by recording observations of operating conditions and by monitoring system operating parameters using available instrumentation. During the demonstration, the LTTA system consisted of nine trailer-mounted components and five support trailers. The entire system occupied approximately 10,000 square feet. The system processed soil at a consistent rate of approximately 34 tons/hr and a temperature of 730°F. Soil residence time in the dryer was 9 to 12 minutes. The materials dryer rotated at two revolutions per minute and was maintained at an angle of 2.5 degrees. The burner for the materials dryer consumed approximately 7.5 gallons of propane for each ton of soil treated. Diesel fuel consumption was 1.2 gallons per ton of soil treated for the generator and 0.7 gallons per ton of soil treated for the excavation equipment. The baghouse influent temperature was approximately 380°F, and the baghouse effluent temperature was approximately 350°F. The materials dryer was maintained at a negative pressure of 0.10 inches of water relative to atmospheric pressure. The Venturi scrubber recirculated 147 gpm of scrubber liquor. Pressure drop across the venturi was maintained at slightly greater than 10 inches of water. The pug mill used approximately 80 gpm of water. The whole LTTA system used approximately 60 kilowatt-hours of electricity supplied by a 900-kilowatt generator.

Table **B-4.** Fate of Chlorine in the LTTA System

Process Stream	Run	Flow Rate	Conversion Factor a	Chloride Concentration	TOX/EOX Concentration	Total Chloride (kg)	Total TOX/EOX b (kg)
INFLUENT STREAMS							
Feed Soil	1	34.8 ton&r 34.3	7257	27.5 mg/kg	32.4 mg/kg <21 .o	7.6	82
	2	tons/hr 34.6 tons/hr	7257	22.1 mgkg	mg/kg <20.5 mg/kg	5.5	<5.23
	3		7257	28.8 mg/kg		7.2	<5.15
Makeup Water	I/2/3	80 gal/min	1817	62mg/L	12Omg/L	9	17.44
EFFLUENT STREAMS							
Treated Soil	1	32.9 tons/hr 34.4	7257	97.2 mg/kg	<22.0 mg/kg <22.3	23	<5. 3
	2	tons/hr 34.0 tons/hr	7257	83.9 mgkg	mg/kg <21.5 mg/kg	21	< 5 . 6
	3		7257	66.1 mg/kg		16	< 5 . 3
Scrubber Blowdown	1	80 gal/min	1817	365mg/L	165mg/L	53	24
	2	80 gal/min	1817	128mgL	140 mg/L	19	20
	3	80 gal/min	1817	110mgL	120mg/L	16	17
GAC Beds	1/2/3	1 00,000 lbs	0.0324	483mg/kg	<31.4 mg/kg	1.5	<0.95
Stack Gas	1	289 dscm/min 286	489	0.265 mg/dscm	NA	0.036	NC
	2	dscm/min 286	480	0.271 mg/dscm	NA	0.036	NC
	3	dscm/min	480	0.283 mg/dscm	NA	0.033	NC

a	Conversion factor for flow rate to mass or volume units for 8-hour run to allow direct multiplication with concentration values
b	Total mass for 8-hour run
c	Assumed 120 hours of operation for GAC beds
NA	Not analyzed
NC	Not calculated
TOWEOX	Total organic halides/extractable organic halides
GAC	Granular activated carbon
kg	Kilogram
tons/hr	Tons per hour
mg/kg	Milligram per kilogram
gal/min	Gallon per minute
mg/L	Millgram per liter
Ibs	Pounds
dscm/min	Dry standard cubic meters per minute
mg/dscm	Milligrams per dry standard cubic meter
<	Less than

No operational problems occurred during the SITE demonstration. Potential operational problems would include mechanical problems with the process equipment, fugitive dust generated by the operations, noise pollution, the availability of a water supply capable of producing 100 gpm, and availability of space for locating the LTTA system and staging of soils.

B.3. 7 Soil Properties

Feed soils were sandy with a high silt-clay content and moderate plasticity. The liquid limit (water content at which the soil behaves as liquid) was approximately 19 percent. The soils were classified as A-4 according to the American Society for Testing and Materials (ASTM) classification scheme (ASTM 1989). Moisture content was between 4.5 and 6.5 percent. Approximately 37 percent of the feed soil was finer than 74 microns, 43 percent was between 74 and 425 microns and slightly more than 20 percent was coarser than 425 microns. The avemge pH was 7.6. Characteristics of the treated soil were only slightly changed, with the most notable difference being an increase in moisture content to 10.2 percent.

B. 3.8 Effect on Soil Bearing Capacity

The bearing capacity of both the feed and treated soil was determined using the CBR test. The CBR measures the ratiopf the stress applied to the soil to provide a 0.100 inch penetration' divided by a standard value of 1,000 pounds per square inch. These values are presented in Table B-5. The CBR values of the treated soil were slightly higher than those of the untreated soil, indicating that the bearing capacity was slightly improved.

B.4 **References**

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Table B-5. California Bearing Ratio

Process Stream	Run	10 Blows			25 Blows			56 Blows		
		CBR	Dry Density		CBR	Dry Density		CBR	Dry Density	
			kg/m³	lb/ft³		kg/m³	lb/ft³		kg/m³	lb/ft³
Feed Soil	1	7	1714	107	17.5	1865	116.4	40	1985	123.9
	2	7.4	1755	109.5	20.4	1917	119.6	30.1	2017	125.9
	3	6.5	1740	108.6	19.1	1892	118.1	38.9	1985	123.9
Treated Soil	1	8.9	1802	112.4	26.7	1914	119.4	36.8	1991	124.2
	2	7.6	1737	108.4	25.3	1869	116.6	52.3	1955	122
	3	9.9	1766	110.2	22.3	1856	115.8	43.3	1970	122.9

CBR California Bearing Ratio
kg/m³ kilogram per cubic meter
lb/ft³ pound per cubic foot

Appendix C
Case Studies

This appendix was prepared using information provided by Canonie Environmental Services Corporation. Claims and interpretations of results in this appendix are made by Canonie and are not necessarily substantiated by test or cost data. Many of Canonie's claims regarding cost and performance can be compared to the available data in Section 3 and Appendix B.

The cumulative results from five case studies and the Arizona pesticide site for contaminant removal efficiency are shown in Table C-l. Short descriptions of the sites, remedial activities, and type of contaminated materials treated are presented in the sections that follow.

C.1 McKin Superfund Site Remediation

Client: Steering committee representing over 300 Potentially Responsible Parties

Location' Gray, Maine - EPA Region

Performance Period: December 1985 - May 1987

Material: Contaminated soil and groundwater containing VOCs and oils

Scope of Work: Aeration of soils at low temperature to remove VOCs

Total Cost: $6,500,000

Site Description

The McKin site was formerly used as a liquid waste storage, treatment, and disposal facility for volatile organic solvents, chemicals, and heavy oils. As a result of improper operation practices, VOCs and oils were released to soils and groundwater. The resulting groundwater and soil contamination was exacerbated by the geological structure. A silty clay layer was located 20 feet below the silty, coarse, sandy surface material. The contaminant leachate dispersed along the clay layer affecting a local drinking water aquifer. This site was ranked number 32 on the National Priorities List (NPL) and was the first NPL project to be completed in Region 1.

LTTA" Process Operations

The McKin site was the first site to implement the LTTA technology. More than 9,500 cubic yards of soil contaminated with VOCs and 2,000 cubic yards of soil contaminated with waste petroleum were treated with the LTTA process. Concentrations of VOCs were reduced from greater than 3,000mg/kg to levels averaging less than 0.05 mg/kg. Polynuclear aromatic hydrocarbons were reduced to concentrations less than 10 mg/kg. The innovative design and construction techniques implemented by Canonie reduced the overall cost of remediation by approximately $8,000,000. Processing rates ranged from 35 to 45 tons/hour.

The soil treatment results for contaminant removal using the LTTA system at the McKin site are shown in Table C-2.

C.2 *Cannons Bridgewater Superfund Site*

Client: Cannons Bridgewater Superfund Site Settling Parties

Location: Bridgewater, Massachusetts - EPA Region 1

Performance Period: September 1988 - September 1990

Material: Contaminated building structures, tanks, and VOC- and PCB-contaminated soils

Scope of Work: Thermally treat VOC-contaminated soils; excavate and decontaminate PCB-contaminated soils; demolish and dispose of tanks and buildings

Total Cost: Confidential

Table C-l. Reported Full-Scale LTTA System Chemical Removal Efficiencies

Compound	Pretreatment Concentration (mglkg)	Posttreatment Concentration (mglkg)	Removal Efficiency (percent)	Site Name
Volatile Organic Compounds				
Benzene	5.3	< 0.025	>99	Cannons
1,2-Dichlorobenzene	320	< 0.02	>99	McKin
trans-1,2-Dichloroethene	300	< 0.02	>99	McKin
Ethylbenzene	1,400	< 0.05	>99	Spencer
Tetrachloroethene	1,200	< 0.025	>99	Ottati and Goss
Toluene	3,000	< 0.05	>99	Spencer
Trichloroethene	460	< 0.025	>99	Ottati and Goss
1 ,1,1-Trichloroethane	470	< 0.025	>99	Ottati and Goss
Xylenes	3,700	0.25	>99	Spencer
Total VOCs	5,420	0.45	>99	Spencer
Organochlorine Pesticides				
DDD	206	< 0.01	>99	Arizona
DDE	46	0.94	>99	Arizona
DDT	321	< 0.04	>99	Arizona
Toxaphene	1,540	< 0.5	>99	Arizona
Organophosphorus Pesticides				
Ethyl parathion	116	< 0.07	>99	Arizona
Methyl parathion	0.78	< 0.059	>92	Arizona
Merphos	195	< 0.004	>99	Arizona
Mervinphos	20.4	< 0.002	>99	Arizona
Total Petroleum Hydrocarbons	2,000	< 50	>99	Cannons

Table C-l. Reported Full-Scale LTTA System Chemical Removal Efficiencies (continued)

Compound	Pretreatment Concentration (mglkg)	Posttreatment Concentration (mglkg)	Removal Efficiency (percent)	Site Name
Semivolatile Organic Compounds				
Acenaphthene	1.1	< 0.39	>65	Spencer
Anthracene	1.1	0.062	94	Spencer
Benzo(a)anthracene	2.2	0.22	90	Spencer
Benzo(a)pyrene	2.0	0.30	85	Spencer
Benzo(b)fluoranthene	2.1	0.34	84	Spencer
Benzo(g,h,i,)perylene	1.0	0.33	67	Spencer
Benzo(k)fluoranthene	1.6	0.32	80	Spencer
bis(2-Ethylhexyl)phthalat	6.5	1.0	85	South Kearny
Chrysene	2.3	0.30	87	Spencer
Dibenzo(a,h)anthracene	0.15	0.05	67	Spencer
Fluoranthene	3.4	0.20	94	Spencer
Fluorene	0.79	< 0.39	>51	Spencer
Indeno(l,2,3_cd)pyrene	1.0	0.24	76	Spencer
Naphthalene	1.2	0.042	96	Spencer
Phenanthrene	3.8	0.23	94	Spencer
Pyrene	4.7	0.26	94	Spencer

Source: Canonie 1992

mg/kg Milligrams per kilogram
< Less than
> Greater than

Table C-2. LTTA Process Representative Soil Treatment Results McKin Superfund Site Gray, Maine

Compound	Concentration (mg/kg)	
Volatile Organic Compounds	**Pretreatment Soil**	**Posttreatment Soil**
Benzene	**2.7**	<1
1,2_Dichlorobenzene	320	< 0.02
trans-1 ,2-Dichloroethene	300	< 0.02
Ethylbenzene	130	<1
Tetrachloroethene	120	c 0.02
Toluene	62	<1
1 ,l , l -Trichloroethane	19	< 0.02
Trichloroethene	3,310	0.04
Xylenes	840	**<l**
Semivolatile Organic Compounds		
Anthracene	0.44	< 0.33
Butylbenzylphthalate	0.8	< 0.33
Fluoranthene	1.2	< 0.33
Isophorone	0.79	< 0.33
Naphthalene	0.8	< 0.33
Phenanthrene	1.2	0.51

Source: Canonie 1992

mg/kg Milligrams per kilogram
< Less than

Site Description

This 4-acre site was formerly used as a waste oil processing facility. The site was then converted to a solvent incineration facility which operated from 1974 to 1980.

The site structures, tanks, soils, and adjacent wetlands were contaminated with VOCs and SVOCs. On-site structures included an incinerator which was tested for dioxins and PCBs. On-site buildings and tanks were found to be contaminated with PCBs and SVOCs.

LTTA Process Operations

The soils at the Cannons Bridgewater site that were contaminated by VOCs and SVOCs were processed with the LTTA system to reduce the volatile organics. Posttreatment soil samples were collected and analyzed to verify compliance with the thermal aeration treatment criteria. All posttreatment soil samples met the thermal treatment criteria. The treated soils were backtilled on site. A total of 11,330 tons of soil (containing approximately 1,242 pounds of VOCs was treated at the Cannons Bridgewater site. Processing rates ranged from 42 to 48 tons/hour.

C.3 *Ottati and Goss Superfund Site*

Client: Three-member settling party committee

Location: Kingston, New Hampshire - EPA Region 1

Performance Period: November 1988 - April 1989

Material Contaminated soils, sediments, and groundwater containing VOCs

Scope of Work: Utilize LTTA to remove VOCs from soil

Total Cost: $1,470,000

Site Description

The Ottati and Goss Superfund site was used to stabilize spent organic solvents. Due to improper operation, soils and groundwater at the site were contaminated by VOCs. This site ranked number 129 on the NPL.

LTTA Process Operations

The LTTA system treated 4,700 cubic yards of soil contaminated with VOCs. All soils treated by the LTTA system met the performance standard of 1 .O mg/kg total VOCs and 0.1 mg/kg for the compounds 1,2-dichloroethane, 1, 1,1-trichloroethane and tetrachloroethene. Processing rates ranged from approximately 35 to 45 tons/hour.

The soil treatment results for contaminant removal using the LTTA system at the Ottati and Goss site are shown in Table C-3.

C.4 *South Kearny Site Remediation*

Client: TP Industrial, Inc

Location: South Kearny, New Jersey - EPA Region 2

Performance Period: June 1989 - December 1989

Material: Site soils contaminated with VOCs and SVOCs at levels up to 10,000 mg/kg

Scope of Work: Thermally treat 16,000 tons of contaminated vadose zone soils with the LTTA system; confirm compliance with cleanup criteria at an on-site laboratory; replace soils on site

Total Cost: Confidential

Site Description

The 2-acre site was a former manufacturing facility where spent solvents were disposed of. Soil samples indicated elevated concentrations of VOCs and semivolatile organic compounds. Maximum concentrations were 10,000 mg/kg for VOCs and 150 mg/kg for semivolatile organic compounds.

LTTA Process Operations

The LTTA process treated 16,000 tons of soil contaminated with VOCs and polynuclear aromatic hydrocarbons (PAHs). Residual concentrations averaged 0.3 mg/kg for VOCs and 0.93 mg/kg for PAH compounds. All remedial activities were conducted under a permit issued by the New Jersey Department of Environmental Protection and were completed within 7 months to comply with site "fast-track' status. Processing rates of up to 50 tons/hour were achieved.

The soil treatment results for proof-of-process runs using the LTTA system at the South Kearny site are shown in Table C-4.

Table C-3. LTTA® Process Soil Treatment Results Ottati and Goss Superfund Site Kingston, New Hampshire[1]

Compound	Location 1		Location 2		Location 3		Location 4	
	Pretreatment[2]	Posttreatment[3]	Pretreatment[2]	Posttreatment[3]	Pretreatment[2]	Posttreatment[3]	Pretreatment[2]	Posttreatment[3]
1,1-Trichloroethane	33	< 0.025	12	< 0.025	27	< 0.025	470	< 0.025
Trichloroethene	19	< 0.025	6.5	< 0.025	27	< 0.025	460	< 0.025
Tetrachloroethene	12	< 0.025	4.9	< 0.025	40	< 0.025	1,200	< 0.025
Toluene	>470	< 0.025	260	< 0.025	>87	< 0.025	3,000	0.11
Ethlybenzene	>380	< 0.025	>300	< 0.025	>50	< 0.025	440	< 0.025
Total xylenes	>1,100	14	>900	< 0.025	>170	< 0.025	180	0.14

Source: Canonie 1992

1 All concentrations are reported in milligrams per kilogram
2 Pretreatment soil samples were analyzed by EPA Method 8240
3 Posttreatment soil samples were analyzed by EPA Methods 8010 and 8020

Table C-4. LTTA Process Representative Proof-of-Process Analytical Results South Kearny, Ne Jersey

	Concentration (mg/kg)	
Compound	Pretreatment Soil	Posttreatment Soil
Volatile Organic Compounds		
1,2-Dichloroethene (total)	0.55	ND
1,1,1-Trichloroethane	3	ND
Trichloroethene	15	0.15
Tetrachloroethene	190	0.38
1,2-Dichlorobenzene	100	ND
Toluene	5.6	ND
Ethylbenzene	15	ND
Xylenes (total)	5.2	ND
Total VOCs	308	0.51
Semivolatile Organic Compounds		
Acenaphthene	0.7	ND
Anthracene	2.5	ND
Benzo(a)anthracene	5.9	0.94
Benzo(a)pyrene	5.4	0.58
Benzo(b)fluoranthene	5	1.2
Benzo(g, h,i)perylene	3.5	0.63
Benzo(k)fluoranthene	4.9	0.71
bis(2-Ethylhexyl)phthalate	6.5	1
Chrysene	5.9	1.3
di-n-Butylphthalate	1.9	0.84
Fluoranthene	7	1.8
Fluorene	1	ND
Indeno(l,2,3-cd)pyrene	3.2	0.55
Naphthalene	2	0.34
Phenanthrene	6.4	1.2
Pyrene	15	1

Source: Canonie 1992

mg/kg Milligrams per kilogram
ND Not detected

C.5 *Former Spencer Kellog Facility*

Client: Textron, Inc.

Location: Newark, New Jersey - EPA Region 2

Performance Period: November 1991 - March 1992

Material: VOC- and SVOC-contaminated soils

Scope of Work: Thermally treat VOC- and SVOC-contaminated soils with minimal impact to daily facility operations

Total Cost: Confidential

LTTA" Process Operations

A total of ***6,500*** tons of soil contaminated with VOCs and SVOCs from 22 discrete sites were excavated and treated with the LTTA process. The overall processing rate was approximately 15 tons/hour. The LTTA removed all contaminants to below specified cleanup levels.

The soil treatment results for contaminant removal using the LTTA system are shown in Table C-5.

Table C-5. LTTA Process Representative Soil Treatment Results Former Spencer Kellogg Facility Newark, New Jersey

Compound	Concentration (mg/kg) Pretreatment Soil	Posttreatment Soil
Volatile Organic Compounds		
Benzene	0.24	0.072
Ethylbenzene	1,400	< 0.05
Toluene	3,000	< 0.05
Total xylenes	3,700	0.25
Total VOCs	5,420	0.45
Semivolatile Organic Compounds		
Acenaphthene	1.1	< 0.39
Anthracene	1.1	0.062
Benzo(a)anthracene	2.2	0.22
Benzo(a)pyrene	2	0.3
Benzo(b)fluoranthene	2.1	0.34
Benzo(g,h,i)perylene	1	0.33
Benzo(k)fluoranthene	1.6	0.32
bis(2-Ethylhexyl)phthalate	0.95	0.071
Chrysene	2.3	0.3
Dibenzo(a,h)anthracene	0.15	0.05
Fluoranthene	3.4	0.2
Fluorene	0.79	< 0.39
Indeno(l,2,3-cd)pyrene	1	0.24
Naphthalene	1.2	0.042
Phenanthrene	3.8	0.23
Pyrene	4.7	0.26

Source: Canonie 1992

mg/kg Milligrams per kilogram
< Less than