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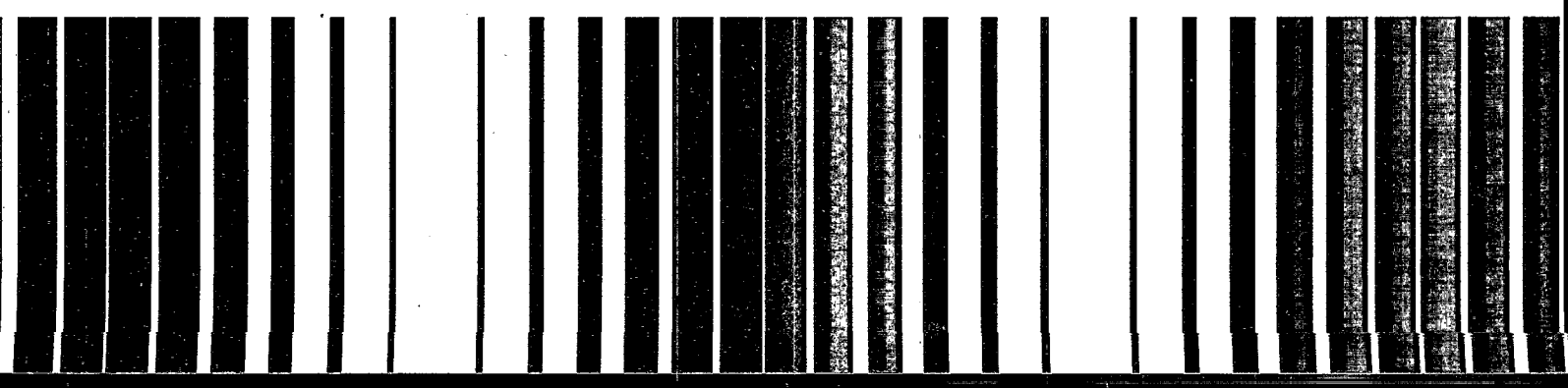
Treatment Technology Performance and Cost Data for Remediation of Wood Preserving Sites



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Treatment Technology Performance and Cost Data for Remediation of Wood Preserving Sites

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

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Notice

The information in this document has been funded wholly or in part by the U.S. Environmental Protection Agency (EPA) under Contract No. 68-C5-0001, Work Assignment 1-23, and Order No. 7C-R327-NNLX issued to Science Applications International Corporation (SAIC). Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Foreword

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

The National Risk Management Research Laboratory (NRMRL) 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 and to develop scientific and engineering information needed by EPA to support regulatory and policy implementation of environmental regulations and strategies.

A key aspect of the Laboratory's success is an effective program for technical information dissemination and technology transfer. The Center for Environmental Research Information (CERI) is the focal point for these types of outreach activities in NRMRL.

This summary document, *Treatment Technology Performance and Cost Data for Remediation of Wood Preserving Sites*, produced by CERI, is a technical resource guidance document for the remediation of wood preserving sites.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Abstract

Wood preserving has been an industry in North America for more than 100 years. During this time, wood preserving facilities have utilized a variety of compounds, including pentachlorophenol (PCP), creosote, and certain metals to extend the useful life of wood products. Past operations and waste management practices have resulted in soil and water contamination at a portion of the more than 700 wood preserving sites identified in the United States. Many of these sites are currently being addressed under Federal, State, or voluntary cleanup programs. The U.S. Environmental Protection Agency (EPA) National Risk Management Research Laboratory (NRMRL) has responded to the need for credible information aimed at facilitating remediation of wood preserving sites by conducting treatability studies, issuing guidance, and preparing reports.

This report presents information pertaining to applicable treatment and control alternatives for the remediation of contaminated soil and water at wood preserving sites. It provides background information on the wood preserving industry; common contaminants, including pentachlorophenol (PCP), polycyclic aromatic hydrocarbons (PAHs), polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans (PCDDs/PCDFs), and metals-containing compounds, such as chromated copper arsenate (CCA); and environmental concerns associated with these contaminants.

Ten technologies previously employed for remediation of soil and water at wood preserving sites are discussed. For soil, the advantages, limitations, and costs associated with implementation of soil washing, solidification/stabilization (S/S), thermal desorption (TD), incineration, solvent extraction, base-catalyzed decomposition (BCD), and bioremediation are presented. Treatability and/or case studies are provided for each technology. Similar information is provided for the remediation of water using photolytic oxidation, carbon adsorption, hydraulic containment, and bioremediation. Sources of additional information, in the form of documents and databases, are also listed. The appendices provide a list of known wood preserving sites and additional soil and water treatability and case studies.

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Acronyms and Abbreviations

AAR	Applications Analysis Report
ACA	ammoniacal copper arsenate
ACC	acid copper chromate
ACQ	ammoniacal copper quat
ACT	Accelerated Column Test
ACW	American Creosote Works
ACZA	ammoniacal copper zinc arsenate
a.k.a.	also known as
APC	air pollution control
APEG	alkaline polyethylene glycol
ARAR	Applicable or Relevant and Appropriate Requirement
ATTIC	Alternative Treatment Technology Information Center
AWPI	American Wood Preservers Institute
B(a)P	benzo(a)pyrene
B.E.S.T.®	RCC's Basic Extractive Sludge Treatment
BCD	base-catalyzed decomposition
BDAT	best demonstrated available technology
bls	below land surface
BWP	Broderick Wood Products
CCA	chromated copper arsenate
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CERI	Center for Environmental Research Information
CIS	contaminant isolation system
CLU-IN BBS	Cleanup Information Bulletin Board System
CO	carbon monoxide
COD	chemical oxygen demand
COC	contaminant of concern
CRF	Combustion Research Facility
DME	dimethyl ether
DNAPL	dense nonaqueous phase liquid
DRE	destruction removal efficiency
EDTA	ethylenediamine tetraacetic acid
EPA	U.S. Environmental Protection Agency
ES&S	AlliedSignal Environmental Systems and Services
GAC	granular activated carbon
gpm	gallons per minute
gr/dscf	grains per day standard cubic feet
GWM	groundwater medium
$HgCl_2$	mercuric chloride
H_2O_2	hydrogen peroxide
HpCDD	heptachlorodibenzo-*p*-dioxin
HpCDF	heptachlorodibenzofuran
HPLC	high performance liquid chromatography
HWSFD	Hazardous Waste Superfund Collection Database
HxCDD	hexachlorodibenzo-*p*-dioxin

Acronyms and Abbreviations (continued)

KOH	potassium hydroxide
KPEG	potassium polyethylene glycol
kW	kilowatt
kWh	kilowatt hour
L/D	length to diameter
LDR	Land Disposal Restrictions
LNAPL	light nonaqueous phase liquid
LP	liquefication process
LTU	land treatment unit
MCB	McCormick & Baxter
MCL	maximum contaminant level
mg/L	milligram per liter
m^2g	square meters per gram
MS	matrix spike
MSD	matrix spike duplicate
NAPL	nonaqueous phase liquid
NPDES	National Pollutant Discharge Elimination System
NPL	National Priorities List for Uncontrolled Hazardous Waste Sites
NRMRL	National Risk Management Research Laboratory
NTIS	National Technical Information System
O&M	operations and maintenance
O_3	ozone
OCDD	octachlorodibenzo-*p*-dioxin
OCDF	octachlorodibenzofuran
OHEA	Office of Health and Environmental Assessment
ORD	Office of Research and Development
OSC	On-Scene Coordinator
OU	operable unit
PAH	polycyclic aromatic hydrocarbon
PCDD	polychlorinated dibenzo-*p*-dioxin
PCDF	polychlorinated dibenzofuran
PCP	pentachlorophenol
PeCDD	1,2,3,7,8-pentachlorodibenzo-*p*-dioxin
PeCDF	1,2,3,7,8-pentachlorodibenzofuran
POHC	principal organic hazardous constituents
POP	proof of performance
POTW	publicly owned treatment works
ppb	parts per billion
ppm	part per million
ppq	parts per quadrillion
psi	pounds per square inch
QA	quality assurance
RBC	rotating biological contactor
RCC	Resources Conservation Company
RCRA	Resource Conservation and Recovery Act
RCRIS	Resource Conservation and Recovery Information System
RI/FS	remedial investigation/feasibility study
ROD	Record of Decision
RODS	Records of Decision System
RPM	Remedial Project Manager

Acronyms and Abbreviations (continued)

rpm	revolutions per minute
S/S	solidification/stabilization; a.k.a. immobilization
SAIC	Science Applications International Corporation
SBOD	soluble biochemical oxygen demand
SIC	standard industrial classification
SITE	Superfund Innovative Technology Evaluation
SPLP	Synthetic Precipitation Leaching Procedure
STC	STC Remediation Inc.
SVE	soil vapor extraction
SVOC	semivolatile organic compound
TCDD	dioxin (tetrachlorodibenzo-*p*-dioxin)
TCDF	2,3,7,8-tetrachlorodibenzofuran
TCLP	Toxicity Characteristic Leaching Procedure
TCPAH	total carcinogenic polycyclic aromatic hydrocarbon
TD	thermal desorption
TEF	Toxicity Equivalency Factor
TEQ	Toxicity Equivalent
TiO_2	titanium dioxide
tpd	tons per day
TPH	total petroleum hydrocarbons
UCS	unconfined compressive strength
UPRR	Union Pacific Railroad
μm	micrometers
UV	ultraviolet
UV/H_2O_2	ultraviolet/hydrogen peroxide
Vendor FACTS	Vendor Field Analytical and Characterization Technology System
VISITT	Vendor Information System for Innovative Treatment Technologies
VOC	volatile organic compound

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CHAPTER 1
INTRODUCTION

1.1 Purpose and Scope of Document

The primary objective of this document is to present information pertaining to treatment and control alternatives applicable to the remediation of contaminated soil and water at wood preserving sites. The information presented herein includes performance data and order-of-magnitude cost estimates for 10 remediation technologies that have been applied to environmental media containing wood preserving contaminants. It is hoped that this information will enable remedial project managers (RPMs); on-scene coordinators (OSCs); State, Local, and Tribal regulators; technology vendors; consultants; private organizations; and citizens to evaluate the potential use of these technologies to effectively clean up wood preserving sites.

This document is divided into seven chapters and three appendices. Chapter 1 provides background information about the wood preserving industry, past and present. Chapter 2 discusses the common contaminants of concern (COCs) at wood preserving sites, and identifies which technologies described in this document are effective in treating each class of contaminant. Analytical methods for quantification of wood preserving contaminants and factors affecting their behavior and remediation are also presented in Chapter 2. Chapter 3 summarizes the performance and cost information provided for each technology discussed in this document. Chapter 4 presents a discussion of each technology identified in the document for the treatment of soils, sediments, and sludges; included are advantages, limitations, technology costs, and treatability/case studies. Chapter 5 discussions parallel Chapter 4, but focus on technologies for the remediation of groundwater and surface water contamination. Chapter 6 provides sources of additional information. Chapter 7 lists the references cited in the document. Appendix A provides a list of known wood preserving sites in the United States, compiled from several sources. Appendix B presents additional treatability/case studies in which soils, sediments, or sludges were treated. Appendix C presents the same types of studies conducted on water from wood preserving sites.

This document is not intended to be a comprehensive description of the wood preserving industry, remedial technologies, or cost estimation. Rather it is intended to be used as a resource guide in conjunction with other references, such as those listed in Chapter 6, the opinions of technology experts, and site-specific information. Therefore, the reader is cautioned that information provided in this document is specific to the study cited, and may not be directly transferable to other applications. An example of this is in the comparison of cost information among technologies and across sites. Given the overwhelming influence of site-specific factors on treatment technology and project costs, no attempt has been made to standardize estimates presented in the cited literature. Consequently, assumptions and cost categories used in the specific estimates have been referenced. Therefore, the cost information presented is to be considered general guidance providing order-of-magnitude estimates.

Each technology profiled in this document was selected as being applicable, either as stand-alone or in conjunction with other technologies, in successfully reducing the mobility, toxicity, and/or volume of wood preserving contaminants in soil and groundwater. The soil treatment technologies presented in this resource guide are: soil washing, solidification/stabilization (S/S), thermal desorption (TD), incineration, solvent extraction, base-catalyzed decomposition (BCD), and bioremediation. The water treatment and control technologies profiled are hydraulic containment, carbon adsorption, photolytic oxidation, and bioremediation. The term bioremediation as it is used in this document includes both *in situ* remediation and

ex situ treatment of contaminated media. Although bioremediation and biotreatment are not synonymous, the term bioremediation should be taken in this document to encompass both processes.

This document also discusses the use of treatment trains. A treatment train is two or more remediation technologies used sequentially, such as, solid-phase bioremediation followed by S/S, or solvent extraction followed by BCD treatment of the extract. Since the successful use of a given technology approach is site-specific, treatability studies should be performed to determine the effectiveness of a given technology at a specific site. Sources of information regarding the design and performance of treatability studies are presented in Section 6.1.

1.2 Description of Wood Preserving Industry

Wood preserving has been an industry in the United States for more than 100 years. The most common wood preservatives are pentachlorophenol (PCP), creosote, and chromated copper arsenate (CCA). Many wood preserving facilities use, or have used, more than one type of preservative. When properly used and disposed of, these preservatives do not appear to threaten human health. However, due to operating procedures that were standard practices at the time, almost all wood preserving plants 20 years or older have some degree of soil and groundwater contamination. This contamination typically represents multiple types of preservatives.

At present, there are 71 wood preserving sites listed on the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) National Priorities List for Uncontrolled Hazardous Waste Sites (NPL) [Federal Register, 1996]. There are at least 678 additional sites where wood preserving operations have been or are currently being conducted; contamination may be present at many of these sites as well.

The primary sources of pollution at wood preserving facilities are lagoons or waste ponds into which wastewater and sludges were placed. Other lesser sources of contamination include the areas around storage and treatment tanks, which may be contaminated due to broken or leaky pipes or spills during transfer operations, and the storage areas contaminated with the drippings from freshly treated wood and the stored treated lumber. In some instances, runoff from drip racks and storage areas has impacted surface waters as well.

1.3 Number and Status of Sites

A list of wood preserving sites has been compiled using the following sources:

- The 1995 Wood Preserving Industry Production Statistical Report [American Wood Preservers Institute (AWPI), 1996]
- Contaminants and Remedial Options at Wood Preserving Sites [EPA, 1992a]
- Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) database query results (query executed February 1997)
- Resource Conservation and Recovery Information System (RCRIS) database query results (query executed March 1997)
- National Priorities List for Uncontrolled Hazardous Waste Sites [Federal Register, 1996]
- National Priorities List for Uncontrolled Hazardous Waste Sites, Proposed Rule [Federal Register, 1996].

These references identify a total of 749 sites in the United States where wood preserving is or has been conducted or where wood preserving wastes have been identified. These 749 sites are listed in Appendix A. The geographical distribution of wood preserving sites by State and territory is presented in Figure 1-1. The distribution of wood preserving sites by EPA Region is presented in Table 1-1.

The number of wood preserving facilities currently in operation has not been determined; however, several related estimates have been made. It is estimated, based on "The 1995 Wood Preserving Industry Production Statistical

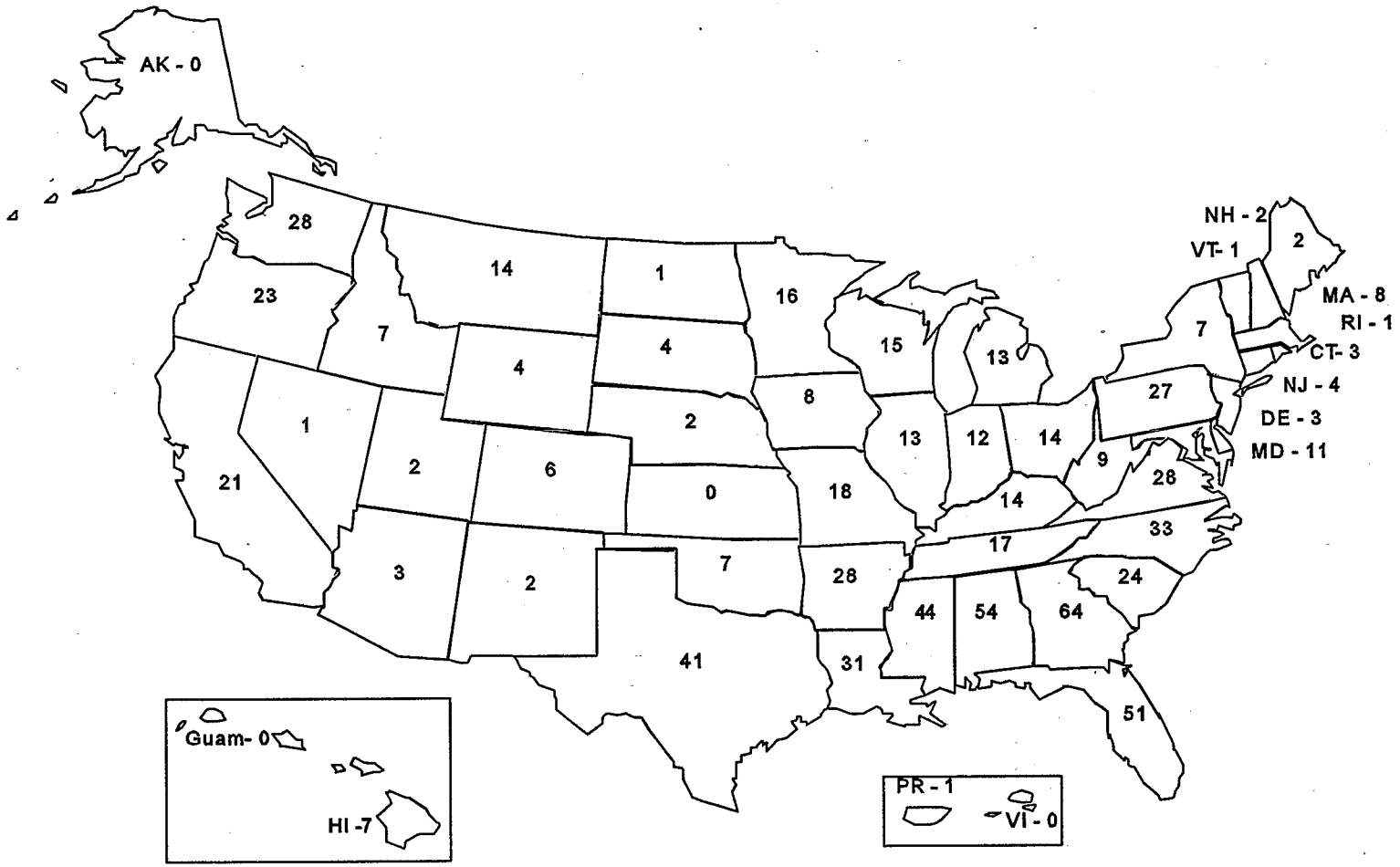

Figure 1-1. Distribution of wood preserving sites by state.

Table 1-1. Distribution of Wood Preserving Sites by EPA Region

EPA Region	Number of Sites
I	17
II	12
III	78
IV	301
V	83
VI	109
VII	28
VIII	31
IX	32
X	58
Total	749

Report (AWPI Report)" and other sources of information, that at least 452 wood preserving plants are in operation (as of 1995). The compilation also identified 105 wood preserving sites believed not to be in operation [AWPI, 1996]. These 105 sites include wood preserving facilities that are not listed in the AWPI Report, but are listed in CERCLIS or on the NPL. The compilation also identified 192 wood preserving facilities for which the operating status is unknown. These 192 facilities are not included in the AWPI Report; most were found in the Resource Conservation and Recovery Act (RCRA) database, RCRIS, using a Standard Industrial Classification (SIC) Code of 2491 (Manufacturing - Wood Preserving) to limit the searches.

The CERCLA NPL, published December 23, 1996, includes 71 wood preserving sites. The proposed NPL (also published December 23, 1996) includes two wood preserving sites [Federal Register, 1996]. In addition, one wood preserving site (Brown Wood Preserving in Live Oak, FL) was deleted from the NPL on September 22, 1995, and a second wood preserving site (Boise Cascade/Onan Corporation/Medtronic, Inc.) was removed from the proposed NPL on February 15, 1995. The list presented in Appendix A also identifies 40 wood preserving sites that are being addressed under programs other than CERCLA.

CHAPTER 2
WOOD PRESERVING CONTAMINANTS AND REMEDIAL APPROACHES

2.1 Background

This chapter provides information on four classes of environmental contaminants commonly found at wood preserving sites: creosote, focusing on polycyclic aromatic hydrocarbons (PAHs); PCP; polychlorinated dibenzo-*p*-dioxins (PCDDs) and polychlorinated dibenzofurans (PCDFs); and metals. For each class of compounds, this chapter presents information on physical and chemical properties, occurrence, and environmental fate. In addition, the general effectiveness of featured remediation technologies, analytical methods commonly employed to quantify wood preserving contaminants, and soil and water characteristics affecting contaminant behavior are discussed. Special emphasis has been placed on PCDDs/PCDFs and nonaqueous phase liquids (NAPLs), since they often present the greatest challenge in remediating wood preserving sites.

It is important to note that EPA has established presumptive remedies for soils, sediments, and sludges at wood preserving sites. The objective of the presumptive remedies approach is to streamline site characterization and accelerate the selection of cleanup strategies by utilizing previous experience gained at similar sites. Presumptive remedies are expected to be used at all appropriate sites except under unusual site-specific circumstances or when high levels of PCDDs/PCDFs are identified [EPA, 1995b]. The presence of these compounds, however, does not automatically preclude the use of presumptive remedies at the site. Bioremediation, TD, and incineration are the presumptive remedies for soils, sediments, and sludges when they are contaminated with organic compounds. S/S is the presumptive remedy when the above media are contaminated with metals.

While presumptive remedies specific to wood preserving sites have not been established for contaminated groundwater, EPA has developed generic guidance in the form of a presumptive response strategy and *ex situ* treatment technologies document [EPA, 1996a]. That document describes a presumptive response strategy that should be useful, at least in part, at all sites with contaminated groundwater. It also identifies presumptive technologies that should be investigated for *ex situ* treatment of dissolved organic and metals contamination. Several of these *ex situ* technologies have been used at wood preserving sites and are included in this document. Others may be appropriate and should be considered when *ex situ* treatment of groundwater is a remedial option at a wood preserving site.

In addition to these presumptive remedies, several other treatment technologies have been shown to be effective in the treatment of wood preserving contaminants. Those discussed in this document are soil washing, solvent extraction, and BCD for soils, sediments, and sludges. The remediation of contaminated water at wood preserving sites using hydraulic containment, carbon adsorption, photolytic oxidation, and bioremediation is also discussed in this document. Their effectiveness in remediating contaminants at wood preserving sites is presented in Table 2-1. For each of these technologies, the remedial mechanism (i.e., process by which effective remediation is accomplished) and the level of effectiveness (demonstrated, potential, or not effective) is listed. All of the previously identified technologies are discussed in greater detail in Chapters 4 and 5 of this document.

Due to site-specific conditions, it is necessary in some instances to evaluate the effectiveness of

Table 2-1. Effectiveness of Selected Technologies for the Treatment of Wood Preserving Contaminants[1]

Technology	Effectiveness Mechanism	Contaminant Group: Creosote/ PAHs	PCP	PCDDS/ PCDFs	Metals
Soil Treatment					
Soil Washing	Removal	D	D	P	D
Solidification/ Stabilization	Reduced Leachability	D	D	D	D
Thermal Desorption	Removal	D	D	D	N
Incineration	Destruction	D	D	D	N
Solvent Extraction	Removal	D	D	P	N
Base-Catalyzed Decomposition	Destruction	N	D	D	N
Bioremediation (soils, sediments, and sludges)	Destruction	D	D	N	N
Water Treatment					
Photolytic Oxidation	Destruction	P	D	N	N
Carbon Adsorption	Removal	D	D	D	D
Hydraulic Containment	Containment	D	D	D	D
Bioremediation (water)	Destruction	D	D	N	N

[1] Sources for this table are: Contaminants and Remedial Options at Wood Preserving Sites [EPA, 1992a]; Engineering Bulletins (listed in Table 6-1); and the studies included in this document.
D = Demonstrated effectiveness at either bench-, pilot-, or full-scale.
P = Potential effectiveness as reported in reference source.
N = Not effective

these other treatment technologies in relation to the presumptive remedies. In evaluating the ability and appropriateness of using treatment alternatives to address environmental concerns, the Remedial Investigation and Feasibility Study (RI/FS) process uses the following nine criteria:

1. Overall protection of human health and the environment
2. Compliance with Applicable or Relevant and Appropriate Requirements (ARARs)
3. Long-term effectiveness and permanence
4. Reduction of toxicity, mobility, or volume
5. Short-term effectiveness
6. Implementability
7. Cost
8. State acceptance
9. Community acceptance

Consideration of these criteria may confirm or preclude the use of a presumptive remedy at a specific site or show use of another technology to be preferable.

2.2 Environmental Concerns

The environmental issues at a given wood preserving site depend on the media in which the contaminants are present. At most contaminated wood preserving sites, the soil has been contaminated first, then contaminants have migrated into the groundwater. The migration of contaminants into the groundwater

is influenced by many contaminant- and site-specific factors, including the following:

Contaminant Characteristics

- Solubility in water
- Density
- Viscosity
- Volatility

Site Characteristics (Soil and Groundwater)

- pH
- Pore space
- Hydraulic conductivity
- Extent to which the soil is saturated with water (or contaminants)
- Natural organic content of the soil
- Soil/subsurface material structure and heterogeneity
- Soil particle size distribution
- Weather conditions
- Depth of groundwater
- Ion exchange capacity of soil

The extent to which the contaminants adsorb to the soil is influenced by many of the factors just mentioned. Many contaminants, particularly organics, have a high affinity for natural organic materials present in soil. As a result, these contaminants are most strongly sorbed when the natural organic content of the soil is high. In addition, contaminants generally adsorb to fine soil particles such as silt and clay more strongly than to larger soil particles such as sand and gravel. Contaminants that are not strongly adsorbed to the soil have a greater tendency to migrate.

The solubility of contaminants in water is also a major factor in contaminant migration. Water-soluble contaminants are often quite mobile, since they have a tendency to be leached from the soil by rainfall infiltration and surface water phenomena. Contaminants that are dissolved in groundwater or surface water will migrate with the water. If contaminants are leached from the soil by surface water that flows into a stream, they will quickly migrate offsite. The migration of contaminants dissolved in a pond or in the groundwater, however, will generally occur more slowly.

Contaminants that are insoluble in water, referred to as nonaqueous phase liquids (NAPLs), generally migrate more slowly than water-soluble contaminants. The migration of insoluble contaminants is usually due to gravity, rather than the movement of water. Insoluble organics that are moved ahead of the plume by the hydraulic pressure of the groundwater, however, can move as fast as water-soluble contaminants [Pivetz, 1997]. The rate of migration of these contaminants can also be less than the velocity of the groundwater if there is contaminant retardation caused by sorption onto soil particles [Huling, 1997]. Other factors that may influence the migration of insoluble contaminants include the extent to which the soil is saturated. NAPLs are discussed in detail in Section 2.7.

In addition to soil and groundwater, other media that may be contaminated by wood preserving compounds are air, sediment, and surface water. Most wood preserving contaminants are not volatile, so evaporation from surface soils into the air is not a major concern. Particulate emissions may be a concern, however, particularly during site operations that disturb the soil. If sediment and surface water are present at the site, the contamination pathways for these media must be considered in order to achieve effective site remediation.

2.3 Creosote

2.3.1 Contaminant Description

Creosote is produced as a distillate from coal tar and is a variable mixture of hundreds of compounds, primarily semivolatile organic compounds (SVOCs). In wood preserving applications, it may be used either full strength or diluted with oil. The use of creosote solutions has generally declined in the last 10 years, but still represented the second largest volume of wood preserving solutions consumed in 1995 [AWPI, 1996]. Undiluted creosote is denser than water and typically collects at the bottom of aquifers as a dense nonaqueous phase liquid (DNAPL). PAHs are SVOCs that generally account for 85 percent (by weight) of the chemical constituents of undiluted creosote [EPA, 1992a]. The predominant PAHs in creo-

sote have two to four aromatic rings, but larger compounds are also present. The lipophilicity (i.e., tendency to accumulate in fatty tissues), environmental persistence, and genetic toxicity of individual PAHs generally increase with increasing molecular weight. Some major components of creosote are as follows [EPA, 1990a][EPA, 1992a]:

- Acenaphthene
- Acenaphthylene
- Anthracene
- Carbazole
- Chrysene
- Dibenzofuran
- Fluoranthene
- Fluorene
- 2-Methylnaphthalene
- Naphthalene
- Phenanthrene
- Pyrene

All of the compounds listed above are PAHs, except for carbazole and dibenzofuran.

Many of the lower concentration components of creosote are also PAHs. Those having substantial environmental significance are listed below. These seven, and the 10 previously listed PAHs are included in the data tables in Chapters 4 and 5 and Appendices B and C of this document.

- Benz(a)anthracene
- Benzo(b)fluoranthene
- Benzo(k)fluoranthene
- Benzo(ghi)perylene
- Benzo(a)pyrene
- Dibenz(a,h)anthracene
- Indeno(1,2,3-cd)pyrene

The EPA Office of Health and Environmental Assessment (OHEA) has judged seven PAHs to be probable human carcinogens and has provided, as temporary guidance, order-of-magnitude relative potency factors for these seven PAHs [EPA, 1993a]. These relative potency factors, presented in Table 2-2, can be used as weighting factors in the calculation of a benzo(a)pyrene [B(a)P] potency estimate. This ranking of potential potency considers only PAH carcinogenicity; it does not consider other health or environmental effects. The use of the relative potency factors is discussed in more detail in EPA/600/R-93/089, "Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons" [EPA, 1993a].

Table 2-2. Relative Potency Factors for PAHs [EPA, 1993a]

PAH	Relative Potency Factor
Benzo(a)pyrene	1.0
Benz(a)anthracene	0.1
Benzo(b)fluoranthene	0.1
Benzo(k)fluoranthene	0.01
Chrysene	0.001
Dibenz(a,h)anthracene	1.0
Indeno(1,2,3-cd)pyrene	0.1

Different sets of relative potency factors have also been developed and used by some EPA Regions. Relative potency factors different from those presented in this document could, therefore, be used to calculate a B(a)P potency estimate that is greater or lesser than one derived from the use of these factors. Because of these inconsistencies, B(a)P potency estimates should always include a list of the relative potency factors used. The potency factors presented in Table 2-2 are used to calculate B(a)P potency estimates for the data presented in Chapters 4 and 5 of this document.

EPA has identified several types of creosote wastes as listed hazardous wastes under RCRA [EPA, 1996e]. These include wastewater process residuals, preservative drippage, and spent formulations from plants that use creosote formulations (EPA hazardous waste code F034). Bottom sediment and sludge from wastewater treatment (K001) and discarded unused creosote (U051) are also listed hazardous wastes. The presence of these wastes in media subjects the media to RCRA regulations.

2.3.2 *Remedial Approaches*

EPA has identified bioremediation, TD, and incineration as presumptive remedies for creosote-contaminated soils, sediments, and sludges. Bioremediation can incorporate a variety of treatment approaches, each with a potentially different level of effectiveness. Bioremediation of soil and water has been shown to be effective in degrading PAHs to concentrations below cleanup levels in several full-scale remediations. The technology is currently in full-scale use at sites throughout the country [EPA, 1995b, 1995c, 1995d, 1996b].

TD has been demonstrated to be effective in removing PAHs from soil to concentrations below cleanup levels in bench-, pilot-, and full-scale applications. Similarly, incineration has been effective in destroying PAHs in soil from wood preserving sites at all three scales of testing [EPA, 1995b]. In addition to the established presumptive remedies, soil washing and solvent extraction have been shown to effectively remove PAHs to below cleanup levels. S/S is not considered to be a conventional treatment technology for organic contaminants but has been shown to reduce the leachability of PAHs present in soil [SAIC, 1997c]. Because PAHs are not chlorinated, BCD has not been shown to reduce PAH concentrations significantly. PAH-contaminated groundwater has been treated using traditional pump-and-treat technologies, such as carbon adsorption, as well as by innovative techniques, including photolytic oxidation. Membrane separation is another innovative technology being evaluated for the treatment of PAH-contaminated groundwater.

2.4 PCP

2.4.1 *Contaminant Description*

The PCP solutions used in wood preserving are prepared by dissolving technical-grade PCP in oil to produce a solution that is 4 to 8 percent PCP. As with creosote, the use of PCP has declined over the last 10 years. Technical grade PCP contains 85 to 90 percent PCP; 2 to 6 percent higher molecular weight chlorophenols; 4 to 8 percent 2,3,4,6-tetrachlorophenol; and about 0.1 percent PCDDs and PCDFs [EPA, 1990a][EPA, 1992a]. It is the presence of PCDDs and PCDFs that is of most concern in PCP solutions.

PCP is slightly soluble in water (8 mg per 100 mL) but very soluble in oil. Consequently, PCP-oil solutions that leach into the ground often collect as light nonaqueous phase liquids (LNAPLS). PCP adheres strongly to soil. The extent of sorption is influenced by organic content, pH, and soil type, with high organic content correlating most strongly with increased adsorption [EPA, 1992a].

2.4.2 *Remedial Approaches*

As with creosote, EPA has identified bioremediation, TD, and incineration as presumptive remedies for PCP-contaminated soils, sediments, and sludges. The effectiveness of these three technologies has been demonstrated in full-scale applications [EPA, 1992a]. Soil washing has been shown to be effective in removing PCP at bench- and pilot-scale [EPA, 1992a] [IT Corp., 1996c]. Solvent extraction also has been shown to be effective in removing PCP from soil at all three levels [EPA 1992a] [EPA, 1995c]. Bench-, pilot-, and full-scale applications have demonstrated the ability of S/S to reduce the leachability of PCP based on certain test methods [Bates and Lau, 1995] [SAIC, 1997c]. BCD has been shown to be effective in destroying PCP in bench-scale studies [SAIC, 1997a]. Photolytic oxidation of PCP in groundwater has been shown at bench- and full-scale to be most effective when hydrogen peroxide is incorporated into the treatment [EPA, 1993b] [IT Corp., 1996a]. Carbon adsorption can be employed to remove PCP from groundwater, with demonstrated effectiveness at bench scale [IT Corp., 1996a].

2.5 Dioxins/Furans (PCDDs/PCDFs)

2.5.1 *Contaminant Description*

PCDDs and PCDFs are compounds that form, as by-products, during the production of certain chlorophenolic chemicals, comprising approximately 0.1 percent of commercial grade PCP. Of the PCDDs present, the primary congeners are octachlorodibenzo-*p*-dioxins (OCDDs) with traces of hexa- and heptachlorodibenzo-*p*-dioxins (HxCDDs and HpCDDs) [EPA, 1990a]. The PCDD congener of most concern, 2,3,7,8-

tetrachlorodibenzo-*p*-dioxin (TCDD), has not been found in PCP produced in the United States.

TCDD and other congeners, not typically present in PCP solutions, can be formed during the incomplete combustion of PCP [EPA, 1992a]. The optimal temperature for the formation of TCDD is estimated to be between 750° and 900°C, but formation may occur at temperatures as low as 350°F [EPA, 1986] [EPA, 1995b]. The implications of this occurrence for remediation of wood preserving sites is discussed later in this section. PCDDs and PCDFs display a very low solubility in water, but are significantly more soluble in non-polar organic solvents. The compounds adsorb strongly to organic matter and are persistent under ambient environmental conditions. They migrate primarily through the movement of particulate matter (i.e., as dust, through earth-moving activities, and as soils or sediments carried by water) and are also transported by the migration of organic solvents and carrier oils. Since the primary source of PCDDs and PCDFs at wood preserving sites is discharged PCP, these compounds can be expected to occur in areas where PCP was used or where PCP wastes were disposed. In groundwater, PCDDs and PCDFs are most often associated with LNAPL layers.

EPA's concern with the potentially detrimental effects of PCDDs and PCDFs on human health and the environment is evidenced by the listing of several wastestreams that can potentially contain these compounds as hazardous waste. Discarded unused formulations of tri-, tetra-, and pentachlorophenol are regulated as acute hazardous waste (EPA hazardous waste code F027) and, consequently, are subject to the most stringent management scheme possible under RCRA. Wastewaters, process residue, preservative drippings, and spent formulations from wood preserving processes generated at plants that currently use or previously used chlorophenolic formulations (F032), as well as bottom sediment sludge from the treatment of these wastewaters (K001), are listed as toxic waste under RCRA, due, in part, to the presence of PCDDs and PCDFs [EPA, 1996e].

The relative toxicities of PCDDs and PCDFs are typically assessed using the Toxicity Equivalency Factors (TEFs) from the "I-TEF/89 scheme" [EPA, 1989a]. The TEFs are used to calculate the toxicity of a mixture of PCDDs and PCDFs by using the toxicity of 2,3,7,8-TCDD as a basis. The calculated equivalent toxicity of a mixture is, therefore, referred to as the 2,3,7,8-TCDD toxicity equivalent (TEQ), TCDD-TEQ, or simply TEQ. The TEFs from the "I-TEF/89 scheme" are presented in Table 2-3 [EPA, 1989a].

Table 2-3. TEFs for PCDDs and PCDFs from the I-TEF/89 Scheme [EPA, 1989a]

Compound	TEF
2,3,7,8-TCDD	1.0
1,2,3,7,8-pentachlorodibenzo-*p*-dioxin	0.5
2,3,7,8-HxCDD	0.1
2,3,7,8-HpCDD	0.01
OCDD	0.001
2,3,7,8-tetrachlorodibenzofuran (TCDF)	0.1
1,2,3,7,8-pentachlorodibenzofuran	0.05
2,3,4,7,8-PeCDF	0.5
2,3,7,8-hexachlorodibenzofuran	0.1
2,3,7,8-heptachlorodibenzofuran	0.01
Octachlorodibenzofuran	0.001

2.5.2 Remedial Approaches

EPA's presumptive remedy guidance for wood preserving sites contains several caveats that need to be considered when using bioremediation, TD, or incineration to treat soils, sediments, and sludges containing PCDDs and PCDFs [EPA, 1995b]. The document states that it was not designed to address sites containing high levels of PCDDs and PCDFs. Bioremediation generally is not considered effective in the treatment of these compounds [EPA, 1992d] [EPA, 1994d] [EPA, 1996b]. The use of TD on soils, sediments or sludges containing PCDDs and PCDFs, as well as chlorinated phenolic compounds, must be carefully monitored and adjusted in order to minimize the formation of additional PCDDs and PCDFs and to prevent their conversion to more toxic congeners. In addition to treatability studies, a full-scale "proof

of performance" (POP) test should be performed [EPA, 1995b].

Incineration is recognized as an established technology for the treatment of media and waste containing PCDDs and PCDFs. Through trial burns and full-scale applications, incineration has been shown to consistently reduce levels of these contaminants to below cleanup standards in soils, sediments, and sludges. Destruction of PCDDs and PCDFs in organic liquids (e.g., PCP carrier oils) can exceed 99.99 percent. With properly controlled secondary combustion chambers (where required by incinerator design) and effective air pollution control devices, incinerator off-gasses can also meet operating standards for PCDDs and PCDFs [EPA, 1992a].

Soil washing, when employing a surfactant, has been shown in bench-scale studies to be effective in separating PCDDs and PCDFs from soil [IT Corp., 1996c]. S/S is not a presumptive remedy for the treatment of media contaminated with PCDDs and PCDFs. Nonetheless, S/S has been demonstrated to reduce the leachability of these compounds to below cleanup goals in bench-scale tests [SAIC, 1997c] and full-scale applications [SAIC, 1996a]. Solvent extraction of soil during bench-scale treatability testing achieved significant removal of PCDDs and PCDFs in several studies [EPA, 1995c]. In bench-scale studies, BCD has been demonstrated to be very effective in destroying PCDDs and PCDFs in soils and oily concentrates produced by other technologies (e.g., condensates from TD) [Tiernan, et al., 1989 and 1996].

Photolytic oxidation of PCDDs and PCDFs in water from wood preserving sites has resulted in varying levels of destruction in bench-scale studies [IT Corp., 1996a]. Based upon bench-scale testing, carbon adsorption appears to effectively remove these compounds from water [IT Corp., 1996a].

Regardless of the technology employed, treatment residuals will need to be analyzed to determine the effectiveness of PCDD/PCDF removal or destruction. Additionally, residuals from the treatment of chlorinated compounds using TD and incineration may need to be analyzed to verify that PCDDs and PCDFs were not generated during treatment. Depending on the testing frequency and detection limits required, analytical costs for PCDD/PCDF screening can comprise a significant portion of the project analytical budget. Based upon information from two nation-wide laboratories, PCDD/PCDF analytical costs can range from $650 to $1,125 per sample.

2.6 Metals

2.6.1 Contaminant Description

The use of metals in water-borne wood preserving solutions has increased over the last 10 years, with consumption in 1995 exceeding all other processes combined [AWPI, 1996]. By far the most widely used formulation is CCA. Other common formulations include ammoniacal copper arsenate (ACA), acid copper chromate (ACC), ammoniacal copper quat (ACQ), and ammoniacal copper zinc arsenate (ACZA). Consequently, metals contamination at wood preserving sites usually involves arsenic, chromium, copper, and zinc.

The environmental fate of these metals is strongly influenced by their intrinsic properties (e.g., solubility when combined with other elements) and the properties of the media in which they are distributed (e.g., pH, cation exchange capacity). Significant leaching of metals into groundwater occurs when the metal retention capacity of the soil becomes overloaded. Arsenic occurs in the environment in two forms: arsenite (III) and arsenate (V). The arsenite form is four to ten times more soluble than arsenate. Both adsorb strongly to soils containing iron, aluminum, and calcium. Chromium occurs in two valence states; trivalent chromium is less mobile and toxic than hexavalent chromium. Hexavalent chromium is the form used in wood preserving solutions, but soil conditions favor reduction to trivalent chromium [EPA, 1992a].

Copper adsorbs to soils more strongly than any of the four wood preserving metals. Zinc also adsorbs strongly to soils, especially clay carbonates and hydrous oxides. Under environmental conditions, some zinc compounds can be solubilized and migrate through the soil column [EPA, 1992a].

EPA has identified several types of arsenic- and chromium-containing wastes as listed hazardous wastes under RCRA [EPA, 1996e]. These wastes include wastewater, process residuals, preservative drippage, and spent formulations from plants that use inorganic preservatives containing arsenic or chromium (EPA hazardous waste code F035). The presence of these wastes in media subjects the soil or water to RCRA regulations.

2.6.2 Remedial Approaches

S/S is the presumptive remedy for metals contamination of soils, sediments, and sludges at wood preserving sites [EPA, 1995b]. The S/S process has been demonstrated to be effective in reducing the leachability of metals in these materials at bench-, pilot-, and full-scale, with success dependant on proper selection of binders and additives and the test method used. Bioremediation, TD, and incineration are not effective in treating metals contamination at wood preserving sites. Depending on the distribution of metals across the particle sizes in the material to be treated, soil washing has been shown to be effective in separating the metals of concern from the fraction of soil or sediment destined for return to the site [Biogenesis Enterprises, Inc., 1993] [EPA, 1995c]. Solvent extraction and BCD are not designed to remediate metals in media or sludges.

Groundwater contaminated with metals from wood preserving operations typically is not treated by photolytic oxidation or bioremediation. Carbon adsorption has been effective in removing low concentrations of metals in some applications [EPA, 1991c]. Ion exchange resins are commonly used to treat metals. One *in situ* treatment technique currently being evaluated is the addition of an excess of chemical reductants to recovered water contaminated with hexavalent chromium. Once mixed, the water is then re-injected into the aquifer. The excess reductant (sodium metabisulfate in the cited work) then reduces the hexavalent chromium in the surrounding aquifer to the less soluble trivalent form, which precipitates from the water. Pilot-scale testing has shown the technique to be technically and economically feasible [Geochem, 1993].

2.7 Nonaqueous Phase Liquids (NAPLs)

The extent to which contaminants will dissolve in the groundwater is determined by their concentration in the soil and their solubility in water. Liquid contaminants that are insoluble or have limited solubility in the groundwater are often present as NAPLs. DNAPLs or "sinkers" have densities greater than that of water and will, therefore, migrate downward through the saturated soil until they are confined by a less permeable layer. LNAPLs or "floaters" have densities less than that of water and, consequently, will float on top of the water table. PCP is denser than water; however, because of the carrier oils used, the PCP solutions applied in wood treating are lighter than water. When present, PCDDs and PCDFs also would be expected to be found in the LNAPL layer. Creosote, on the other hand, is usually present as a DNAPL [EPA, 1992a].

The depth at which an LNAPL is present varies with fluctuations in the groundwater level (since the LNAPL floats on top of the groundwater). If the groundwater rises and subsequently falls, organic material from the LNAPL may be present in pore spaces or remain sorbed to the soil after the LNAPL layer has receded. The area of soil that retains LNAPL material after the groundwater level has fallen is known as the "smear zone."

The presence of NAPLs complicates *in situ* remediation. NAPLs are difficult to recover; however, if NAPLs are not removed, they may act as a continuing contaminant source for the soil and/or groundwater. Selection and implementation of a cleanup technology must take this potential source into consideration. At many sites, the following cleanup scenario has been employed: (1) utilize a pump-and-treat system to treat the groundwater and any NAPL that is recovered with the groundwater; and (2) install hydraulic containment to contain any remaining NAPL.

At sites where the NAPL is of sufficient thickness, free-product recovery has been added to this scenario. The recovered product in some cases is of sufficient quality to be used in wood preserving operations. In other

instances, the recovered NAPL can be used as fuel.

Depending on site conditions, the described approach, coupled with free-product recovery, usually provides sufficient hydraulic containment and rapidly decreases contaminant concentrations. Layers of NAPL too thin for free-product recovery and soil in the smear zone, however, can continue to act as sources, often causing contaminant levels to remain above cleanup goals for years [Haley et al., 1991]. One potentially promising variation is the addition of surfactants to the areas of an aquifer where NAPLs are present. Regulatory approval and cost effectiveness, along with surfactant selection, are areas where further research and effort are required before surfactant use is expanded [EPA, 1996d].

2.8 Analytical Methods

Table 2-4 presents some common analytical methods that can be used to determine the concentrations of wood preserving contaminants in soil, water, and organic materials. When analyses are intended to determine the amount of contaminants that will leach from a soil (or other material), rather than the amount of contaminants present in the soil, the soil is subjected to a special leaching procedure. Two common leaching procedures are SW-846 Method 1311, the Toxicity Characteristic Leaching Procedure (TCLP), and SW-846 Method 1312, the Synthetic Precipitation Leaching Procedure (SPLP) [EPA, 1995a]. TCLP and SPLP leachates are analyzed using the same methods used to analyze water samples. However, it should be noted that the two methods are not comparable and will produce different results.

Table 2-4. Analytical Procedures[1]

Matrix	Analytical Parameter	Preparation Methods	Analytical Methods
Soil/Sediment	Arsenic	3050A, 3051	6010, 7060A
	Chromium	3050A, 3051	6010A
	Copper	3050A, 3051	6010A
	Zinc	3050A, 3051	6010A
	SVOCs[2]	3540B, 3541, 3550A	8270B
	PAHs	3540B, 3541, 3550A	8100, 8310
	PCP	3540B, 3541, 3550A	8040A
	Dioxins/Furans	NA[3]	8280, 8290
Water/Leachate	Arsenic	3005A, 3010A, 3015	6010A, 7060A[4]
	Chromium	3005A, 3010A, 3015	6010A
	Copper	3005A, 3010A, 3015	6010A
	Zinc	3005A, 3010A, 3015	6010A
	SVOCs[2]	3510B, 3520B	8270B
	PAHs	3510B, 3520B	8100, 8310
	PCP	3510B, 3520B	8040A
	Dioxins/Furans	NA[3]	8280, 8290
Organic-Phase Materials	Arsenic	3051	6010A, 7060A[4]
	Chromium	3051	6010A
	Copper	3051	6010A
	Zinc	3051	6010A
	SVOCs[2]	3580A	8270B
	PAHs	3580A	8100, 8310
	PCP	3580A	8040A
	Dioxins/Furans	NA[3]	8280, 8290

1 All methods are from *Test Methods for Evaluating Solid Waste*, EPA 1987, SW-846, 3rd Ed. (through Update IIB, 1995) [EPA, 1995a].

2 SVOCs include PAHs and PCP; however, the detection limits available by the designated method(s) are commonly too high for many applications.

3 Preparation procedures are included in the analytical method.

4 If 7060A will be performed, the preparation procedures included in that procedure should be used.

CHAPTER 3
OVERVIEW OF PERFORMANCE AND COST

This chapter provides tabular summaries of the performance and cost data acquired through the literature search performed for this project. More detailed information on performance and cost for each technology is presented in Chapters 4 and 5.

3.1 Performance

Table 3-1 presents a range of effectiveness for each of the treatment technologies profiled in this document. Listed by contaminant (i.e., PAHs as B(a)P potency estimates, PCP, PCDDs/PCDFs as TCDD-TEQs, and metals), the range reflects the percent change between untreated and treated samples. It should be noted that the objectives of many treatability studies did not include quantifying percent change or the development of statistically defensible results. Instead, the objective often was to determine whether a particular application of a treatment technology would be effective under optimal conditions. Consequently, results often lack sufficient replicates and quality assurance (QA) documentation necessary to quantify potential full-scale effectiveness. Soil and contaminant heterogeneity also affects study results and, in some cases, causes treated concentrations to exceed untreated values. Additionally, site-specific factors, including contaminant concentrations, media characteristics, contaminant distribution, and moisture/solids content, greatly affect treatment performance. Notwithstanding, the ranges presented here can be used as general guidance on the ability of a technology to treat a class of contaminants.

3.2 Cost

Table 3-2 presents cost ranges for each technology discussed in this report. The costs are presented on a "per unit treated" basis. For water treatment technologies, costs are typically presented as dollars per 1,000 gallons ($/1,000 gal.) treated. For soil, sediment, and sludge treatment technologies, costs are usually listed as dollars per cubic yard ($/yd^3) or dollars per ton ($/ton) of material treated. To facilitate intertechnology comparison, all soil and sediment treatment costs have been converted to $/ton using a reported density of excavated, moist, packed earth (1.3 tons per yd^3) [Perry and Green, 1984], except when site-specific density measurements were available.

When available, the cost ranges are presented as treatment costs and project costs. Treatment costs are defined as the expenses incurred in operating the treatment equipment, presented on a per unit treated basis. Treatment costs include 6 of the 12 categories typically included in Superfund Innovative Technology Evaluation (SITE) Demonstration Test economic analyses. The categories considered are startup, equipment purchase/leasing, supplies and consumables, labor (limited to operation of the treatment unit), utilities, and maintenance. These categories represent costs directly related to treatment of the media. Treatment costs presented in Table 3-2 were compiled primarily from the studies presented in Chapters 4 and 5 and Appendices B and C. Additional details can be found in these sections.

Project costs typically include the additional SITE Demonstration Test cost categories of site preparation, permitting and regulatory activities, effluent disposal, residuals and waste management, analytical expenses, and site demobilization. These six categories are more sensitive to site-specific factors and represent activities typically ancillary to the treatment process. In some applications of the technologies, ancillary costs are responsible for a higher percentage of total costs than treatment costs. While treatment costs were compiled from the studies discussed in this document, the ranges of project costs presented in Table 3-2 were compiled from these studies and from other references. Due to this larger base of informa-

Table 3-1. Summary of Treatment Effectiveness

Technology	Percent Change[1]					References
	Total PAHs	B(a)P Potency Estimate	PCP	TCDD-TEQ	Metals	
Soil Treatment						
Soil Washing	-69 to -90	-72 to -85[2]	-5 to -83	0 to -71	-37 to - 55	IT Corp., 1996c Biogenesis Enterprises, Inc., 1993
Solidification/Stabilization	-69 to >-96[3]	-76 to >-93[3]	-23 to >-99[3]	-73 to >-99[3]	0 to >-91[3]	SAIC, 1997a[5] SAIC, 1997e
Thermal Desorption	-99.9 to >-99.9	>-99	>-97	-57	NR	Whiting, et al., 1992
Incineration	>-99.9	>-99	>-99	NR	+2 to -93	EPA, 1988
Solvent Extraction	-93 to >-99	-83	-61 to >-99	-96	NR	EPA, 1995c SAIC, 1997b[5]
Base-Catalyzed Decomposition	NA	NA	>-99	>-99[4]	NA	Tiernan, 1994[5] SAIC, 1997c[5]
Bioremediation	0 to -97	0 to -61	0 to -72	-35 to -56	NA	Mueller, et al., 1991[5] IT Corp., 1996b EPA, 1995c
Water Treatment						
Photolytic Oxidation	0 to -31	-51	-58 to -99	-99	NR	IT Corp., 1996 EPA, 1993b Koppers Industries, 1989[6]
Carbon Adsorption	NR	NC	NC	-53	NR	IT Corp., 1996a
Hydraulic Containment[7]	NA	NA	NA	NA	NA	
Bioremediation	-12 to -97.9	-93 to -95	0 to ~-100	NC	NR	IT Corp., 1996b EPA, 1991a

1 Comparison of concentrations in untreated and treated samples; percent change is stated as a decrease (-) or increase (+).
2 Excludes test in which soil washing was performed using DI water only (no additives).
3 Percent reduction in SPLP or TCLP leachate.
4 Based upon PCDD/PCDF isomers instead of TCDD-TEQ.
5 Reference is cited in Appendix B.
6 Reference is cited in Appendix C.
7 Hydraulic containment is not a contaminant reduction technology; therefore, a calculation of percent change is not applicable.

NR = Not reported
NC = Not calculated (typically due to detection limits)
NA = Not applicable

Table 3-2. Summary of Cost Information

Technology	Cost Range[3] ($/1,000 gal or $/ton)	Year of Estimate[5]	Important Cost Factors	References
Soil Treatment				
Soil Washing				
Treatment[1]	30 - 200	1993	Residuals Disposal	Biogenesis Enterprises, Inc., 1993
Project[2]	120 - 200	1994		EPA, 1994a
Solidification/Stabilization				
Treatment	98 - 250	1995-96	Heterogeneity of Contaminants, Binder/Waste Ratio	Bates and Lau, 1995 SAIC, 1996 and 1997d EPA, 1993e
Project	50 - 483	1992-95		Bates and Lau, 1995
Thermal Desorption				
Treatment	NR		Residuals Disposal, Moisture Content	
Project	100 - 600	1992-93		EPA, 1994b Whiting, et al., 1992
Incineration				
Treatment	140 - 190	1989	Heating Value of Waste, Moisture Content	EPA, 1989b EPA, 1990b
Project	NR			
Solvent Extraction				
Treatment	94 - 112	1992	Residuals Disposal	EPA, 1993f
Project	75 - 400	1994		EPA, 1995c
Base-Catalyzed Decomposition				
Treatment	NR		Contaminant Media, Pretreatment Requirements	
Project	200 - 500	1990		EPA, 1990b EPA, 1994a
Bioremediation				
Treatment				
Slurry-Phase	49 - 105		Cleanup Levels	EPA 1993d
Composting	187 - 290	1996	Cleanup Levels	EPA, 1996c
Landfarming	27	1992	Cleanup Levels	EPA, 1996b

Table 3-2. Summary of Cost Information (continued)

Technology	Cost Range[3] ($/1,000 gal or $/ton)	Year of Estimate[5]	Important Cost Factors	References
Project				
Slurry-Phase	96 - 268	1990-94	Cleanup Levels	EPA, 1990e EPA, 1993d EPA, 1994a
Composting	187 - 310	1996	Cleanup Levels	EPA, 1996c
Landfarming	NR		Cleanup Levels	EPA, 1996b
Water Treatment				
Photolytic Oxidation				
Treatment	3.90 - 13.28	1993	Electricity	EPA, 1993b
Project	2.76 - 58.50	1993-94		EPA, 1994a Venkatadri and Peters, 1993
Carbon Adsorption				
Treatment	1.38	1995	Contaminant Concentration	IT Corp., 1996a
Project	1.20 - 6.30	1991		EPA, 1991b
Hydraulic Containment				
Treatment	NR	NR	NR	
Project	3 - 75[4]	1992	Depth of Containment Required	EPA, 1992a
Bioremediation[6]				
Treatment	2.94 - 14.56	1991	Treatment Location (*In Situ* vs. *Ex Situ*)	EPA, 1991a
Project	50 - 90	1992		EPA, 1992a

1 Treatment costs include expenses incurred in operating the treatment equipment only. These expenses typically include startup, equipment purchase/leasing, supplies and consumables, operator labor, utilities, and maintenance. Treatment costs were compiled from the studies presented in this document.

2 Project costs include treatment costs and additional expenses associated with remediation. These expenses include site preparation, permitting and regulatory activities, effluent disposal, residuals and waste management, excavation, analytical services, and demobilization. Project costs were compiled from the studies presented in this document and a review of general treatment technology literature. Consequently, project costs may be reported as less than treatment costs, reflecting the broader base of information reviewed for project costs.

3 Water treatment in $/1,000 gal; soil treatment in $/ton.

4 $/ft^2 of containment structure.

5 Cost ranges have not been adjusted to 1997 dollars.

6 Treatment costs for bioremediation of water are based on cost estimates for *ex situ*, fixed-film bioremediation; a specific type of bioremediation was not specified for the project costs.

NR = Not reported

tion, some project cost ranges may include values that are less than their corresponding treatment cost ranges.

It is important to note that much of the literature reviewed did not divide costs into these categories and did not specify whether profit was included. Instead, a single estimate or range was presented without a discussion of the factors included. In these cases, the information is presented as project costs.

It is equally important to recognize that the costs presented are order-of-magnitude estiates and, in many cases, may not reflect full-scale costs. As with the performance data in Table 3-1, site-specific factors greatly influence treatment and project costs. Depending on the technology, these factors include: contaminant type and concentration, remediation goals, media characteristics, media preprocessing requirements, quantity of media to be treated, and equipment capacity. Table 3-2 presents the factors that have the greatest influence on project costs for each technology. The costs in Table 3-2, therefore, should be viewed with the understanding that the uncertainties, anomalies, and disparities among different applications of a treatment technology, along with the aforeentioned site-specific factors, may greatly affect the actual cost of a specific remediation.

CHAPTER 4
SOIL TREATMENT TECHNOLOGY PROFILES

This chapter provides information on six technologies used to treat contaminated soils, sediments, and sludges from wood preserving sites. For each technology, the chapter provides a description of the technology, along with advantages and limitations of its use. A discussion of the costs associated with operation of the technology and factors that affect costs are included. When available, a treatability study and a case study using the technology to treat soils from wood preserving sites are presented. Additional studies are described in Appendix B. It should be noted that some studies present costs based upon volume (yd^3) instead of weight (tons). To facilitate inter-technology comparison, all soil and sediment treatment costs have been converted to $/ton, using a reported density of excavated, moist, packed earth (1.3 tons per yd^3) [Perry and Green, 1984], unless stated otherwise.

4.1 Soil Washing

4.1.1 Technology Description

Soil washing is an *ex situ* remediation technology that uses aqueous-based separation and/or extraction techniques to remove a broad range of organic, inorganic, and radioactive contaminants. The process is typically used as a pretreatment in conjunction with other technologies when treating wood preserving wastes. Soil washing processes may be either continuous or batch processes. Typical applications do not detoxify, destroy, or significantly alter contaminants. Rather, the technology reduces contaminant concentrations in soils by three mechanisms: particle size separation, phase transfer, and physical removal (attrition scrubbing). When appropriately utilized, a substantial portion of the washed soil will be amenable to further treatment or can either be backfilled onsite or beneficially reused/recycled in some other way. The spent wash water is then treated to concentrate the contaminants and fine particles in a residual wastestream. The residual stream will then require further treatment and/or disposal, as will the residuals from water treatment and recycling.

4.1.2 Advantages

There are several advantages to using soil washing for the remediation of wood preserving sites. The technology can be customized, by the addition of appropriate surfactants, chelants, acids or bases, to remove PAHs, PCP, and inorganic contaminants from soil [EPA, 1990e]. Removal of contaminants from a significant percentage of the soil allows the material to be reused onsite or at other locations. The percentage of residuals requiring further treatment is substantially smaller than the volume of soil originally requiring treatment, reducing the volume of hazardous material to be transported for treatment or disposal.

4.1.3 Limitations

The distribution of contaminants across the particle size range of the soil is the most important factor in determining whether soil washing is appropriate at a site [EPA, 1990e]. Soil washing may not be cost-effective for soils with high percentages of silt and clay. Soils in which the majority of contaminants are tightly bound to larger fractions also may not be good candidates for this technology. Hydrophobic contaminants, such as PAHs and PCP, may not be effectively removed by soil washing without the addition of surfactants or organic solvents. These additives may require additional treatment of wash waters prior to recycling or disposal.

4.1.4 Technology Costs

The cost of performing soil washing is dependent on several site- and contaminant-specific factors. The quantity of soil to be treated affects the size of the soil washing unit and the time present onsite. Generally, treatment of larger soil volumes reduces the

per-ton-treated cost of equipment. Table 4-1 presents treatment costs reported in an EPA-managed pilot-scale soil washing study. In July 1992, EPA performed pilot-scale soil washing tests for which one objective was to determine cost factors for pilot- and full-scale operations [Roy F. Weston, Inc. 1992]. Cost factors considered included equipment rental, startup, treatment labor, consumables/supplies, health and safety equipment, contingencies, maintenance, and utilities. The estimate was based upon the washing of 250,000 tons of soil with an actual processing rate of 18 tons per hour for 300 days per year. A total treatment cost of $35.65 per ton of soil washed was estimated.

Table 4-1. Estimated Treatment Costs for Soil Washing [Roy F. Weston, Inc., 1992]

Cost Categories	Cost per Ton of Soil Treated ($)
Treatment Equipment Leasing	6.00
Startup	1.20
Treatment Labor	6.70
Consumables and Supplies	8.75
Health & Safety Equipment	3.60
Utilities	2.80
Maintenance and Contingency	6.60
Total Treatment Costs[1,2]	35.65

[1] Does not include mobilization/demobilization, excavation, analytical services, process water treatment, or residuals management.

[2] Based on the treatment of 250,000 tons using a 20 ton/hr soil washing unit and 24 hr/day operation with 10 percent downtime.

The characteristics and quantity of waste generated by the soil washing process have been identified as two major factors having a significant effect on soil washing costs [EPA, 1995c]. The quantity of soil to be treated, target treatment levels, and site preparation also were identified as important factors.

4.1.5 Treatability Study - American Creosote Works (ACW) Site

Background/Waste Description: Samples of contaminated soil to be used in soil washing treatability studies were collected from the ACW Superfund site located in Jackson, TN [IT Corp., 1996c]. The site is a former wood preserving facility contaminated with PAHs, PCP, and PCDDs/PCDFs. The soil was described in the project report as black silty or clayey sand with 4 to 10 percent gravel and 15 to 18 percent silt or clay. Approximately 35 percent of the soil was smaller than 0.3 millimeters (mm) in diameter. The concentrations of PAHs, PCP, and PCDDs/PCDFs in the untreated soil are presented in Table 4-2.

Summary of Study: The treatability studies were performed at the facility of a soil washing vendor in the spring of 1996. Two studies, one using deionized water and one using deionized water containing 3 percent by weight of Makon-12 surfactant were performed on soils from ACW. For both studies, 1.8 kilograms (kg) of contaminated soil were placed into a 19-liter (L) washing chamber. Approximately 10.8 kg of wash solution, adjusted to pH 9 and 49° C, were then added, and the mixture was agitated for 1 hour. The solids were then allowed to settle for 45 minutes. Free liquids and unsettled solids were decanted from the chamber and the remaining soil was sampled.

Performance: Table 4-2 presents the results from the analysis of the soil and wash water for the test with and without the surfactant.

Results indicate that washing with surfactant-containing deionized water increases the removal of PAHs compared to washing with deionized water alone. This trend also can be seen for TCDD-TEQ results. Site- and matrix-seen for TCDD-TEQ results. Site- and matrix-specific matrix spike/matrix spike duplicate (MS/MSD) analyses were not performed for this project. Increases in the concentrations of some PAHs in the deionized water-washed soil suggested either that the raw soil and washed soil were not comparable prior to treatment, or that analytical results were not accurate.

Table 4-2. Selected Results - ACW Soil Washing Treatment [IT Corp., 1996c]

Description	Untreated Soil	Soil Washed with Deionized Water	Percent Change[4]	Soil Washed in a 3% Solution of Makon-12 in Deionized Water	Percent Change[4]
Matrix	Soil	Soil		Soil	
PAHs, ppb					
Acenaphthene	440,000	630,000	+43	110,000	-75
Acenaphthylene	16,000	ND (11,000)	>-31	5,500	-66
Anthracene	2,800,000	2,300,000	-18	1,000,000	-64
Benz(a)anthracene[1]	220,000	240,000	+9.1	58,000	-74
Benzo(b)fluoranthene[1]	310,000	260,000	-16	71,000	-77
Benzo(k)fluoranthene[1]	120,000	92,000	-23	24,000	-80
Benzo(ghi)perylene	57,000	54,000	-5.2	18,000	-68
Benzo(a)pyrene[1]	130,000	120,000	-7.7	36,000	-72
Chrysene[1]	350,000	350,000	0	84,000	-76
Dibenz(a,h)anthracene[1]	16,000	16,000	0	4,400	-73
Fluoranthene	940,000	1,300,000	+38	350,000	-63
Fluorene	760,000	1,300,000	+71	160,000	-79
Indeno(1,2,3-cd)pyrene[1]	60,000	59,000	-1.7	20,000	-67
2-Methylnaphthalene	470,000	510,000	+8.5	100,000	-79
Naphthalene	380,000	460,000	+21	86,000	-77
Phenanthrene	1,500,000	1,900,000	+27	430,000	-71
Pyrene	800,000	1,100,000	+38	320,000	-60
Total PAHs[2]	9,400,000	11,000,000	+14	2,900,000	-69
B(a)P Potency Estimate	200,000	190,000	-5.0	56,000	-72
Other SVOCs, ppb					
Dibenzofuran	480,000	640,000	+33	110,000	-77
Pentachlorophenol	650,000	620,000	-4.6	110,000	-83
Phenol	ND (54,000)	2,700	NC	ND (12,000)	NC
TCDD-TEQ, ppq[3]	38,780,000	256,259,000	+561	11,079,890	-71

1 Used in calculation of B(a)P potency estimate [EPA, 1993a].
2 For nondetected results, the detection limit has been used for calculating total PAHs.
3 TCDD-TEQ by I-TEFs/89 [EPA, 1989a] reported in ppq.
4 Percent change is stated as a decrease (-) or increase (+).
NC = Not calculated.
ND = Not detected at the reporting limit stated in parentheses.

Cost: Costs were not provided with this study.

4.1.6 Treatability Study - Thunder Bay

Background/Waste Description: In June 1993 a bench-scale treatability study was performed on contaminated sediment from an unidentified wood preserving site located on Thunder Bay, ON, Canada [Biogenesis Enterprises, Inc., 1993]. The primary contaminants in the sediment were PAHs. Low levels of PCB, phenols, and metals also were present. Greater than 80 percent of the sediment was medium silt or finer particles (i.e., grain sizes less than 0.038 mm). Prior to treatment, the sediment contained approximately 9 percent oil and grease; 2 percent SVOCs; 5,000 ppm total petroleum hydrocarbons (TPH); and 4,000 ppm PAHs.

Summary of Study: A bench-scale soil washing unit was configured to simulate the full-scale sediment washing unit. First, oversize materials were removed. Next, the sediment was heated, using saturated steam, to a temperature between 80° and 90°F. After transfer to a sediment/chemical collision chamber, the proprietary cleaning agents, adjusted to a pH of 10, were added at a pressure of 10,000 pounds per square inch (psi). The sediment and cleaning agents then flowed to a collision scrubber where further contaminant removal took place. This mixture was recycled through the process two more times. Finally, the mixture passed through two hydrocyclones and a centrifuge where liquids and solids were separated.

Performance: Table 4-3 presents initial concentrations of PAHs, arsenic, chromium, and copper in the untreated sediment. Concentrations in the solids after final cycloning (cleaned sediment), and in the buffer tank (contaminated fines) are presented. Concentrations in the liquid after cycloning also are listed. Overall, the treatment produced a 90 percent reduction in total PAH concentration between the untreated and clean sediment. The B(a)P potency estimate decreased by 85 percent. Reductions in metals concentrations were 39, 55, and 37 percent for arsenic, chromium, and copper, respectively.

Cost: Full-scale treatment costs for remediation of less than 10,000 tons (using a batch feed system) were estimated to be between $40 and $200 per ton. For larger quantities of sediment, a continuous feed process would be used, with an estimated treatment cost between $30 and $110 per ton. Primary factors affecting cost are sediment type, degree of contamination, and cleanup target levels. Capital costs of the system were listed as $400,000 to $800,000 depending on system configuration.

4.2 Solidification/Stabilization (S/S)

4.2.1 Technology Description

Solidification and stabilization are both immobilization technologies, since they remediate soils and other contaminated materials by reducing the mobility of contaminants. In S/S processes, the contaminated materials are combined with various additives that reduce contaminant mobility by one or more of the following mechanisms:

- Decreasing the permeability of the contaminated material
- Encapsulating and adsorbing the contaminants
- Incorporating the contaminants into the crystalline structure of the material.

Solidification treatment techniques typically produce a solid block of waste material that has a high structural integrity and low permeability. The contaminants are mechanically encapsulated within the solid matrix; they may also chemically react with certain reagents. Stabilization treatment techniques chemically limit the solubility or mobility of waste contaminants but may not change the physical characteristics of the waste. Stabilization is often applied to wastes containing a high fraction of nonvolatile organics, such as sludges. Solidification and stabilization are often employed together.

Table 4-3. Selected Results - Thunder Bay Sediment Soil Washing Treatment [Biogenesis Enterprises, Inc., 1993]

Parameter	Untreated Sediment	After Cyclone (Clean Sediment)	Percent Change[3]	Buffer Tank (Contaminated Fines)	After Cyclone (Liquid)
PAHs, ppb					
Acenaphthene	305,000	34,000	-89	100,000	1,500
Acenaphthylene	16,000	1,500	-91	4,500	99
Anthracene	110,000	16,000	-85	40,000	560
Benz(a)anthracene[1]	115,000	19,000	-83	46,000	680
Benzo(b)fluoranthene[1]	120,000	19,000	-84	47,000	720
Benzo(k)fluoranthene[1]	42,000	6,100	-85	12,000	240
Benzo(ghi)perylene	28,000	3,900	-86	9,200	200
Benzo(a)pyrene [1]	82,000	12,000	-85	29,000	490
Chrysene[1]	75,000	12,000	-84	28,000	430
Dibenz(a,h)anthracene[1]	8,900	1,400	-84	ND	54
Fluoranthene	400,000	59,000	-85	160,000	2,150
Fluorene	240,000	30,000	-88	86,000	1,250
Indeno(1,2,3-cd)pyrene[1]	30,000	5,000	-83	12,000	200
2-Methylnapthalene	NR	NR	NC	NR	NR
Naphthalene	1,400,000	73,000	-95	300,000	5,600
Phenanthrene	770,000	88,000	-89	240,000	3,550
Pyrene	300,000	44,000	-85	110,000	1,700
Total PAHs[2]	4,000,000	420,000	-90	1,200,000[4]	19,000
B(a)P Potency Estimate	118,000	17,800	-85	39,600[4]	710
Metals, ppb					
Arsenic	15,000	9,100	-39	NR	NR
Chromium	71,000	32,000	-55	NR	NR
Copper	73,000	46,000	-37	NR	NR

1 Used in calculation of B(a)P potency estimate [EPA, 1993a].
2 Total PAHs does not include 2-methylnapthalene.
3 Percent change is stated as a decrease (-) or increase (+).
4 No detection limit was provided for the non-detected dibenz(a,h)anthracene in this sample; therefore, a value of zero was assigned for the ND in the calculation of the B(a)P potency estimate and total PAHs.

NR = Not reported
NC = Not calculated
ND = Not detected
Shaded row contains only NR and NC designations.

4.2.2 *Advantages*

S/S processes are relatively inexpensive and can be designed to immobilize both organic and inorganic contaminants. The technology can be employed *in situ* or *ex situ*. The use of S/S to immobilize inorganic contaminants is well accepted; immobilization is the presumptive remedy for wood preserving sites with soils, sediments, and sludges contaminated with inorganic contaminants [EPA, 1995b]. The use of S/S to immobilize organic contaminants is still considered innovative, but has been used to remediate a number of sites.

4.2.3 Limitations

S/S processes increase the volume of the material being treated (since reagents are added and are not consumed) and are not appropriate for wastes containing significant quantities of volatile contaminants. If volatile organic compounds (VOCs) are present in the waste material, they may be released during S/S treatment if not captured by sealed equipment. It may, however, be possible to remove VOCs prior to S/S treatment. It also should be noted that formulations that are developed to reduce the leachability of one contaminant group may not be effective on other contaminants (e.g., formulations that effectively treat metals may not reduce the leachability of organics). In some studies, it appears that formulations actually may increase the leachability of certain contaminants.

4.2.4 Technology Costs

One document estimates project costs for S/S treatment to be between $50 and $250 per ton (1992 dollars)[EPA, 1993e]. Costs are highly variable due to variations in site, soil, and contaminant characteristics that affect the performance of the S/S processes evaluated. Economies of scale likely to be achieved in full-scale operations are not reflected in pilot-scale data [EPA, 1993e].

Information regarding economies of scale can be obtained from parallel cost estimates developed for the S/S treatment of 36,000 tons and 90,000 tons of contaminated soil at the ACW site in Jackson, TN [SAIC, 1996b]. These cost estimates are based on conceptual designs. Estimated costs for treatment only are $98 per ton for the treatment of 90,000 tons of soil and $99 per ton for the treatment of 36,000 tons of soil. Treatment costs include only the equipment, labor, reagents, and consumables required for S/S treatment. Estimated project costs are $108 per ton for the treatment of 90,000 tons of soil and $119 per ton for the treatment of 36,000 tons of soil. Project costs include costs associated with treatability tests; site preparation; mobilization; permits; equipment, labor, reagents, and consumables required for S/S treatment; equipment, labor, and materials required for placement of the treated material back into the excavation, including compaction and capping, analyses; and demobilization.

A detailed S/S cost estimate was developed for a SITE Demonstration Test conducted at Selma Pressure Treating, a wood preserving site in Selma, CA [EPA, 1992c]. All costs for this SITE demonstration are given in 1992 dollars. This cost estimate was based on the S/S treatment of 15,000 yd^3 (approximately 18,800 tons) of contaminated soil, using a batch process where the soil and reagents would be mixed together in a large mixer. The treatment cost was estimated for four options: mixer sizes of 5 and 15 yd^3, and mixing times of 0.5 and 1.0 hour. The authors considered a 0.5-hour mixing time optimistic. Estimated costs are summarized in Table 4-4.

Note that reagent cost represents a significant portion of the total S/S treatment cost. The S/S formulation used during the demonstration results in an estimated reagent cost of $122 per ton of soil treated [EPA, 1992c]. At other sites, it may be possible to use formulations that have significantly lower reagent costs. For example, estimated reagent costs for the formulations used in the S/S treatability study described in Subsection 4.2.5 are $50 to $60 per ton of soil treated.

The total costs determined for the SITE demonstration are presented in Table 4-5 [EPA, 1992c].

Following the SITE demonstration, EPA proceeded with the implementation of an S/S remedy at the Selma Pressure Treating site [Bates and Lau, 1995]. Full-scale S/S treatment

Table 4-4. Estimated S/S Treatment Costs for 18,800 Tons of Soil [EPA, 1992c][1]

	Option 1	Option 2	Option 3	Option 4
Mixer capacity, yd^3	5	5	15	15
Batch mix time, hours	1	.5	1	.5
S/S Equipment Cost[1]	$228,250	$114,125	$92,750	$46,375
Startup Cost	$5,000	$5,000	$5,000	$5,000
Reagent Cost	$2,298,375	$2,298,375	$2,298,375	$2,298,375
S/S Labor Cost	$630,020	$319,184	$210,860	$109,604
Utilities Cost	$86,250	$48,450	$37,500	$24,317
Maintenance Cost	$7,500	$3,750	$7,500	$3,750
Total S/S Treatment Cost[2]	$3,255,395	$2,788,884	$2,651,985	$2,487,421
Unit S/S Treatment Cost (per ton)[2]	$173	$148	$141	$132

[1] The costs presented are for S/S treatment only. Items that are excluded from this cost estimate but included in the SITE demonstration cost estimate (Table 4-5) are: auxiliary equipment (earthmoving equipment, wastewater tank, and wastewater truck); auxiliary labor (does not include off-site support, security, per diem, home leave, and training; site preparation; analyses; and demobilization. In addition, costs associated with residuals treatment and disposal are excluded from both this cost estimate and the SITE cost estimate.

[2] Equipment cost over life of project, based on straight-line depreciation.

Table 4-5. Total Project Costs for 18,800 Tons of Soil [EPA, 1992c][1]

	Option 1	Option 2	Option 3	Option 4
Total Project Cost[1]	$4,913,308	$3,668,884	$3,262,123	$2,843,534
Unit Project Cost (per ton)[1]	$261	$195	$174	$151

[1] The costs presented are for a complete S/S project and exclude only costs associated with residuals treatment and disposal. This cost estimate includes costs for site preparation, equipment (process equipment and auxiliary equipment), startup, reagents, labor (associated with treatment and auxiliary activities), utilities, maintenance, analyses, and demobilization.

Table 4-6. Approximate Costs for Full-Scale Remediation Using S/S [Bates and Lau,1995][1]

Activity	Project Cost ($)	Unit Cost ($ per ton of raw soil treated)[3]
Mobilization/Demobilization	240,000	15
Excavation of Contaminated Soil	680,000	41
Soil Treatment by S/S	4,200,000	256
Cap	700,000	43
Sampling and Analysis	400,000	24
Excavation and Handling of Clean Soil	60,000	4

Table 4-6. Approximate Costs for Full-Scale Remediation Using S/S (Continued)

Activity	Project Cost ($)	Unit Cost ($ per ton of raw soil treated)[3]
Construction Oversight[2]	660,000	40
Other	960,000	59
Total	7,900,000	482

1 The costs presented exclude remedial design costs and other costs incurred before remediation began.
2 Construction oversight was provided by the U.S. Army Corps of Engineers, Sacramento District.
3 Unit costs were calculated by dividing project costs by the tons of soil treated during the project. The 13,088 yd^3 of raw soil treated during the project are estimated, based on information provided in the SITE cost estimate for the Selma Pressure Treating Site, to be equivalent to 16,403 tons of raw soil.

13,088 yd^3 of raw soil was completed during 1993. A summary of actual remediation costs is presented in Table 4-6. S/S treatment costs were approximately $256 per ton of raw soil treated; total project costs were approximately $482 per ton of raw soil treated.

4.2.5 Treatability Study - ACW Site

Background/Waste Description: S/S remedy design treatability studies for the ACW site were performed in late 1996 and early 1997 [SAIC, 1997c]. Soil samples used in this treatability study were collected at the ACW site in Jackson, TN on September 25, 1996. The soil was collected from five pits, screened to remove particles greater than ½ inch in diameter, and homogenized. The soil was placed in five 5-gallon buckets, sampled, and shipped to STC Remediation, Inc. (STC) for S/S treatability studies.

Grain size analysis indicated that the sample was a dark brown silty sand with 2 percent gravel and 64 percent sand. The grain size analysis was performed after screening, which removed a small quantity of rocks and other debris greater than ½ inch in diameter.

Results of chemical analyses of SPLP leachates from the untreated soil are summarized in the performance section to facilitate comparison with the treated soil.

Summary of the Study: The ACW remedy design treatability study was performed in three tiers; this document presents results from Tier 1 only (less expensive formulations were tested in Tiers 2 and 3; however they were less effective). In Tier 1, STC treated the ACW soil with six S/S formulations. This document presents results for two of those six formulations, Mix 2 and Mix 6 (see explanation to follow). Table 4-7 presents the formulations used in Mixes 2 and 6.

Performance: Each of the six treated materials was subjected to geophysical tests for falling head permeability and unconfined compressive

Table 4-7. Selected Formulations Used in ACW Treatability Study [SAIC, 1997c]

	Pounds of Reagent per Ton of Soil Treated				
Formulation	Portland Type 1 Cement	Class F Fly Ash	Activated Carbon	STC P-1[1]	STC P-4[1]
Mix 2	400	200	40	0	0
Mix 6	0	0	0	400	120

1 STC P-1 and STC P-4 are proprietary reagents.

strength (UCS). Each of the six treated materials was also leached using Method 1312; the resulting SPLP extracts were analyzed for metals, SVOCs, and pH. The SPLP leachates from five of the six treated materials met the ACW treatment goals for PCP. Since these results were satisfactory, PCDD/PCDF analyses were subsequently performed for two Tier 1 samples: the least expensive formulation that met all treatment goals (Mix 2), and the most effective (and most expensive) formulation (Mix 6). Table 4-8 summarizes the analytical results for Mixes 2 and 6.

Cost: The reagent cost for Mix 2 is estimated to be $39 per ton of soil treated; the reagent cost for Mix 6 is estimated to be $62 per ton of soil treated. These cost estimates are for reagents only and are based on unit costs provided by STC [SAIC, 1997c].

OHM Corporation prepared a preliminary design and cost estimate for the S/S treatment of soil at the ACW site. Section B.2.1 in Appendix B provides additional information on the design and estimate. The estimate included a cost of $13 per ton for equipment leasing, $0.10 per ton for utilities, $93 per ton for consumables (which included S/S reagents, capping materials, and analytical costs), and $16 per ton for labor [OHM, 1997]. The estimated projects costs were $122 per ton of soil treated.

4.3 Thermal Desorption (TD)

4.3.1 Technology Description

TD is an *ex situ* separation process that uses direct or indirect heat exchange to vaporize VOCs and SVOCs from soil, sediment, sludge, or other solid and semisolid matrices. The technology heats contaminated media to temperatures between 300° and 1,000°F. The vaporized organic contaminants then are swept into an inert carrier gas, which is treated, typically by being burned in an afterburner, condensed in a single- or multi-stage condenser, or captured by carbon adsorption beds.

4.3.2 Advantages

If a site is contaminated with organics, TD offers the advantage of separating the organic contaminant from the medium to an offgas stream where the vapors are treated directly or condensed before treatment. TD has the added advantage of separating VOCs that may be associated with the wood processing wastes (i.e., solvents used in cleaning operations at the site). The total volume of material requiring subsequent treatment is typically small in comparison to the volume of contaminated medium at any given site. TD may be viewed as a step in the sequence of remediating a site in which isolating and concentrating the contaminants are useful. Groups of organic contaminants can be selectively removed from the medium by careful control of the treatment temperature in the desorption unit [EPA, 1992e].

4.3.3 Limitations

All TD systems require excavation and transport of the contaminated medium, use of materials handling/segregation equipment, and feeding of the material into the desorption unit. The contaminated medium must contain at least 20 percent solids to facilitate placement of the waste material into the desorption equipment; some systems specify a minimum of 30 percent solids. Materials handling of soils that are tightly aggregated or largely clay can result in poor processing performance due to caking. A very high moisture content may result in low contaminant volatilization, a need to recycle the soil through the desorber, or a need to dewater the material prior to treatment to reduce the energy required to volatilize the water [EPA, 1994b]. Inorganic constituents or metals that are not particularly volatile will not be effectively removed by TD. Since TD does not destroy contaminants, subsequent treatment of residuals will be required.

TD units have the potential to produce PCDDs/PCDFs when treating chlorinated compounds such as PCP. Careful monitoring of operating conditions and feed rates must be performed. Treated material may need to be tested for PCDDs/PCDFs, even if those compounds were not detected in the feed.

4.3.4 Technology Costs

Operating costs for TD treatment vary according to the characteristics of the contaminated soil; the required cleanup level; and the type, size, and operating conditions of the system.

Table 4-8. Selected Analytical Results for ACW Treatability Study, SPLP Leachates [SAIC, 1997c]

Parameter	Concentration in SPLP Leachate			Percent Change[6]			
				As Analyzed		Adjusted for Dilution	
	Untreated Soil[5]	After Mix 2 Treatment	After Mix 6 Treatment	Mix 2	Mix 6	Mix 2	Mix 6
PAHs, ppb							
Acenaphthene	100	ND (2.0)	ND (2.0)	>-98	>-98	>-97	>-97
Acenaphthylene	5.1	ND (2.0)	ND (2.0)	>-60	>-60	>-47	>-50
Anthracene	22	ND (1.0)	ND (1.0)	>-95	>-95	>-93	>-94
Benz(a)anthracene[1]	1.3	ND (1.0)	ND (1.0)	>-21	>-21	>-0	>-3.1
Benzo(b)fluoranthene[1]	ND (5.0)	ND (5.0)	ND (5.0)	NC	NC	NC	NC
Benzo(k)fluoranthene[1]	ND (5.0)	ND (5.0)	ND (5.0)	NC	NC	NC	NC
Benzo(ghi)perylene[1]	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Benzo(a)pyrene[1]	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Chrysene[1]	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Dibenz(a,h)anthracene[1]	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Fluoranthene	11	1.2	ND (1.0)	-90	>-91	-86	>-89
Fluorene	55	ND (1.0)	ND (1.0)	>-98	>-98	>-97	>-97
Indeno(1,2,3-cd)pyrene[1]	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
2-Methylnaphthalene	170	ND (2.0)	ND (2.0)	>-98	>-98	>-98	>-98
Naphthalene	240	ND (1.0)	ND (1.0)	>-99	>-99	>-99	>-99
Phenanthrene	65	ND (1.0)	ND (1.0)	>-98	>-98	>-97	>-98
Pyrene	6.4	ND (1.0)	ND (1.0)	>-84	>-84	>-79	>-80
Total PAHs[2]	690	28	ND (28)	-96	>-96	-95	>-95
B(a)P potency estimate	2.8	ND (2.8)	ND (2.8)	NC	NC	NC	NC
Other SVOCs, ppb							
Carbazole	160	ND (10)	ND (10)	>-93	>-93	>-91	>-92
Dibenzofuran	52	ND (2.0)	ND (2.0)	>-96	>-96	>-94	>-95
Pentachlorophenol	8,200	120	12	-99	>-99	-98	>-99
Phenol[3]	ND (10)	71	37	>+610	>+270	>+840	>+370
TCDD-TEQ, ppq[4]	320	12	14	-96	-95	-95	-94
Metals, ppb							
Arsenic	ND (20)	ND (20)	ND (20)	NC	NC	NC	NC
Chromium[3]	ND (20)	60	70	>+200	>+250	>+300	>+340
Copper	22	ND (20)	ND (20)	>-7.7	>-7.7	NC	NC
Zinc	420	ND (50)	ND (50)	>-88	>-88	>-84	>-85
pH	7.0	11.8	11.8	NA	NA	NA	NA

1 Used in calculation of B(a)P potency estimate [EPA, 1993a].
2 For nondetected results, the detection limit has been used for calculating total PAHs.
3 Percent change is calculated for these compounds, since leachability could be increased by S/S treatment.
4 TCDD-TEQ by I-TEF/89 [EPA, 1989a] reported in ppq.
5 Three samples of the untreated soil were collected, individually leached, and analyzed. Results were then averaged
6 Percent change is stated as a decrease (-) or increase (+).

NA = Not applicable
NC = Not calculated
ND = Not detected at the reporting limit stated in parentheses.
Shaded rows contain only ND and NC designations.

Examples of operating costs for treatment include the following:

- Capital depreciation
- Labor
- Travel and expenses
- Health and safety
- Maintenance
- Overhead
- Insurance
- Fuel and utilities
- Treatment and disposal of residual waste
- Analytical services
- Other supplies such as chemicals, carbon, filters, etc.

Costs for onsite TD treatment vary widely depending on conditions specific to the site. Unit costs at some recent cleanups have ranged from $270 to $340 per yd^3 and from $100 to $400 per ton [EPA, 1994b]. A key cost variable for using offsite, stationary TD units is the cost of transporting the soil from the excavation site to the unit. Costs for transportation must be included in any comparison between onsite and offsite treatment systems.

For the specific technology that is described in the following subsection, the vendor estimated a unit cost for soils treatment and disposal of condensed liquids and filtrates of approximately $600 per ton. The cost assumed treatment of about 27,000 tons of soil, and included mobilization, labor, health and safety, sampling and analysis, and ambient air monitoring.

4.3.5 Treatability Study - Pacific Place Site

Site/Waste Description: The Pacific Place site is a 185-acre area of industrial land located in Vancouver, BC. A wide variety of industrial activities operated on the site over its history. These included two manufactured gas plants; sawmills; boat building, metal plating, wood preservation, fuel storage, and carpet cleaning facilities; and railway yards. In particular, coal tars and metal oxide wastes from the coal gasification plants and wood preservatives were mixed with fill material. PAHs, cyanide, lead, sulfur, TPHs (extractable), and chlorophenols were among the contaminants detected at elevated concentrations on the site [Whiting, et al., 1992].

Four different sample types, each from a different site locality, were provided for testing in two separate thermal extraction systems. These sample types were numbered Sample 1 through Sample 4. In general, all the soil samples were poorly sorted (well graded) and were characterized as consisting primarily of fine to coarse sand with approximately 17 to 34 percent silt and clay. Samples also contained debris such as brick fragments, metal fragments, and wood chunks. Sample moisture content ranged from 10 to 45 percent and averaged 25 percent. The pH of each sample was near neutral (6.9 to 7.2) except for Sample 1, which had a pH ranging from 4.2 to 5.0.

Summary of Study: Bench-scale treatability testing was conducted using laboratory-scale units belonging to two different vendors. For the purposes of this document, one of the two tests will be discussed. For this selected test, which provided data for the more extensive list of compounds, Samples 1, 2, and 3 were tested at an operating temperature of 482°C and a residence time of 85 minutes. Prior to processing, the samples were screened through a ¼-inch sieve and then homogenized. The feed was sampled once each hour. The feed samples were composited for each temperature condition and later submitted for laboratory analyses. An average of about 7 kg of each soil sample was fed to the system. Feed rates ranged from 8 to 13 g per minute, depending on the sample type.

Treated solids and aqueous condensates were collected and weighed every 15 minutes. Solids were composited for each steady state condition and then were subsampled for analytical testing. Aqueous products were filtered through 25-micron filter paper. Solid and aqueous products were then subjected to chemical and physical analyses.

Since this was a small-scale study, no organic liquid phase products were generated in these studies, and no samples of air emissions were collected and analyzed.

Performance: The selected analytical results for treatment of Samples 1, 2, and 3 are shown in Tables 4-9 through 4-11, respectively. The results indicate that the process effectively removed organic compounds from contaminated soils and met the treatment goals for the treatability study.

In Sample 1, the highly contaminated sample, all PAHs except benz(a)anthracene were reduced by greater than 99 percent. The concentrations of PAHs (as well as other organic constituents) in the treated soil were well below the established treatment goals. Similar PAH and other organic compound removal efficiencies were achieved in Samples 2 and 3.

PCP was reduced by an average of approximately 97 percent and 2,3,4,6-tetrachlorophenol by an average of approximately 76 percent for Sample 1. Due to elevated detection limits, concentrations of chlorophenols in some of the treated soils could have been slightly above the treatment goals. Concentrations of PCDDs/PCDFs (as TCDD-TEQ) decreased by 57 percent in Sample 1; TCDD-TEQ concentrations were not reported for Samples 2 and 3.

Total metals concentrations in the samples did not change significantly as a result of the treatment process, nor did the solubility of the metals appear to be affected by treatment, based on extraction testing. Total cyanide in the treated soils from Sample 1 was reduced from 2,500 mg/kg to 6 mg/kg in the lower temperature run and to less than 0.5 mg/kg in the 482°C run.

Organics concentrations in the aqueous liquids produced during the treatability study were generally very low or insignificant except for oil and grease and total phenolics. Oil and grease concentrations ranged from less than 5 to 24 ppm. Total phenolics were detected at high levels (5.5 ppm to 58 ppm) in aqueous liquids produced during the treatment of Sample 1 and Sample 3 soils. These concentrations exceed the provincial effluent standard for phenols.

There was insufficient volume to allow for the analysis of liquid-phase organics. Analysis of emissions during the treatability study was not performed due to the small scale of the equipment.

Examination of the analytical testing performed on treatment residuals from this study shows that a significant portion of the PAHs from all sample types and chlorophenols in Sample Type 3 were effectively collected by the offgas treatment system.

Cost: Cost information was not provided for this specific study.

4.4 Incineration

4.4.1 Technology Description

Incineration is an *ex situ* process that treats organic contaminants in solids and liquids by subjecting them to high temperatures, typically well in excess of 1,000°F, in the presence of oxygen, thus, causing the volatilization, combustion, and destruction of these compounds. Hazardous waste incinerator systems can be either stationary or mobile/transportable, and are comprised of subsystems for waste preparation and feeding, combustion of feed, air pollution control (APC), and residue/ash handling [Oppelt, 1987]. The three major wastestreams generated by incineration are solids from the incinerator and the associated APC system, water from the APC system, and emissions from the incinerator [Freeman, et al., 1995].

Three common types of incineration systems for treating contaminated soils are rotary kiln, circulating fluidized bed, and infrared systems. They are best distinguished from each other by the design of their combustion chamber. For rotary kiln designs, waste is gravity fed through a slightly inclined and rotating cylindrical combustion chamber, which is referred to as the "primary" chamber. A "secondary" combustion chamber (afterburner) further destroys unburned organics in the flue gases. Circulating fluidized bed incinerators use a high air velocity to circulate and suspend the fuel/waste particles in a combustor loop and do not require an afterburner. For infrared processing systems, waste is conveyed into the combustion chamber and exposed to radiant heat generated by either electrical resistance elements or indirect fuel-fired radiant U-tubes.

Table 4-9. Selected Results - Pacific Place TD Treatment (Sample 1) [Whiting, et al., 1992]

Parameter (Treatment Goal)	Untreated Concentration	Treated Concentration	Percent Change[5]
PAHs, ppb			
Acenaphthene (10,000)	ND (5)	ND (5)	NC
Acenaphthylene (10,000)	45,000	8	-99.9
Anthracene (10,000)	100,000	57	-99.9
Benz(a)anthracene[1] (1,000)	ND (14)	180	+120
Benzo(b)fluoranthene[1] (1,000)	60,000	<1	~-100
Benzo(k)fluoranthene[1] (1,000)	27,000	50	-99.8
Benzo(ghi)perylene (1,000)	190,000	ND (4.7)	~-100
Benzo(a)pyrene[1] (1,000)	400,000	ND (10)	~-100
Chrysene[1]	65,000	200	-99.7
Dibenz(a,h)anthracene[1]	NR	NR	NC
Fluoranthene (10,000)	530,000	680	-99.9
Fluorene (10,000)	110,000	ND (0.6)	~-100
Indeno(1,2,3-cd)pyrene[1] (1,000)	61,000	33	-99.9
2-Methylnaphthalene	NR	NR	NC
Naphthalene (5,000)	1,300,000	410	-99.9
Phenanthrene (5,000)	320,000	290	-99.9
Pyrene (10,000)	220,000	350	-99.8
Total PAHs[2]	3,400,000	2,300	-99.9
B(a)P Potency Estimate[3]	410,000	ND (32)	~-100
Other SVOCs, ppb			
Pentachlorophenol (500)	ND (1,800)	ND (1,800)	NC
2,4,5-Trichlorophenol (500)	ND (660)	ND (660)	NC
2,4,6-Trichlorophenol (500)	ND (420)	ND (420)	NC
2,3,4,6-Tetrachlorophenol (500)	ND (660)	ND (660)	NC
TCDD-TEQ, ppq[4]	3,700	1,600	-57
pH	4.2 - 5.0	NR	NC

1 Used in calculation of B(a)P potency estimate [EPA, 1993a].
2 Total PAHs does not include dibenz(a,h)anthracene and 2-methylnaphthalene. For nondetected results, the detection limit has been used for calculating total PAHs.
3 B(a)P potency estimates for this study do not include dibenz(a,h)anthracene, for which no results were reported.
4 TCDD-TEQ by I-TEF/89 [EPA, 1989a]. Results are reported in ppq.
5 Percent change is stated as a decrease (-) or increase (+).

NR = Not reported
NC = Not calculated
ND = Not detected at the reporting limit stated in parentheses.
Shaded rows contain only ND, NR, and NC designations.

Table 4-10. Selected Results - Pacific Place TD Treatment (Sample 2) [Whiting, et al., 1992]

Parameter (Treatment Goal)	Untreated Concentration	Treated Concentration	Percent Change[4]
PAHs, ppb			
Acenaphthene (10,000)	ND (5)	ND (5)	NC
Acenaphthylene (10,000)	ND (5)	ND (8)	NC
Anthracene (10,000)	8,800	ND (0.7)	~-100
Benz(a)anthracene[1] (1,000)	3,200	ND (14)	~-100
Benzo(b)fluoranthene[1] (1,000)	4,300	ND (1)	~-100
Benzo(k)fluoranthene[1] (1,000)	5,100	ND (0.4)	~-100
Benzo(ghi)perylene (1,000)	ND (4.7)	ND (4.7)	NC
Benzo(a)pyrene[1] (1,000)	9,500	ND (10)	~-100
Chrysene[1]	3,500	ND (1)	~-100
Dibenz(a,h)anthracene[1]	NR	NR	NC
Fluoranthene (10,000)	6,300	ND (0.7)	~-100
Fluorene (10,000)	1,800	ND (0.6)	~-100
Indeno(1,2,3-cd)pyrene[1] (1,000)	3,700	ND (1)	~-100
2-Methylnaphthalene	NR	NR	NC
Naphthalene (5,000)	ND (5)	ND (5)	NC
Phenanthrene (5,000)	3,500	ND (5)	~-100
Pyrene (10,000)	4,400	ND (2.5)	~-100
Total PAHs[2]	54,000	ND (60)	>-99.9
B(a)P Potency Estimate[3]	11,000	ND (12)	~-100
Other SVOCs, ppb			
Pentachlorophenol (500)	9,400	ND (300)	>-97
2,4,5-Trichlorophenol (500)	1,600	ND (110)	>-93
2,4,6-Trichlorophenol (500)	ND (70)	ND (70)	NC
2,3,4,6-Tetrachlorophenol (500)	2,400	580	-76
pH	6.9 - 7.2	NR	NC

1 Used in calculation of B(a)P potency estimate [EPA, 1993a]
2 Total PAHs does not include dibenz(a,h)anthracene and 2-methylnaphthalene. For nondetected results, the detection limit has been used for calculating total PAHs.
3 B(a)P potency estimates for this study do not include dibenz(a,h)anthracene, for which no results were reported.
4 Percent change is stated as a decrease (-) or increase (+).

NR = Not reported
NC = Not calculated
ND = Not detected at the reporting limit stated in parentheses
Shaded rows contain only ND, NR, and NC designations.

Table 4-11. Selected Results - Pacific Place TD Treatment (Sample 3) [Whiting, et al., 1992]

Parameter (Treatment Goal)	Untreated Concentration	Treated Concentration	Percent Change[4]
PAHs, ppb			
Acenaphthene (10,000)	ND (8)	ND (5)	NC
Acenaphthylene (10,000)	ND (8)	ND (8)	NC
Anthracene (10,000)	5,300	ND (0.7)	~-100
Benz(a)anthracene[1] (1,000)	12,000	NR	NC
Benzo(b)fluoranthene[1] (1,000)	9,100	ND (1)	~-100
Benzo(k)fluoranthene[1] (1,000)	6,800	ND (4)	~-100
Benzo(ghi)perylene (1,000)	8,900	ND (4.7)	~100
Benzo(a)pyrene[1] (1,000)	18,000	ND (10)	~-100
Chrysene[1]	11,000	ND (1)	~-100
Dibenz(a,h)anthracene[1]	NR	NR	NC
Fluoranthene (10,000)	43,000	ND (0.7)	~-100
Fluorene (10,000)	4,300	ND (0.6)	~-100
Indeno(1,2,3cd)pyrene[1] (1,000)	6,800	ND (1)	~-100
2-Methylnaphthalene	NR	NR	NC
Naphthalene (5,000)	ND (5)	ND (5)	NC
Phenanthrene (5,000)	27,000	180	99
Pyrene (10,000)	36,000	ND (2.5)	~-100
Total PAHs[2]	180,000	220	99.9
B(a)P Potency Estimate[3]	21,000	ND (10)	~-100
Other SVOCs, ppb			
Pentachlorophenol (500)	ND (35)	ND (300)	NC
2,4,5-Trichlorophenol (500)	ND (110)	ND (110)	NC
2,4,6T-Trichlorophenol (500)	ND (70)	ND (70)	NC
2,3,4,6-Tetrachlorophenol (500)	ND (300)	ND (110)	NC
pH	6.9 - 7.2	NR	NC

1 Used in calculation of B(a)P potency estimate [EPA, 1993a].
2 Total PAHs does not include benz(a)anthracene, dibenz(a,h)anthracene, and 2-methylnaphthalene. For nondetected results, the detection limit has been used for calculating total PAHs.
3 B(a)P potency estimates for this study do not include dibenz(a,h)anthracene, for which no results were reported.
4 Percent change is stated as a decrease (-) or increase (+).
NR = Not reported
NC = Not calculated
ND = Not detected at the reporting limit stated in parentheses.
Shaded rows contain only ND, NR, and NC designations.

A secondary combustion chamber is used to treat exhaust gases [Freeman, et al., 1995].

4.4.2 Advantages

Of all the "terminal" treatment technologies, properly designed incineration systems are capable of the highest overall degree of destruction and control for the broadest range of hazardous wastestreams [Oppelt, 1987]. The technology has effectively treated soils, sludges, sediments, and liquids containing all the organic contaminants found on wood preserving sites, such as PCDDs/PCDFs, PCP, PAHs, and other halogenated and nonhalogenated VOCs and SVOCs [EPA, 1992a].

The performance of an incinerator is measured by the Destruction Removal Efficiency (DRE). DRE requirements for properly operated incinerators exceed 99.99 percent. Incineration has treated wood preserving wastes to the most stringent cleanup levels. A substantial body of trial burn results and other QA data verify that incineration can remove and destroy organic contaminants from a variety of waste matrices to the parts per billion or even the parts per trillion level [EPA, 1992a].

4.4.3 Limitations

The primary disadvantage of incineration is that the inorganic components of hazardous wastes are not destroyed by the process. These residual materials exit the incineration system as bottom ash from the combustion chamber, as contaminants in scrubber wastes and other APC residues, and in small amounts in air emissions from the stack [Oppelt, 1987].

Incineration performance can be limited by the physical properties and chemical content of the waste feed, if not accounted for in the system design. Oversized particles (e.g., stones, boulders, debris) can hinder processing and can cause high particle loading from fines carried through the process. Feeds with high moisture content increase feed handling and energy requirements. Volatile metals, such as arsenic, cadmium, and zinc, vaporize and, thus, become difficult to remove from emissions. Alkali metals such as sodium and potassium can cause severe refractory attack and form a sticky, low-melting-point submicron particulate, which causes APC problems. Halogenated organic compounds and/or high levels of organic phosphorous can lead to formation of acid gases [EPA, 1992a].

More than any other technology, incineration is subject to a series of technology-specific regulations. Concerns with the potential formation of PCDDs/PCDFs during the incineration of chlorinated compounds and other emissions have prompted detailed Federal oversight of trial burns and full-scale operation. In addition, State requirements must be met if they are more stringent than the Federal requirements [Freeman, et al., 1995].

4.4.4 Technology Costs

The cost of incineration includes the relatively fixed costs of site preparation, permitting, and mobilization/demobilization; and variable operational costs, such as labor, utilities, and fuel (operational costs vary according to the type of waste treated and the size of the site) [EPA, 1992a].

The specific factors relating to both the site media and appropriate incinerator design used include [EPA, 1991b]:

- System capacity
- Types of feedstocks being fed
- Regime (i.e., slagging vs. ashing)
- Length-to-diameter (L/D) ratio for rotary kilns
- Type of solids discharge system
- Type and capacity of afterburner
- Type of auxiliary fuel used
- Regulatory climate

The moisture content and the heating value of the contaminated material are two of the more important parameters that affect the economics of the incineration process. The heating value (BTU content) of the feed material affects feed capacity and fuel usage of the incinerator. In general, as the heating value of the feed increases, the feed capacity and fuel usage of the incineration will decrease. Solid materials with high Btu content may also cause transient behaviors that further limit feed capacity. When PCDDs/PCDFs are present, higher temperatures and longer residence times may be required to destroy those compounds to levels

necessary to meet regulatory criteria. Moisture/ water content of soils, sediments, or sludges can create the need to co-incinerate these materials with higher BTU streams, or to use auxiliary fuels [EPA, 1990b].

A detailed cost estimate for the Shirco Infrared Incineration System was developed for two SITE demonstrations conducted at two Superfund sites. Although these were not wood preserving sites, performance data from treatment of wood preserving waste by the same Shirco incineration system are presented in Subsection 4.4.5. The cost estimate (1989 dollars) was based on an economic model provided by ECOVA Corporation, in which a transportable Shirco system having a 100 ton per day (tpd) capacity would treat 36,500 tons of material at onstream factors of 85 percent, 70 percent, and 50 percent [EPA, 1989b]. Table 4-12 presents a breakdown of the model's costs.

4.4.5 Treatability Study - International Paper Company

Background/Waste Description: In 1985, pilot-scale testing of ECOVA's Shirco Infrared incineration unit was conducted on creosote pit waste at an International Paper Company wood treating facility in Joplin, MO. The wood preserving process conducted at the plant used nine pre-RCRA settling ponds for water treatment, which were designated as hazardous waste sites due to the presence of creosote and PCP [EPA, 1989b].

Summary of Study: The purpose of the onsite study was to acquire data that would enable International Paper to clean up the site in the most cost-effective and permanent manner. The study consisted of seven test runs conducted over a 4-day period. The primary objectives of the test program were to confirm the ability of the Shirco technology to decontaminate creosote and PCP-laden soil and to incinerate the PCP at a verified DRE of 99.9999 percent, and other principal organic hazardous constituents (POHCs) at a DRE of 99.99 percent or greater. The primary combustion chamber of the incinerator was set at a nominal 1,600°F for this study because previous testing performed on similar wastes at this temperature indicated successful treatment of creosote and PCP [EPA, 1989b].

The waste materials processed during the test program were pre-specified combinations of waste in ponds that were numbered 1 through 7, and dewatered sludge from the facility's active wastewater treatment process. Based on the results of preliminary chemical analysis, test blends were defined from a combination of the individual pond wastes. (The goal of the Inter-

Table 4-12. Estimated Treatment Costs for the Shirco Commercial Incineration Unit [EPA 1989b]

	Unit Capacity @ 100 tpd Onstream Factor		
	85%	70%	50%
Startup and Fixed Costs	34.89	39.31	49.33
Labor Costs	37.39	45.40	63.56
Supplies and Consumables Costs	10.00	10.00	10.00
Utilities Costs	36.58	36.58	36.58
Facility Modification, Repair, and Replacement Costs	20.62	25.04	35.06
Total Cost, $/ton[1,2]	139.48	156.33	194.53

[1] These costs do not include site preparation, permitting and regulatory, waste excavation, feed preparation, analytical, demobilization, vendor profit, and ash residual disposal.

[2] All costs are in 1989 dollars and are based on a 100 tpd unit treating 36,500 tons of waste.

national Paper Co. was to prepare a blend, or a minimal number of blends, which would maintain a steady and cost-effective thermal process during the site cleanup. Thus, three blends were chosen that would be expected to demonstrate the realistic range of operating conditions.)

The test blend most thoroughly evaluated (designated as Mix 1 in the pilot study report) consisted of one part Pond 6 waste, plus one part Pond 2 waste, plus ⅔ part dewatered sludge. Four of the seven test runs conducted for the entire study consisted of treating Mix 1.

Performance: Table 4-13 presents the untreated mix waste concentration and flue gas DREs for the four test runs that involved incineration of Mix 1 waste. The DREs for each of the four test rounds exceeded RCRA performance standards of 99.99 percent for PCP and 99.99 percent for all other PAHs except for naphthalene. The DRE for naphthalene fell short of the 99.99 percent standard during Test 1.

Table 4-14 presents the particulate emission, average carbon monoxide (CO) emission, and ash organic concentration for the same four tests. With the exception of Test 3, particulate emissions ranged from 0.016 to 0.07 grains per dry standard cubic feet (gr/dscf), corrected to 7 percent oxygen, as compared to the RCRA standard of 0.08 gr/dscf. Particulate emissions reported for Test 3 were 0.147 gr/dscf. The excessive emissions were reported to be a result of soot formation caused by an improper control of oxygen in the primary combustion chamber. (The stack sampling contractor's oxygen monitor was not functioning throughout the entire test program, and Shirco operators were forced to set incinerator air flow conditions using best professional judgement [EPA, 1989b].)

The residual organic concentration of each constituent identified in the waste feed was nondetectable in the furnace ash (detection limit ranging from 20 to 40 ppb) for each run, with the exception of the biphenyl (20 ppb) and naphthalene (53 ppb) compounds in Test 1.

Cost: Cost information was not provided for this specific study; however, cost information for an ECOVA Shirco Commercial Unit, based on an economic model, was provided in Table 4-12.

4.4.6 Treatability Study - Power Timber Company

Background/Waste Description: This study was conducted to test rotary kiln incineration in support of the determination of the Best Demonstrated Available Technology (BDAT) for the waste code K001. Waste code K001 pertains to the wood preserving industry and is listed at 40 CFR 261.32 as "bottom sediment and sludge from the treatment of wastewaters from wood preserving processes that use creosote and/or PCP." Two waste types were obtained for the study. One type consisted of K001 wastes from a wood preserving operation using PCP-based preservative chemicals (K001-PCP). The source of this waste was the American Wood Division of Power Timber Company in Richton, MS. The other waste type was K001 waste containing creosote (K001-Creosote). The source of this waste was the Pearl River Wood Preserving Corporation in Picayune, MS [Hall, 1989].

Summary of Study: Two test facilities were used. One of the facilities was EPA's Combustion Research Facility (CRF) in Jefferson, AK, where the K001-PCP waste was incinerated. The other facility was the John Zink Company Incineration Test Facility in Tulsa, OK where the K001-Creosote waste was incinerated. Nine data sets (matched pairs of untreated and treated data points) were obtained for K001 wastes using rotary kiln incineration. Six of the data sets were from the testing of the K001-creosote waste, and three data sets were from the testing of the K001-PCP waste. For the purpose of this document, the data for the three K001-PCP sample sets were selected to best represent the wood preserving waste. When incinerating the sample sets of the K001-PCP waste, the kiln rotation speed was kept constant at 0.2 rpm. The kiln temperature ranged from 1,650°F at the beginning of the test to 2,046°F at the test's conclusion. The afterburner operated initially at 1,840°F and reached a final temperature of

Table 4-13. Selected Results - International Paper Company Incineration Treatment [EPA, 1989b]

Parameter	Test 1		Test 2		Test 3		Test 4	
	Untreated Conc. (mg/kg)	Flue Gas DRE (%)	Untreated Conc. (mg/kg)	Flue Gas DRE (%)	Untreated Conc. (mg/kg)	Flue Gas DRE (%)	Untreated Conc. (mg/kg)	Flue Gas DRE (%)
PAHs								
Acenaphthene	2,300	>99.99985	1,700	>99.99994	1,700	>99.99996	4,200	>99.99996
Acenaphthylene	1,800	>99.99980	ND	NR	ND	NR	ND	NR
Anthracene	6,700	>99.99995	4,600	>99.99998	4,600	>99.99998	11,000	>99.99998
Benz(a)anthracene[1]	690[3]	>99.99948	650	>99.99983	470[3]	>99.99986	1,300	>99.99998
Benzo(b)fluoranthene[1]	NR	NR	NR	NR	NR	NR	NR	NR
Benzo(k)fluoranthene[1]	NR	NR	NR	NR	NR	NR	NR	NR
Benzo(ghi)perylene	NR	NR	NR	NR	NR	NR	NR	NR
Benzo(a)pyrene[1]	NR	NR	NR	NR	NR	NR	NR	NR
Chrysene[1]	ND	NR	870	>99.99988	720[3]	>99.99991	2,200	>99.99993
Dibenz(a,h)anthracene[1]	ND	NR	ND	NR	ND	NR	ND	NR
Fluoranthene	5,500	99.99968	4,100	>99.99997	4,000	>99.99998	14,000	99.99997
Fluorene	2,200	>99.99984	2,000	>99.99995	2,400	>99.99997	4,600	>99.99996
Indeno(1,2,3-cd)pyrene[1]	NR	NR	NR	NR	NR	NR	NR	NR
1-Methylnaphthalene	850	99.99686	1,700	99.99905	2,500	99.99822	2,100	99.99905
2-Methylnaphthalene	1,100	99.99435	2,800	99.99807	4,100	99.99682	4,400	99.99918
Naphthalene	129[3]	99.94076	1,500	99.99135	2,600	99.99049	2,500	99.99872
Phenanthrene	8,000	99.99956	7,500	99.99996	8,000	99.99998	22,000	99.99996
Pyrene	5,800	99.99969	4,000	>99.99997	2,200	>99.99997	7,400	>99.99998
Total PAHs[2]	34,000	≥99.99816	30,000	≥99.99997	31,000	>99.99865	74,000	≥99.99970
B(a)P potency estimate	NC	NC	NC	NC	NC	NC	NC	NC
Other SVOCs								
Biphenyl	ND	NR	ND	NR	430	>99.99985	1,300	>99.99846
Carbazole	1,700	>99.99979	1,700	>99.99994	2,700	>99.99998	5,400	>99.99997
Dibenzofuran	1,200	99.99926	1,100	99.99980	760	99.99978	2,800	99.99986
Pentachlorophenol	8,600	>99.99996	6,800	>99.99998	12,000	>99.99999	11,000	>99.99998

1 Used in calculation of B(a)P potency estimate [EPA, 1993a]

2 Total PAHs does not include benzo(b) and (k) fluoranthene, benzo(ghi)perylene, benzo(a)pyrene, indeno(1,2,3-cd)pyrene, and 1-methylnaphthalene.

3 Because detection limits were not provided for nondetected results, a value of zero was assigned. Trace concentrations reported below the average detection limit.

NR = Not reported

NC = B(a)P potency estimate was not calculated because values were not reported for four of the seven compounds used in the calculation of the B(a)P potency estimate.

ND = Not detected

Shaded rows contain only NR and ND designations.

Table 4-14. Selected Process Data - International Paper Company Incineration Treatment [EPA, 1989b]

	TEST NO.			
	1	2	3	4
Sample Vol., dscf	42.94	116.10	122.22	86.48
Stack Flow, dscf/minute	115.38	80.68	106.44	119.26
Waste Feed, pounds/hr	40.0	34.0	69.9	49.2
Particulate Emissions, gr/dscf	0.020	0.016	0.147	0.070
Average CO Emissions, ppm	114	28	35	18
Ash Organic Concentration, ppb	73	ND (20)	ND (30)	ND (30)

ND = Not detected at the reporting limit stated in parenthesis.

2,033°F. Monitoring of stack gas emissions included oxygen (3 to 16 percent), carbon monoxide (<1 percent), and carbon dioxide (4 to >10 percent) [EPA, 1988].

Performance: The results for the three data sets representing the K001-PCP waste are presented in Table 4-15. This table presents the total waste range concentrations for BDAT listed PAHs and PCP detected in the untreated waste, the average residual ash concentrations, the calculated percent change in solids, and the average scrubber water concentrations. The percentage of contaminant removal from the untreated waste to the residual ash exceeded 99.5 percent for all organic compounds and exceeded 99.9 percent for 9 of the 12 organic compounds reportedly tested.

Cost: Cost information was not provided in the references for this study.

4.5 Solvent Extraction

4.5.1 Technology Description

Solvent extraction is a means of separating contaminants from soils, sludges, and sediments, thereby reducing the volume of waste that must be treated. The contaminated solid is brought into contact with a fluid that selectively dissolves the contaminants. After a predetermined extraction time, the solid and the fluid are separated, and the contaminants are concentrated in the extraction fluid. If the contaminated soil does not meet cleanup levels after one extraction, multiple extraction phases can be used to improve removal efficiency. Full-scale solvent extraction systems are typically designed so that the solvent can be recovered and reused.

The ability of solvent extraction to treat a given waste relies primarily on the solvent selected. The contaminants present in the waste must have a greater affinity for the solvent than they do for the waste matrix. It is also helpful if the solvent is easily separated from the solid and from the extracted contaminants. Solvent extraction is typically used to remove organic contaminants, and the extraction fluid is usually an organic solvent, liquefied gas, or supercritical fluid.

4.5.2 Advantages

The primary advantage of solvent extraction is that it can efficiently remove many different organic contaminants from a variety of soils, sediments, and sludges. This is partially due to the flexibility of solvent extraction processes. The solvent can be selected based on the target contaminants, and the number and length of the extraction stages selected based on the remediation criteria.

4.5.3 Limitations

The primary disadvantage of solvent extraction is that it produces a concentrated organic extract that requires further treatment or disposal

Table 4-15. Selected Results - Rotary Kiln Incineration of K001-PCP Wastes [EPA, 1988]

Parameter	Untreated Waste	Ash	% Change[4]	Scrubber Water
PAHs, ppm				
Acenaphthene	13,000 - 18,000	<2.5	>-99.98	<0.010
Acenaphthylene	NR	—	—	—
Anthracene	8,500 - 13,000	<2.5	>-99.98	<0.050
Benz(a)anthracene[1]	<2,500 - 3,400	<2.5	>-99.93	<0.010
Benzo(b and/or k)fluoranthene[1]	940 - 2,300	<2.5	>-99.89	<0.050
Benzo(ghi)perylene	NR	—	—	—
Benzo(a)pyrene[1]	<250 - 940	<2.5	>-99.73	<0.050
Chrysene[1]	<2,500 - 3,600	<2.5	>-99.93	<0.050
Dibenz(a,h)anthracene[1]	NR	—	—	—
Fluoranthene	13,000 - 21,000	<2.5	>-99.99	<0.050
Fluorene	8,200 - 12,000	<2.5	>-99.98	<0.050
Indeno(1,2,3-cd)pyrene[1]	NR	—	—	—
2-Methylnaphthalene	NR	—	—	—
Naphthalene	26,000 - 43,000	<2.5	>-99.99	<0.050
Phenanthrene	28,000 - 42,000	<2.5	>-99.99	<0.050
Pyrene	9,200 - 15,000	<2.5	>-99.98	<0.050
Total PAHs[2]	110,000 - 170,000	<28	—	<0.47
B(a)P Potency Estimate[3]	600 - 1,500	<3.0	—	<0.056
Pentachlorophenol	920 - 3,000	<12.5	>-99.58	<0.020
Metals				
Arsenic	1.1 - 2.9	0.4 - 0.8	-64 to -72	<0.01 - 0.12
Chromium	1.5 - 2.7	1.1 - 8.2	-27 to +2.0	<0.045
Copper	6.7 - 11	2.0 - 6.8	-38 to -70	0.07 - 0.15
Zinc	30 - 64	2.1 - 11	-83 to -93	0.61 - 1.1

1 Used in calculation of B(a)P potency estimate [EPA, 1989a].

2 Total PAHs does not include acenaphthylene, benzo(ghi)perylene, dibenz(g,h)anthracene, indeno(1,2,3-cd)pyrene, and 2-methylnaphthalene. For nondetected results (e.g., less than values), the detection limit has been used for calculating total PAHs.

3 B(a)P estimates for this study do not include dibenz(a,h)anthracene or indeno(1,2,3-cd)pyrene, for which no results were reported. In addition, results for benzo(b and/or k)fluoranthene were reported together. B(a)P potency estimates were, therefore, calculated using the relative potency factor for benzo(b)fluoranthene, which is higher than the factor for benzo(k)fluoranthene. This results in a conservative B(a)P potency estimate.

4 Percent change is stated in a decrease (-) or increase (+).

NR = Not reported

Shaded rows contain only NR designations.

(unless the contaminants can be used or recycled after they have been extracted from the soil). In addition to the organic contaminants, the concentrated extract may also contain organically bound metals (which can co-extract with the organic contaminants) and traces of the extraction solvent.

4.5.4 Technology Costs

In the Vendor Information System for Innovative Treatment Technologies, Version 4.0 (VISITT 4.0) (July 1995) [EPA, 1995c], two vendors provide project-specific cost estimates for solvent extraction treatment of contaminated materials from wood preserving facilities. The National Research Council of Canada provides a unit cost estimate of $227 to $363 per ton of sludge treated, based on a treatability study it performed at a wood preserving facility in Edmonton, Alberta. (During this treatability study, the untreated sludge had a PCP concentration of 1,500 ppm; the treated sludge had a PCP concentration of 10 ppm.) CF Systems estimates a unit cost of $220 per ton, based on its remediation of contaminated materials from the United Creosoting Co. site in Conroe, TX. CF Systems also provides a general solvent extraction price range of $75 to $400 per ton of contaminated material. These cost estimates were provided by the vendors, and it is not known whether all indirect costs associated with treatment were included.

The bid submitted to EPA provided a more detailed cost estimate for the remediation of contaminated soil from the United Creosoting site in Conroe, TX [EPA Region VI, 1997]. The cost for treatment only was estimated to be $97 per ton of soil treated; this cost included plant erection, startup, and operation, but did not include system design, plant fabrication, demobilization and salvage, disposal of organics, financial assurances, or peripheral site work (e.g., site preparation, excavation, backfilling, soil handling, and air monitoring). The total project cost was estimated to be $311 per ton of soil treated; this cost included all of the categories previously listed. These cost estimates were prepared in 1995 and were based on the treatment of 114,750 tons of soil.

Independent, detailed solvent extraction cost estimates were developed for a SITE demonstration conducted using the Resources Conservation Company (RCC) Systems Basic Extractive Sludge Treatment (B.E.S.T.®) solvent extraction system. The sediment treated during the SITE demonstration was not from a wood preserving site, but COCs did include PAHs. All costs for this SITE demonstration are given in August 1992 dollars. The SITE demonstration cost estimate is based on a proposed commercial unit with a projected treatment capacity of 186 tons of contaminated material (soils, sediments, or sludges) per day. Cost estimates were based on continuous operation with online percentages of 60 percent, 70 percent, and 80 percent. Estimated treatment costs are summarized in Table 4-16 [EPA, 1993f].

4.5.5 Treatability Study - Unidentified Wood Preserving Facilities [EPA, 1993f]

Background/Waste Description: In June 1991, solvent extraction treatability studies were performed at a laboratory in Vicksburg, MS. These studies used contaminated soil from two unidentified wood preserving facilities [EPA, 1993f]. Analytical results for the untreated materials are presented in Table 4-17 to facilitate comparison with the treated materials.

Summary of Study: Soils from two wood treating facilities were treated using the RCC pilot-scale B.E.S.T.® unit. The treatability studies were sponsored by EPA. The objective of these tests was to determine the BDAT standard for contaminated soil and debris. This standard was successfully established [EPA, 1993f].

Performance: PAHs were the target contaminants in these treatability tests; only total PAHs were reported. Results were as presented in Table 4-17 [EPA, 1993f].

Cost: Cost information was not provided.

Table 4-16. Estimated Solvent Extraction Treatment Costs [EPA, 1993f]

	Cost, $/ton of material treated		
	Option 1	Option 2	Option 3
Online Percentage	60%	70%	80%
Equipment Cost Incurred During Treatment	10.62	9.11	7.97
Fixed Costs[1]	9.13	7.85	6.90
Solvent Extraction Labor Cost	48.14	41.27	36.11
Cost for Supplies	15.40	14.84	14.46
Cost for Consumables	28.48	28.48	28.48
Facility Modification, Repair, and Replacement Costs	0.35	0.30	0.27
Total Cost[2]	112.12	101.85	94.19

[1] The fixed costs presented are only the fixed costs incurred during treatment (insurance, taxes, etc.). Additional one-time fixed costs will be incurred during system startup. The total one-time startup costs are estimated to be $147,480. The impact of these one-time costs on the unit cost of treatment depends on the total amount of material being treated. If the total amount of material is 18,800 tons, the unit costs attributed to startup will be $7.84 per ton.

[2] These cost estimates do not include costs associated with site preparation, excavation or dredging of contaminated materials, permitting or regulatory compliance, startup, treatment or disposal of residuals or effluents, analyses, or demobilization.

Table 4-17. Selected Results - Unidentified Wood Preserving Sites Solvent Extraction Treatment [EPA, 1993f]

	PAH Concentration, ppb		
Material	Before Treatment	After Treatment	Percent Change[1]
Soil from wood treating facility #1	10,900,000	109,000	-99
Soil from wood treating facility #2	14,000,000	8,200	-99.9

[1] Percent change is stated as a decrease (-) or increase (+).

4.5.6 Treatability Study - United Creosoting Co. [EPA, 1995c]

Background/Site Description: In 1995, a treatability study was conducted using solvent extraction at the United Creosoting Co., Inc. in Conroe, TX. Soils, sludges, and natural sediments were contaminated with creosote and other contaminants from wood preserving operations [EPA, 1995c]. Analytical results for the untreated materials are summarized in Table 4-18 to facilitate comparison with the treated materials.

Summary of Study: The treatability study was conducted in order to determine if solvent extraction could be used successfully as a component in the site remediation process. Results indicated that this technology would be capable of meeting site cleanup goals.

Performance: Application of solvent extraction reduced the concentration of selected PAHs by greater than 95 to greater than 99 percent. PCP concentrations were reduced by greater than 61 percent. Results are presented in Table 4-18. Based upon the treatability study results, a full-

Table 4-18. Selected Results - United Creosoting Solvent Extraction Treatment [EPA, 1995c]

Parameter	Concentration[1] Before Treatment	After Treatment	Percent Change[2]
PAHs, ppb			
Acenaphthene	150,000 to 250,000	<1,000 to 1,750	>-98 to ~-100
Chrysene	75,000 to 120,000	<4,000 to 4,000	-95 to >-96
Fluorene	50,000 to 130,000	<1,000 to 900	-98 to -99
Pentachlorophenol, ppb	33,000 to 330,000	<1,500 to 13,000	-61 to >-99

1 Concentrations provided by vendor.
2 Percent change is stated as a decrease (-) or increase (+).

scale cleanup is being implemented using the CF Systems solvent extraction technology to treat 35,000 tons of contaminated soils, sludges, and natural sediments [EPA, 1995c].

Cost (1995): The estimated treatment cost associated with this project was $220 per ton. For other wastes, treatment prices may range from $75 to $400 per ton. These cost estimates were provided by the vendor and it is not known whether they include all indirect costs associated with treatment. The vendor indicated that the factors that most strongly affect the unit treatment price for this process are the quantity of waste requiring remediation, the characteristics of the soil, the target contaminant concentrations, and the initial contaminant concentrations [EPA, 1995c].

4.6 Base-Catalyzed Decomposition (BCD)

4.6.1 Technology Description

The BCD process is a catalytic hydrogenation process in which atoms of chlorine and other halogens (e.g., fluorine, bromine) are removed from molecules and replaced by hydrogen atoms. A related process is alkaline polyethylene glycol (APEG) treatment, in which potassium polyethylene glycol (KPEG) is a common reagent. An example BCD reaction is represented by the following chemical equation [Tiernan, 1996]:

$$\text{Chlorinated Acceptor} + NaOH + \text{Hydrogenated Donor} \xrightarrow[320°-360°C]{\text{Catalysts}} \text{Donor} + \text{Hydrogenated Acceptor} + NaCl + H_2O$$

Several different combinations of reagents can be used in the BCD process, all of which utilize a basic (caustic) reagent such as sodium hydroxide or sodium bicarbonate, usually in combination with liquid carriers/reagents as well as catalytic materials.

BCD can be used to treat soil directly, or it can be used to treat concentrated organic residuals from soil treatment processes such as solvent extraction or TD. The contaminated soil or waste and the BCD reagents are continuously mixed at an elevated temperature for the required reaction time.

4.6.2 Advantages

The primary advantage of BCD is that it is capable of treating chlorinated aromatic contaminant, including PCDDs/PCDFs, by effectively dechlorinating them, even in very concentrated wastes.

4.6.3 Limitations

When BCD is applied directly to soil, it may be necessary to remove residual reagent and treatment by-products from the treated soil before final disposal. Also, the pH of the soil may be raised during treatment and may need to be lowered prior to final disposal. During treatment of oily wastes, precautions may need to be taken to avoid releasing contaminants volatilized by the elevated temperatures required for treatment [EPA, 1990c]. BCD is not applicable to nonhalogenated compounds, such as PAHs.

4.6.4 Technology Costs

According to one reference, chemical dehalogenation using APEG is expected to cost $200 to $500 per ton of waste treated [EPA, 1990c]. A 1989 KPEG reference states that "the cost of KPEG treatment of liquid wastes at field sites evaluated to date is approximately $24 per gallon" [Tiernan, et al., 1989]. Neither of these references presents information regarding the cost categories that are included in these cost estimates.

4.6.5 Treatability Study - Montana Pole Company

Background/Waste Description: In 1989, a BCD treatability study was conducted using soil from the Montana Pole Co., a wood preserving plant in Butte, MT. The soil treated during this treatability study had been contaminated by a petroleum oil waste that was about 3 percent PCP and contained PeCDDs and PeCDFs [Tiernan, et al., 1989]. Analytical results for the untreated soil are presented in Table 4-19 to facilitate comparison with the treated soil.

Summary of Study: Laboratory tests were conducted to determine whether the BCD process would dechlorinate PeCDDs and PeCDFs in the contaminated soil and, if so, to select appropriate operating conditions for treatment. The laboratory procedures were as follows:

1. Contaminated soil (50 g) was placed in a glass reaction vessel with 20 g of solvent and 2 g of solid potassium hydroxide (KOH). These materials were heated to between 80° and 95°C and mixed for 1 hour. The mixture was then allowed to cool, and a small aliquot of the mixture was removed for analysis to determine the effect of treatment with KOH only.

2. Hot KPEG reagent (11 g) was added to the soil slurry. The mixture was heated to maintain a temperature in the range of 70° to 105°C. It was stirred continuously and aliquots of the mixture were removed periodically to determine the effect of KPEG treatment at different reaction times.

3. After being removed from the mixture, each aliquot was mixed with 50 percent sulfuric acid to quench the BCD reaction. The aliquots were then analyzed for PeCDDs and PeCDFs.

Performance: Table 4-19 presents selected results of the study. The percent reduction for compounds that were detected in the untreated soil ranged from greater than 88 to greater than 99 percent [Tiernan, et al., 1989].

Cost (1989): The party performing the treatability studies estimates that full-scale BCD treatment could be performed for approximately $24 per gallon of liquid waste. (Note: Cost categories for cost estimates were not provided in the reviewed references for BCD treatment.) A soil treatment cost estimate was not developed for this study [Tiernan, et al., 1989].

4.7 Bioremediation

4.7.1 Technology Description

Bioremediation usually refers to the use of microorganisms to break down complex organic contaminants into simpler compounds. The technology usually involves enhancing natural biodegradation processes by adding nutrients, oxygen (if the process is aerobic), and in some cases, microorganisms to stimulate the biodegradation of contaminants. (Anaerobic processes utilize microorganisms that can degrade contaminants in the absence of oxygen [EPA, 1993g].) It typically is performed by adding nutrients, adjusting moisture levels, and controlling the concentration of oxygen in the treatment area or vessel. Microorganisms already present in the soil may be biodegraders or additional strains may be introduced.

Table 4-19. Selected Results - Montana Pole BCD Treatment [Tiernan, et al., 1989]

Parameter	Before Treatment	After KOH Treatment	After KOH Treatment Plus KPEG Treatment for the Specified Time						Percent Change[1]
			15 min	30 min	45 min	1 hour	1.5 hour	2 hours	
Dioxins/Furans, ppb									
2,3,7,8-TCDD	ND (5.65)	4.40	ND (0.745)	ND (0.561)	ND (0.787)	ND (0.163)	ND (0.825)	ND (1.02)	NC
2,3,7,8-TCDF	ND (3.83)	10.9	0.673	ND (0.450)	ND (0.509)	ND (0.216)	ND (0.497)	ND (0.610)	NC
Total TCDDs	8.22	60.6	ND (0.745)	ND (0.543)	ND (0.787)	ND (0.163)	ND (0.825)	ND (1.02)	>-88
Total TCDFs	ND (5.17)	29.8	18.0	ND (0.846)	ND (0.509)	ND (0.216)	ND (0.497)	ND (0.610)	NC
Total PeCDDs	ND (6.45)	2,350	27.1	ND (1.34)	ND (1.53)	ND (0.393)	ND (2.51)	ND (1.97)	NC
Total PeCDFs	17.9	8.46	ND (0.729)	ND (0.34)	ND (0.782)	ND (0.266)	ND (0.777)	ND (0.608)	>-97
Total HxCDDs	544	3,632	63.4	9.21	1.07	1.40	10.4	9.06	>-98
Total HxCDFs	686	5.51	ND (0.858)	ND (0.589)	ND (0.977)	ND (0.340)	ND (1.46)	ND (0.907)	>-99
Total HpCDDs	5,020	227	13.6	11.5	8.20	6.86	5.78	5.77	>-99
Total HpCDFs	1,072	ND (2.49)	ND (0.278)	ND (0.377)	ND (0.345)	ND (0.199)	ND (0.374)	ND (0.307)	>-99
Total OCDD	19,266	113	20.5	21.1	14.5	16.8	12.5	12.1	>-99
Total OCDF	1,237	ND (3.78)	ND (1.87)	ND (2.37)	ND (1.41)	ND (1.44)	ND (0.514)	ND (0.639)	>-99

[1] Based upon concentrations before treatment and after 2 hours. Percent change is stated as a decrease (-) or increase (+).
NC = Not calculated
ND = Not detected at the reporting limit stated in parentheses

Although aerobic bioremediation is more widely employed, many highly-chlorinated compounds, including PCP, can be degraded under anaerobic conditions [Litchfield, et al., 1994].

Bioremediation technologies applicable to soils, sediments, and sludges are often divided into four categories: slurry-phase, solid-phase, composting, and *in situ* (bioremediation technologies applicable to contaminated water are discussed in Subsection 5.4). Slurry-phase bioremediation is performed by mixing contaminated soils, sediments, or sludges with water under aerobic conditions [EPA, 1990f]. The mixing provides contact between microorganisms and contaminants, while ensuring aerobic conditions throughout the mixing unit (bioreactor).

Solid-phase bioremediation uses conventional soil management practices, such as tilling, fertilizing, and irrigating, to accelerate microbial degradation of contaminants in above-ground treatment systems. If necessary, highly contaminated soils can be diluted with clean soils in order to reduce contaminants to levels conducive to biodegradation [EPA, 1993g]. Composting uses bulking agents, such as straw or wood chips, to increase the porosity of contaminated soils or sediments. Additional additives employed to increase nutrients and readily degradable organic matter include manure, yard wastes, and food-processing wastes. The resulting mixture often favors the growth of thermophilic microorganisms capable of degrading the organic contaminants of concern [EPA, 1996c].

In situ bioremediation is accomplished by providing electron acceptors (e.g., oxygen and nitrate), nutrients, moisture, or other amendments to soils or sediments without disturbing or displacing the contaminated media. *In situ* bioremediation often is used in conjunction with traditional pump-and-treat and soil flushing groundwater systems, in which the treated water is amended as required to stimulate microbial activity and reinjected into the zone of contamination. Bioventing is a type of *in situ* bioremediation where vacuum extraction wells, air injection wells, or both are installed and operated at relatively low flow rates, providing increased oxygen to microorganisms in the soil [EPA, 1994d].

An emerging and, as yet, unproven application of *in situ* bioremediation is phytoremediation which could potentially remove contaminants (usually metals) from soils through plant uptake mechanisms. Phytoremediation also may degrade organic contaminants in soil through the stimulation of microorganisms in the plant root zone (rhizosphere).

4.7.2 Advantages

Both *in situ* and *ex situ* bioremediation technologies have been shown to be successful in treating both water-soluble and relatively insoluble compounds. Organic compounds that are highly soluble in water may biodegrade rapidly particularly in slurry-phase systems. In general, the rate of biodegradation of a given compound is proportional to the solubility of that compound in water. Slurry-phase bioremediation also has the advantage of allowing more precise control of operating conditions (e.g., temperature, mixing regimes) than solid-phase, or *in situ* applications. Slurry-phase systems utilizing tanks can be operated under anaerobic or aerobic conditions, either sequentially in the same tanks, or in series with multiple units. Slurry-phase bioremediation allows improved contaminant monitoring due to increased homogeneity of the contaminated media.

Solid-phase bioremediation and composting offer several advantages common to slurry-phase, and other *ex situ* treatment technologies: better process control, increased homogeneity, and improved contaminant monitoring. Additionally, treatment units can be built to accommodate large quantities of media. Composting also enriches the treated soil, providing nutrients for revegetation [EPA, 1996c].

In situ bioremediation minimizes the need for excavation and transport of contaminated soils, sediments, or sludges. Materials handling costs, VOC releases, and fugitive dust emissions are consequently reduced [EPA, 1994d]. Energy costs during treatment typically are less than other remedial approaches.

4.7.3 Limitations

Many factors affect the success of bioremediation. The physical form, amount, location, and distribution of contaminants greatly impact the degree to which contaminants will be degraded [EPA, 1993g]. Biodegradable contaminants may undergo mineralization (complete degradation to inorganic constituents); however, incomplete degradation (ending with the formation of organic intermediates) is also possible. Soil characteristics, including particle size distribution, moisture content, and permeability also affect the success of bioremediation. Soil and contaminant characteristics will both affect bioavailability (the extent to which contaminants are available to microorganisms). For example, high molecular weight PAHs and soils consisting primarily of fine particles (i.e., silts and clays) are often associated with low bioavailability. Bioavailability of contaminants in soil can decrease with time, as the contaminants "age" and become more strongly sorbed to soil particles.

Bioremediation is slower than many other technologies and may require frequent monitoring during startup. Monitoring and sampling will also be necessary to determine when cleanup levels have been achieved. Temperature, moisture content, and pH values below or above the optimal range for the microorganisms will slow or halt bioremediation. In some cases, excessive biomass growth may impede further remediation [EPA, 1992d]. Concentrations of certain contaminants (e.g., PCP and wood preserving metals) may be high enough to be toxic to the microorganisms. Bioremediation has not proven to be effective on PCDDs/PCDFs. These and other factors

limit the effectiveness of bioremediation in some situations.

In addition to these general limitations, *in situ* and, to a lesser extent, solid-phase bioremediation present potential difficulties in measuring the performance of the treatment. Contaminant spatial heterogeneity, fate and transport, and sorption dynamics all lead to variability in results across the site and over time. Sorption dynamics are a particularly important consideration for composting, during which contaminants may bind strongly to the added organic matter, reducing bioavailability. Degradation rates, therefore, may be limited by desorption kinetics instead of microbial activity [EPA, 1996c]. Also, composting usually results in a three-to-four-fold increase in the volume of material to be managed after remediation.

4.7.4 Technology Costs

Costs for implementing bioremediation vary widely depending on the type of treatment. *In situ* approaches generally cost less than treatments requiring excavation and soil handling [EPA, 1994d]. *Ex situ* applications incur these costs but still are economically preferable to many other treatment technologies. Estimates of the treatment costs for the composting remediation of 20,000 tons of explosives-contaminated soils ranged from $187 per ton for windrow composting to $290 per ton for mechanically-agitated in-vessel composting [EPA, 1996c]. Slurry-phase bioremediation costs were estimated in 1990 to be $105 to $195 per ton [EPA, 1990f]. In a 1993 SITE demonstration of slurry-phase bioremediation, costs were developed for operation of 70,000- and 290,000-gallon reactors used to treat 22,000 tons (20,000 yd^3 with a site-specific, measured density of 1.1 tons/yd^3) of contaminated soil from a wood preserving facility. Table 4-20 presents treatment and project cost estimates for both reactors. The two largest cost components for the entire project were total project labor (including labor associated with screening and milling the soil) and analytical costs.

Conceptual cost estimates were prepared for three solid-phase bioremediation scenarios for the Southern Maryland Woodtreating Site in Hollywood, MD [Roy F. Weston, 1994]. The three scenarios are based on 5, 10, and 15 years of operation for an onsite, *ex situ*, solid-phase bioremediation system. Capital and operating cost estimates are presented in Table 4-21. (The capital and operating costs were not combined into a total project cost because the cost basis for the capital costs is different from the cost basis for the operating costs.)

4.7.5 Case Study - Champion International Superfund Site [EPA, 1996a]

Background/Site Description: The Champion International Superfund Site is a former wood preserving facility in Libby, MT [EPA, 1996b]. Soil and groundwater at the site are contaminated with PAHs and PCP. The Record of Decision (ROD) for the site specifies biological treatment for the remediation of both soil and groundwater.

Summary of Study: Full-scale prepared bed bioremediation of contaminated soil has been underway at the Champion International Superfund Site since 1989 [EPA, 1996b]. In 1989, it was projected that treatment of the stockpiled soil (45,000 yd^3 of soil, screened to 1 inch) would take 10 years. In 1996, treatment was still on schedule for completion in 1999.

The prepared bed system consists of two 1-acre lined, bermed land treatment units (designated LTU 1 and LTU 2) with leachate collection systems [EPA, 1996b]. Contaminated soils are placed in the LTUs in 6- to 12-inch lifts for treatment during the summer season (approximately March to October). The system uses indigenous microorganisms, and a new lift is added to an LTU when the soil in the preceding lift meets treatment goals. Water (recycled leachate or water from other onsite sources) is added to maintain moisture levels at approximately 40 to 70 percent of field capacity. Nutrients (inorganic forms of nitrogen and phosphorus) are added, sometimes as frequently as every other day. Each active LTU is tilled at least weekly, when weather conditions permit.

Several laboratory studies were conducted in conjunction with the full-scale treatment process [EPA, 1996b]. One of these studies evaluated the contribution of nonbiological mechanisms, such as volitilization and leach-

Table 4-20. Estimated Treatment Costs for Slurry-Phase Bioremediation [EPA, 1993d]

Cost Category	Cost, $ 70,000-Gallon Capacity Unit	290,000-Gallon Capacity Unit
Capital Equipment		
Reactor and mechanism	125,000	256,000
Startup and Fixed		
H&S Monitoring	2,000	2,000
Establish Operating Procedures	9,000	9,000
Equipment Mobilization	7,500	7,500
Scale Up Optimization	50,000	50,000
Labor[1]	1,875,000	645,000
Supply and Consumable	27,000	15,000
Utilities	110,000	43,000
Equipment Repair and Replacement	95,000	40,000
Treatment Costs	2,300,500	1,067,500
Treatment Cost/yd^3 (Cost/Ton)[2]	$115 ($105)	$53 ($49)
Project Cost/yd^3 (Cost/Ton)[3]	$295 ($268)	$145 ($132)

1 Labor associated with operation of reactor only. Estimate does not include labor for screening and milling.

2 Based on treatment of 20,000yd^3 (22,000 tons, based on measured soil density of 1.1 tons/yd^3 at the site. Estimate does not include costs for site preparation and regulatory; pretreatment equipment; design, engineering, and construction; treatment or disposal of effluent and residuals; analytical; and demobilization.

3 Includes treatment cost and additional categories listed in Footnote 2.

Table 4-21. Conceptual Cost Estimates for Solid-Phase Bioremediation [Roy F. Weston, 1994]

Cost Category	Cost, $ Operating Time of 5 Years	Operating Time of 10 Years	Operating Time of 15 Years
Capital Costs[1]			
Construction of Cells	3,753,610	3,753,610	3,753,610
Excavation of Soils	1,277,200	1,277,200	1,277,200
Farming	1,658,400	3,140,400	4,622,400
Handling and Backfill	673,500	673,500	673,500
Site Restoration	4,860,250	4,860,250	4,860,250
Biological Study	1,000,000	1,000,000	1,000,000
Groundwater Treatment Plant	475,220	475,200	475,220

Table 4-21. Conceptual Cost Estimates for Solid-Phase Bioremediation (continued)

Cost Category	Cost, $ Operating Time of 5 Years	Operating Time of 10 Years	Operating Time of 15 Years
Mobilization, Construction Management, Site Services, and Demobilization	3,013,602	3,339,642	3,665,682
Technology Implementation (designs, plans, specifications, regulatory approval, insurance, bonds, permits)	3,013,602	3,339,642	3,665,682
Overhead and Profit	1,369,818	1,518,018	1,666,218
Contingency on Capital Costs	3,425,405	3,794,519	4,165,239
Total Capital Costs[1]	**24,521,000**	**27,172,000**	**29,825,000**
Annual Operating Costs			
Groundwater Treatment Plant	445,950	445,950	445,950
Monitor Wells Sampling/Analysis	259,460	259,460	259,460
Contingency on Annual Operating Costs	176,353	176,353	176,353
Total Annual Operating Costs	**881,763**	**881,763**	**881,763**
Total Operating Costs for Duration of Treatment, Present Value[2]	**4,005,000**	**7,647,000**	**10,957,000**

1 Capital costs are in 1993 dollars and do not include any interest or escalation.
2 Present value of operating costs for the duration of treatment, calculated using an annual interest rate of 6 percent and an annual cost escalation of 4 percent

ing; this study indicated that the majority of the apparent decrease in contaminant concentrations was due to biological processes. Additional laboratory studies demonstrated the ability of indigenous microorganisms to mineralize the target contaminants at temperatures and moisture contents representative of site conditions.

Performance: The primary COCs at the site are naphthalene, phenanthrene, pyrene, PCP, and total carcinogenic PAHs (TCPAHs), which are defined as the sum of the following 10 PAHs: fluoranthene, pyrene, benzo(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenz(a,h)anthracene, benzo(ghi)perylene, and indeno(1,2,3-cd)pyrene [EPA, 1996b]. Tables 4-22 and 4-23 present mean concentrations and percent removals for the COCs in LTU 1, Lifts 4 and 5, respectively.

Costs: Construction costs for the two LTUs totaled $400,000, and monitoring requirements plus annual operations were estimated to cost $117,000 in 1992. Using this information and the projected total treatment duration of 10 years for 45,000 yd^3, the total treatment cost and unit treatment costs can be estimated. Assuming that costs remain constant (no increase due to inflation), the total treatment cost (construction, monitoring, and operation of the system) will be $1,570,000 to treat 45,000 yd^3 of soil. The unit treatment cost is therefore approximately $35 per yd^3, or approximately $27 per ton of contaminated soil.

4.7.6 Case Study - Southeastern Wood Preserving

Background/Site Description: The Southeastern Wood Preserving Superfund Site, located in Canton, MS, used creosote and PCP to treat wood products. Large quantities of soil and sludge contaminated with PAHs are present at the site.

Summary of Study: A full-scale slurry-phase bioremediation of sludge was performed at the Southeastern Wood Preserving site by OHM Corporation. Approximately 10,000 yd^3 (estimat-

Table 4-22. Mean Contaminant Concentrations in LTU 1, Lift 4 [EPA, 1996b]

Contaminant	5/8/91[1]	6/27/91[1]		9/19/91[1]		9/1/92[1]	
	Concentration (mg/kg)	Concentration (mg/kg)	Percent Change[3]	Concentration (mg/kg)	Percent Change[2]	Concentration (mg/kg)	Percent Change[2]
Naphthalene	4.5	1.7[2]	-62	0.4[2]	-91	1.5[2]	-67
Phenanthrene	2.5[2]	1.0[2]	-60	0.2[2]	-92	0.7[2]	-72
Pyrene	76.5	4.8[2]	-94	4.6	-94	3.9[2]	-95
TCPAH	230	40.1[2]	-83	33.0	-86	41.0	-82
PCP	132.1	10.1	-92	20.7	-84	10.5[2]	-92

1 Lift 4 was placed in LTU 1 on May 7, 1991; Lift 5 was added on top of Lift 4 on July 26, 1991.
2 Mean includes one or more non-detects that were averaged in as zeros.
3 Percent change is stated as a decrease (-) or increase (+).

Table 4-23. Mean Contaminant Concentrations in LTU 1, Lift 5 [EPA, 1996b]

Contaminant	7/27/91[1]	9/19/91[1]		9/1/92[1]	
	Concentration (mg/kg)	Concentration (mg/kg)	Percent Change[4]	Concentration (mg/kg)	Percent Change[4]
Naphthalene	1.1[2]	1.0[2]	-9.1	2.0	+82
Phenanthrene	<0.95[3]	0.7[2]	NC	1.0[2]	+5.2
Pyrene	135	35.3	-74	4.3[2]	-97
TCPAH	254	103	-59	37.1	-85
PCP	119.4	40.5	-66	16.9	-86

1 Lift 5 was placed in LTU 1 on July 26, 1991.
2 Mean includes one or more non-detects that were averaged in as zeros.
3 All results were non-detects; detection limits were averaged together.
4 Percent change is stated as a decrease (-) or increase (+).

ed to be 13,000 tons) of RCRA-listed wastewater treatment sludge (EPA hazardous waste code K001) were treated in 200,000-gallon reactors [EPA, 1995c]. Treatment for each batch required 5 to 30 days depending on temperatures in the reactors.

Performance: Table 4-24 presents initial and final concentrations along with percent change for PAHs. Percent reductions ranged from 33 for indeno(1,2,3-cd)pyrene to 99 for acenaphthene. The B(a)P potency estimate decreased by 61 percent. The initial and final concentrations of benzo(k)fluoranthene were not reported and, therefore, are not included in the B(a)P potency estimate. QA results were not presented in this report.

Cost: Remediation costs were reported at $190 per yd^3 (approximately $146 per ton). Factors considered in this vendor-reported cost were not listed.

Table 4-24. Selected Results - Southeastern Wood Preserving Slurry-Phase Bioremediation Treatment [EPA, 1995c]

Parameter	Initial Concentration	Final Concentration	Percent Change[4]
PAHs, ppb			
Acenaphthene	909,000	6,000	-99
Acenaphthylene	93,000	15,000	-84
Anthracene	1,950,000	121,000	-94
Benz(a)anthracene[1]	280,000	12,000	-96
Benzofluoranthene[1]	321,000	209,000	-35
Benzo(ghi)perylene	92,000	18,000	-80
Benzo(a)pyrene[1]	130,000	79,000	-39
Chrysene[1]	296,000	36,000	-88
Dibenz(a,h)anthracene[1]	92,000	9,000	-90
Fluoranthene	1,708,000	32,000	-98
Fluorene	630,000	14,000	-98
Indeno(1,2,3-cd)pyrene[1]	94,000	31,000	-33
2-Methylnaphthalene	NR	NR	NR
Naphthalene	93,000	ND	NC
Phenanthrene	1,031,000	34,000	-97
Pyrene	1,148,000	33,000	-97
Total PAHs[2]	8,867,000	649,000	-93
B(a)P Potency Estimate[3]	292,000	113,000	-61

1 Used in calculation of B(a)P potency estimate [EPA, 1993a].
2 Total PAHs does not include 2-methylnaphthalene. Since a detection limit was not provided for the nondetected result, a value of zero was assigned.
3 Results were reported for benzofluoranthene only, rather than for benzo(b)fluoranthene and benzo(k)fluoranthene separately. B(a)P potency estimates were, therefore, calculated using the benzo(b)fluoranthene factor, which is higher than the relative potency for benzo(k)fluoranthene. This results in a conservative B(a)P potency estimate.
4 Percent change is stated as a decrease (-) or increase (+).
NR = Not reported
NC = Not calculated
ND = Not detected
Shaded row contains only NR designations.

CHAPTER 5
WATER TREATMENT TECHNOLOGY PROFILES

This chapter provides information on four technologies used in the remediation of contaminated water. For each technology, the chapter provides a description of the technology, along with advantages of the technology, and limitations of its use. A discussion of costs associated with operation of these technologies and with factors that affect costs is included. When available, a treatability study and a case study using the technology to treat water from wood preserving sites are presented. Additional studies are described in Appendix C.

5.1 Hydraulic Containment

5.1.1 Technology Description

Hydraulic containment involves the design and installation of a system that physically and/or hydraulically prevents contaminant migration. Physical control can be achieved by slurry walls (a.k.a, cut-off walls), buried drainlines, collection sumps, infiltration galleries, and geomembranes. Hydraulic containment systems often consist of a physical control used in conjunction with hydraulic controls (e.g., in conjunction with a pump-and-treat system).

5.1.2 Advantages

The main advantage of hydraulic containment technologies is that they usually can be implemented quickly in situations where soluble and mobile constituents pose an imminent threat to a source of drinking water. The design requirements and practices associated with their installation are well understood.

5.1.3 Limitations

Some hydraulic containment systems (i.e., dewatering wells) require periodic maintenance to remain operational. They also frequently require monitoring equipment to anticipate and alert personnel of operational problems (i.e., system shutdowns). Physical barriers (i.e., slurry walls) can be susceptible to chemical attack, which can eventually lead to increased hydraulic activity. Successful applications of physical barriers for containment of DNAPLs rely on the presence of a horizontal impermeable boundary which prevents further downward migration of the DNAPLs, as well as the ability to key-in the physical barrier to the impermeable boundary [Huling, 1997]. Once physical barriers are installed, it is often difficult to assess their actual performance.

5.1.4 Technology Costs

Costs for implementing hydraulic containment vary greatly depending upon site- and technology-specific factors. Depth of confining layers, soil type, contaminant mobility, and groundwater pH are important site-specific factors. Materials of construction, emplacement approaches, and maintenance requirements of the chosen technology affect project costs. Costs are generally less for shallow (less than 30 feet) slurry walls, and most expensive for deep (greater than 50 feet) injection grouting. The range (in 1992 dollars) was $3 to $75 per square foot of containment structure [EPA, 1992a].

5.1.5 Case Study - Laramie Tie Plant

Background/Waste Description: In 1986, hydraulic containment was implemented at the Laramie Tie Plant site located near Laramie, WY [Piontek & Simpkin, 1992]. Railroad tie treating operations began in 1886 and continued on an intermittent basis until the facility closed in 1983. Creosote was the primary wood-preserving agent used and is responsible for the majority of the contamination now present at the site. PCP was also used, but in much smaller quantities. Site soils and groundwater are believed to have become contaminated by drippings and spills associated with the wood-preserving activities, direct discharges of wastewaters to low-lying areas,

and contaminant release from some wastewater impoundments at the site.

A remedial investigation conducted at the site revealed widespread contamination, which consisted largely of an immiscible, heavier-than-water mixture of creosote and PCP in carrier oil. The mixture resulted in a DNAPL pool that had accumulated at the base of a highly permeable alluvial deposit, at an average depth of approximately 10 feet. It was estimated that this alluvial deposit contained approximately 6.5 million gallons of DNAPL distributed over an area of approximately 90 acres. DNAPL migration into the underlying bedrock has been generally limited by the fine-grained character of the bedrock and the naturally upward flow of groundwater.

Summary of Study: While the site investigation was still under way, the Union Pacific Railroad (UPRR) began implementing a series of measures to address the potential risks to human health and the environment posed by the site contamination. Early in the project, several actions were quickly undertaken to mitigate the potential for severe contaminant release from the site. In 1983, a dike was built along the adjacent Laramie River to protect the site from floods. In the fall of 1983, a short section of sheet-pile wall was installed to cut off the subsurface flow of oil from the site into the Laramie River along a suspected preferential flow path.

As the remedial investigation was nearing its conclusion, UPRR began evaluating more permanent options for preventing the intermittent seepage of DNAPLs into the Laramie River, as well as the more constant flow of contaminated alluvial groundwater into the river.

In 1986, a system installed to prevent further contaminant migration from the site began operation. This system, called the Contaminant Isolation System (CIS), consisted of the following:

- A physical barrier to contaminant migration: a 10,000-linear-foot, soil-bentonite cutoff wall
- A hydraulic barrier to contaminant migration: 17,000 linear feet of horizontal drainline that sustains inward groundwater flow to the site
- A system to treat the contaminated groundwater generated in the hydraulic containment system: an oil removal system and filtration with activated carbon

Performance: Installation of the CIS was reported to have stopped the intermittent seepage of oil into the Laramie River. Contaminated alluvial groundwater that formerly flowed into the Laramie River is now intercepted and treated before it reaches the river. The contaminated groundwater that had the highest potential for offsite migration to receptor wells is now being pumped out of the ground and treated in the CIS activated carbon water treatment plant. The conclusion reached after 4 years of operating and monitoring this system is that the actual and most imminent risks formerly posed by the site contamination have been addressed by these remedial actions and the other site management practices that are currently being employed.

Cost: Cost information was not available.

5.2 Carbon Adsorption

5.2.1 Technology Description

Carbon adsorption is used to remove organic contaminants from groundwater by adsorption of the contaminants onto a carbon surface. The adsorption of contaminants to carbon is caused by chemical and physical interactions between the contaminant molecules and the carbon surface. The surface area and pore size of the carbon, the solubility and molecular size of the organic contaminants, and the contact time between the water and activated carbon surface determine the effectiveness of the adsorption process. Generally, organics of low solubility and high molecular weight are the most readily removed by this process, since these molecules enable the most effective use of the carbon's adsorption area. Granular activated carbon (GAC) is frequently used because its structure provides a large number of

adsorption sites per pound of carbon. The contaminants adsorb to the surfaces of the microporous carbon granules until most of the adsorption sites are utilized. The GAC may then be either regenerated or disposed of. GAC may be used in a fixed adsorption bed or a moving adsorption bed.

5.2.2 *Advantages*

Carbon is an excellent adsorbent because of its large surface area, which can range from 500 to 2,000 m^2/g, and because its surfaces are highly attractive to many different types of contaminants. Almost all organic compounds can be adsorbed to GAC to some degree. GAC can be and is commonly used in conjunction with other treatment technologies. For example, GAC can be used to remove contaminants from the offgas from air stripper and soil vapor extraction (SVE) operations. GAC has also been used to remove low concentrations of certain types of inorganics (i.e., metals); however, it is not widely used for this application. (Ion exchange is a common treatment for metals.)

5.2.3 *Limitations*

The wide-scale use of GAC can cause it to be inappropriately selected when an alternative technology may be more effective. Compounds that have low molecular weight and high polarity are not recommended for GAC treatment. Streams with high suspended solids (≥50 mg/L) and oil and grease (≥10 mg/L) may cause fouling of the carbon and require frequent backwashing. In such cases, pre-treatment prior to GAC is generally required. High levels of organic matter (e.g, ≥1,000 mg/L) may result in rapid reduction of the carbon's effectiveness. Even lower levels of background organic matter (e.g., 10 to 100 mg/L) such as fulvic and humic acids may cause interferences in the adsorption of specifically targeted organic contaminants which are present in lower concentrations. In such cases, GAC may be most effectively employed as a polishing step in conjunction with other treatments.

5.2.4 *Technology Costs*

Costs associated with GAC are dependent on wastestream flow rates, type of contaminants, concentrations, and site and timing requirements. Typically, costs are less with lower concentration levels of a contaminant of a given type. Costs are also less at higher flow rates. At liquid flow rates of 100 million gallons per day (mgd), costs range from $0.10 to $1.50 per 1,000 gallons treated. At flow rates of 0.1 mgd, costs increase to $1.20 to $6.30 per 1,000 gallons treated [EPA, 1991c].

The amount of carbon required and the regeneration/reactivation frequency are important economic considerations. Compounds that do not adsorb well often require large quantities of GAC, and this will increase costs. In some cases, the spent GAC may be a hazardous waste, the management of which can significantly add to the cost of treatment.

5.2.5 *Treatability Study - McCormick & Baxter (MCB) Site*

Background/Waste Description: The contaminated medium for this treatability study was groundwater contaminated with PAHs, PCP, and PCDDs/PCDFs. The groundwater was collected from two wells screened in different aquifers. The shallow well was screened at 20 ft below land surface (bls) and the deep well was screened at 175 ft bls. The water from each of these wells was composited to generate a 50:50 test water mixture.

Summary of Study: A carbon adsorption treatability study was conducted on water from the MCB Superfund site at an undisclosed vendor facility [IT Corp, 1996a]. This study consisted of an accelerated column test (ACT) evaluation of a GAC system. The ACT system achieves acceleration of the carbon adsorption cycle through a scaling down of the conventional column testing hardware. The ACT simulates actual stream conditions and process performance to provide dynamic data, rather than the equilibrium capacity data generated by an isotherm. This ensures full consideration of flow conditions and the effects of flow on adsorption capacity. The minimum amount of carbon that will be consumed at full-scale is then predicted based on the amount of water treated before breakthrough of the target chemical(s) occurs. Except for the reduced scale, all other components of the test system (reservoir, pump, tubing, etc.) and the overall system design are essentially identical to larger-scale

laboratory or field evaluation systems [IT Corp., 1996a].

One 19-L (5-gallon) sample of groundwater from the MCB site was used for testing. The water was filtered using a 1.0-micrometer (μm) glass-fiber filter to remove solids. The filtered water was then used as the influent to the ACT. The ACT was conducted using a high-activity, pulverized GAC. The water was also filtered with regular carbon before treatment in order to prevent clogging of the fine carbon bed in the ACT filter. The carbon adsorption vendor designed the ACT system to simulate the expected MCB groundwater flow rate of 80 gpm and the amount of carbon in one of its stock treatment units. The size of the water sample requested by the vendor was determined to be too small to ensure breakthrough of the contaminants. Therefore, the quantity of carbon actually used in the ACT was 25 percent of the amount specified in the ACT design.

The ACT column was operated for 7 days, during which time the operation of the column was monitored by compositing two 1-L samples of treated water per day. Samples of treated groundwater were screened for the presence of PAHs using D-TECH PAH test kits (Model TK-1006-1). Based on the results of the sample screening, samples were selected for laboratory analysis for SVOCs and PCDDs/PCDFs.

Performance: The results for selected contaminants of concern (PCP and PCDDs/PCDFs) and the calculated B(a)P potency estimates and TCDD-TEQs are presented in Table 5-1. Acenaphthylene was the only PAH detected in the influent or effluent. (The Day-3 sample was analyzed by a more sensitive method, high performance liquid chromatography (HPLC); however, the influent was not reanalyzed using HPLC.) The concentrations of all seven PAH compounds used in the calculations of the B(a)P potency estimates were not detected and, consequently, the estimates were not calculated.

The document in which these results were reported stated that PCP results for the ACT effluent indicated that breakthrough of the chemical may have occurred within the first day. The Day 1-ACT sample analysis indicated that about 47 percent of the PCP was removed [IT Corp., 1996a]. The carbon treatment vendor extrapolated the carbon use data to a full-scale system.

Table 5-1. Selected Results - MCB Site ACT [IT Corp., 1996a]

	Influent Results	Effluent Results			
Parameter	Conc.	Conc. Day 1	Conc. Day 2	Conc. Day 6	Test End % Change[2]
SVOCs, ppb					
Pentachlorophenol	7,400	3,900	11,000	8,000	+8.1
Phenol	38	<10	27	30	-21
2-Methylphenol	94	<10	74	82	-13
4-Methylphenol	30	<10	29	29	-3.3
2,4,5-Trichlorophenol	4 J	<50	<50	3 J	-25
2,4,6-Trichlorophenol	1 J	<10	<10	1 J	0
TCDD-TEQ (ppq)[1]	51.2	21.2	25.9	24.1	-53

[1] TCDD-TEQ by I-TEFs/89 [EPA, 1989a]. Results are reported in ppq.
[2] Percent change is stated as a decrease (-) or increase (+)
J = Estimated value

The phenol data are largely inconclusive. Many influent and effluent values are well within sample variability. In the case of 2,4,5- and 2,4,6-trichlorophenol, Day-1 and Day-2 effluent detection limits were above their respective influent concentrations.

The measured concentrations of 2,3,7,8-TCDD in all ACT samples (including the filtered influent) were nondetectable at a level below the treatment objective. Other PCDD and PCDF congeners were detected in all samples. Overall, there was a 53 percent reduction in TCDD-TEQ between the influent and Day-6 effluent.

Costs: Table 5-2 presents the capital and O&M costs for the ACT carbon treatment system. Capital and O&M costs were reported for a system with a flow rate of 80 gpm. Dividing the capital cost evenly over 10 years (a reasonable duration for pump-and-treat remediation) and adding O&M costs produces a treatment cost of $1.38 per 1,000 gallons treated.

simultaneous introduction of ozone (O_3), hydrogen peroxide (H_2O_2), or titanium dioxide (TiO_2) catalyst. The combination of chemical oxidation and UV photolysis has been shown to destroy a wide variety of organic contaminants. This destruction is accomplished through the generation of highly reactive hydroxyl radicals, which theoretically break down complex compounds into simpler ones. However, intermediate compounds can be more toxic than the parent compound; therefore, screening tests should be performed [Manilal, et al., 1992]. In groundwater remediation, UV/oxidation, a subset of photolytic oxidation, is a viable alternative to air stripping, activated carbon adsorption, and biotreatment [EPA, 1991d].

5.3.2 Advantages

Photolytic oxidation effectively treats liquids that contain oxidizable contaminants. The UV/H_2O_2 process is effective over a wide pH range and the process creates no waste by-products or air emissions. Phenols, which are common contaminants at wood preserving

Table 5-2. Estimated Treatment Costs for Carbon Adsorption

		Cost		
Treatability Vendor	Recommended Treatment System	Capital ($) ($/1,000 gal)	O&M ($/1,000 gal)	Treatment ($/1,000 gal)[1]
Carbon Treatment -	Dual-vessel system containing 20,000 lbs of 8 x 30 mesh virgin activated carbon at a carbon use rate = 1.19 lb/1,000 gal	0.19	1.19	1.38

[1] Based on treatment of 420,480,000 gallons of water at the design flow rate of 80 gpm. (Capital costs divided evenly over a 10-year project), Expenses included in O&M were not itemized. The cost estimates do not include site preparation, permitting and regulatory compliance activities, or demobilization.

5.3 Photolytic Oxidation

5.3.1 Technology Description

Photolytic oxidation is a process that uses ultraviolet (UV) radiation to destroy or detoxify hazardous chemicals in aqueous solutions. Absorption of energy in the UV spectrum elevates molecules to higher energy states, thus increasing the ease of bond cleavage and subsequent oxidation of the molecule. Photolytic treatment can be enhanced by the

sites, are easily oxidized and, therefore, can be easily treated by photolytic oxidation processes. Another advantage of these processes is that several oxidants or photocatalysts can be used in combination with UV light.

5.3.3 Limitations

If oxidation reactions are not complete, residual hazardous compounds may remain in the

treated water. In addition, intermediate hazardous compounds may be formed (e.g., trihalomethanes, epoxides, and nitrosamines). Incomplete oxidation may be caused by insufficient strength or quantity of the oxidizing agent(s), inhibition of oxidation reactions by low or high pH, the presence of interfering compounds that consume reagent, or inadequate mixing or contact time of the contaminant and oxidizing agent(s). Determination of potential reactions and their rates by way of treatability tests may be critical to prevent explosion or formation of unwanted compounds.

Oil and grease in the media should be minimized to optimize the efficiency of the oxidation process. Oxidation is not cost-effective for highly concentrated wastes because of the large amounts of oxidizing agent(s) required. The cost of generating UV light and the problem of scaling or coating on the lamps are two of the biggest drawbacks to UV-enhanced chemical oxidation systems. These systems do not perform as well in turbid waters and slurries because the reduced light transmission reduces their effectiveness.

5.3.4 Technology Costs

Treatment costs for photolytic oxidation are strongly influenced by site-specific factors. These factors include: contaminant type and concentration, quantity of water, flow rate of water to be treated, local energy costs, treatment costs, and interfering compounds. Direct treatment costs for a 10-year treatment period were determined from information presented in three SITE Demonstration Test Applications Analysis Reports (AARs). The range of values for treating 1,000 gallons of water were $4.35 to $16.30 [EPA, 1990d], $5.14 to $13.28 [EPA, 1993b], and $5 to $11 [EPA, 1994c]. (The values have not been adjusted for inflation.) Direct treatment costs include only the costs associated with setup, operation, and demobilization of the treatment unit. They do not include expenses such as site preparation, ancillary equipment, analytical services, and residuals disposal. It also should be noted that none of the demonstrations were conducted on water with wood preserving contaminants as a major constituent.

In an effort to standardize the cost components considered when performing intertechnology comparisons, direct treatment costs have been reduced to the expenses common to the operation of most technologies. Table 5-3 provides an example of a revised analysis of one of the AARs previously cited. The example provides annual treatment costs for the treatment of 260,000,000 gallons of contaminated water using three different treatment rates.

5.3.5 Treatability Study - MCB Site

Background/Waste Description: In September 1995, a photolytic oxidation treatability study was conducted on groundwater from the MCB Superfund site in Stockton, CA [IT Corp., 1996a]. The contaminated medium for this treatability study was groundwater contaminated with PAHs, PCP, and PCDDs/PCDFs. The groundwater was collected from two wells that were screened in different aquifers. The shallow aquifer well was screened at 20 ft bls; the deep aquifer well was screened at 175 ft bls. The water from each of these wells was composited to generate a 50:50 test water mixture.

Summary of Study: The purpose of the treatability study was to examine the destruction of PCP, PCDDs/PCDFs, and PAHs in groundwater using cavitation with UV oxidation and H_2O_2. This treatment used H_2O_2, hydrodynamic cavitation, and UV radiation to photolyze and oxidize organic compounds present in water. Cavitation occurs when a liquid undergoes a dynamic pressure reduction while under constant temperature. Ideally, the end products of the process are water, carbon dioxide, halides, and in some cases, organic acids. The treatment objectives for the site groundwater were the criteria for discharge to the Stockton, CA publicly owned treatment works (POTW). The local utility had set the discharge criteria as the drinking water maximum contaminated levels (MCLs).

A 50:50 mixture of water from the two wells was collected and mixed in a 500-gallon tank. This mixture was considered representative of the groundwater contamination at the site.

Table 5-3. Estimated Annual Treatment Costs for the perox-pure™ Technology [EPA, 1993b]

	Estimated Annual Costs (1993 $)		
	10 gpm	50 gpm	100 gpm
Treatment Equipment	2,200[1]	18,500[2]	58,000[3]
Labor	39,000	39,000	39,000
Start-Up	100[1]	500[2]	1,000[3]
Consumables	7,550	24,200	48,450
Utilities	9,200	45,900	91,700
Maintenance & Modifications	11,000	18,500	29,000
Total Treatment Costs/1,000 gal.	$13.28[4]	$5.64[5]	$5.14[6]

1 One-time cost divided over a 50-year treatment period
2 One time cost divided over a 10-year treatment period
3 One time cost divided over a 5-year treatment period
4 Assumes 5.2 million gallons treated annually
5 Assumes 26 million gallons treated annually
6 Assumes 52 million gallons treated annually

Note: These cost estimates do not include costs associated with site preparation, permitting and regulatory compliance, ancillary equipment, analytical services, effluent disposal, and residuals shipping and handling.

Approximately 475 gallons of groundwater were available for onsite treatment using a pilot-scale cavitation system. The system that was transported to the MCB site contained a low-energy and a high-energy UV reactor. Each UV reactor housed low-pressure, mercury-vapor lamps that generate UV radiation. The low-energy reactor housed 1.2-kilowatt (kW) lamps; the high-energy reactor housed 10-kW lamps.

For this pilot-scale study, the flow rate was kept constant at 1 gallon per minute (gpm) for the test runs that included UV radiation. (Note: There were other test runs conducted which did not involve UV radiation.) Variables for the UV studies included lamp intensity (1.2 kW versus 10 kW), irradiation time (10 min. versus 8 min.), and H_2O_2 dosage (0 ppm to 100 ppm).

Performance: The results of three runs, which included UV radiation as part of the treatment of the groundwater, are presented in Table 5-4. The results are difficult to interpret due to the lack of QA data that would indicate accuracy of the values. However, in a general sense, the data show that UV alone (Condition 1) was somewhat effective in degrading PAHs and PCP.

The data are inconclusive with respect to photolytic oxidation because more than one test condition was varied for each of the test conditions. For example, for PCP, the lowest percent removal achieved occurred not only when lamp intensity was low, but when no H_2O_2 was added. When H_2O_2 was added, lamp intensity was increased. Condition 3 appears to have performed better for treating PAHs than Condition 2, as a result of a 25 percent increase in H_2O_2; however, the best removal of PCP was achieved under Condition 2. Since there is only one sample result for each of the two conditions, sample variability cannot be ruled out as the cause of the variations observed between Conditions 2 and 3.

Cost: Capital and operation and maintenance (O&M) cost information are presented in Table 5-5. Treatment costs for cavitation were not provided. Capital and O&M costs were reported for a system with a flow rate of 80 gpm. Dividing the capital cost evenly over 10 years (a reasonable duration for pump-and-treat remediation) and adding O&M costs produces a treatment cost of $8.27 to $9.00 per 1,000 gallons treated.

Table 5-4. Selected Results - Photolytic Oxidation/Cavitation Treatment [IT Corp., 1996a]

Parameter	Influent Results	Effluent Results					
		Condition 1[a]		Condition 2[b]		Condition 3[c]	
	Conc.	Conc.	% Change[4]	Conc.	% Change[4]	Conc.	% Change[4]
PAHs, ppb							
Acenaphthene	690	660	-4.3	360	-48	240	-65
Acenaphthylene	<60	<21	NC	9 J	NC	6 J	NC
Anthracene	220	150	-32	72	-67	54 J	-75
Benz(a)anthracene[1]	120	61	-49	72	-40	51 J	-58
Benzo(b)fluoranthene[1]	78	40	-49	52 J	-33	40 J	-49
Benzo(k)fluoranthene[1]	39 J	20 J	-49	30 J	-23	17 J	-56
Benzo(ghi)perylene	19 J	9 J	-53	13 J	-32	<55	NC
Benzo(a)pyrene[1]	58 J	28	-52	34 J	-41	25 J	-57
Chrysene[1]	120	65	-46	81	-33	58	-52
Dibenz(a,h)anthracene[1]	6 J	3 J	-50	<60	NC	<55	NC
Fluoranthene	520	360	-31	330	-37	270	-48
Fluorene	410	290	-29	250	-39	160	-61
Indeno(1,2,3-cd)pyrene[1]	20 J	11 J	-45	16 J	-20	11 J	-45
2-Methylnaphthalene	130	40	-69	690	+430	490	+280
Naphthalene	17 J	<21	NC	5,400	+32,000	4,200	+25,000
Phenanthrene	1,300	970	-25	800	-38	580	-55
Pyrene	490	220	-55	280	-43	190	-61
Total PAHs[2]	4,300	3,000	-31	8,500	+99	6,500	+51
B(a)P Potency Estimate[2]	86	42	-51	<108	NC	<90	NC
Other SVOCs, ppb							
Dibenzofuran	370	300	-19	250	-32	170	-54
Pentachlorophenol	11,000*	4,600	-58	140 J	-99	1,200	-89
Phenol	36 J	38	+6	29 J	-19	19 J	-47
TCDD-TEQ, ppq[3]	2.2×10^4	NR	NC	4.8×10^4	+118	2.8×10^4	+27

[a] Condition 1:
H_2O_2 = 0 ppm
UV lamp = 1.2 kW
Flow rate = 1 gpm
Treatment time = 10 min.

[b] Condition 2:
H_2O_2 = 80 ppm
UV lamp = 10 kW
Flow rate = 1 gpm
Treatment time = 8 min.

[c] Condition 3:
H_2O_2 = 100 ppm
UV lamp = 10 kW
Flow rate = 1 gpm
Treatment time = 8 min.

1 Used in calculation of B(a)P potency estimate [EPA, 1989a].
2 For nondetected (i.e., less than) results, the detection limit was used to calculate total PAHs and the B(a)P potency estimate.
3 TCDD-TEQ by I-TEFs/89 [EPA, 1989a]. Results reported in ppq.
4 Percent change is stated as a decrease (-) or increase (+).
* Value is suspect due to MS/MSD recoveries of 560 and 577 percent.
J = Estimated Value
NC= Not calculated
NR = Not reported

Table 5-5. Estimated Treatment Costs for Cavitation/UV Peroxidation Treatment [IT Corp., 1996a]

Treatability Vendor	Recommended Treatment System	Cost		
		Capital ($) ($/1,000 gal)	O&M ($/1,000 gal)	Treatment ($/1,000 gal)[4]
Cavitation	Vendor did not recommend a treatment system design	--	--	--
UV Peroxidation[1]	a) UV type SX H_2O_2 dose = 300 mg/L Catalyst[2] 270-kW system	0.74	7.53[3]	8.27
	b) UV type SX H_2O_2 dose = 300 mg/L Without catalyst 360-kW system	0.92	8.08[3]	9.00

1 Designed for PCP destruction only.
2 Ferrous sulfate
3 Based on $0.06/kWh and 10% of capital expense per year.
4 Based on treatment of 420,480,000 gallons of water at the design flow rate of 80 gpm. (Capital costs divided evenly over a 10-year project.) These cost estimates do not include ancillary costs such as site preparation, disposal, permitting, and analyses.

5.3.6 Case Study - PCP Manufacturing Facility

Background/Waste Description: In 1988, a case study of photolytic oxidation was conducted on groundwater from an unidentified PCP production site in Washington State [EPA, 1993b]. PCP contamination was discovered in local groundwater surrounding a chemical manufacturing company that had produced PCP for more than 30 years. The site geology has caused brackish groundwater containing high concentrations of iron and calcium carbonate. The chemical company initiated a remediation effort that included a pump-and-treat process.

Summary of Study: After bench-scale testing, the perox-pure™ chemical oxidation system was selected to reduce PCP concentrations in treated groundwater to below a target level of 0.1 mg/L. A full-scale perox-pure™ system was installed in 1988. When the remediation effort began, groundwater was contaminated with PCP at levels of up to 15 mg/L, three times higher than expected. Iron was detected at levels of up to 200 mg/L, 20 times higher than expected. Pretreatment recommendations resulted in the selection of an iron oxidation and removal system, which included clarification and multimedia filtration. The groundwater was stabilized and the scaling tendency was reduced by adding acid to lower the groundwater pH to approximately 5. H_2O_2 was added to the influent to achieve a concentration of 150 mg/L. The average flow rate was approximately 70 gpm, and the power requirement was 180 kW.

Performance: The perox-pure™ system treated maximum influent PCP concentrations of 15 mg/L to an average effluent concentration of 0.1 mg/L. The perox-pure™ system also reduced iron concentrations in the groundwater to acceptable levels.

Cost: The O&M costs for continuous operation of the perox-pure™ system installed at the Washington site were reported for a flow rate of 70 gpm. Included in the O&M costs were electricity, chemicals (H_2O_2 and acid), and general maintenance. For each 1,000 gallons treated, costs were as follows: electricity (at $0.06 per kilowatt hour [kWh]), $2.57; 50 percent H_2O_2 (at $0.35 per pound), $0.87; acid (at $0.085 per pound), $0.03; and estimated maintenance requirements, $0.43. The total O&M cost per 1,000 gallons treated was reported to be $3.90.

5.4 Bioremediation

5.4.1 Technology Description

Bioremediation involves the use of microorganisms that have the ability to metabolize and degrade organic contaminants, either in the presence of oxygen (aerobic) or in oxygen depleted environments (anaerobic). PCP, for example, has been degraded under both aerobic and anaerobic conditions. The microorganisms can be indigenous (naturally occurring in the wastestream) or exogenous (introduced from another source).

Bioremediation can be performed *in situ* or *ex situ*. *In situ* biological treatment of aquifers is usually accomplished by stimulation of indigenous microorganisms to degrade organic waste constituents present at a site. The microorganisms are stimulated by injection of inorganic nutrients and, if required, an appropriate electron acceptor (e.g., oxygen) into aquifer materials [EPA, 1994d]. In general, biological systems can degrade only the soluble fraction of the organic contamination. Thus, the applicability of the treatment is ultimately dependent upon the solubility of the contaminant and the mass transfer of the contaminant from the sorbed or NAPL phase to the dissolved phase.

Rotating biological contactors (RBCs) are a common *ex situ* bioremediation system for the treatment of wastewaters. RBCs employ aerobic fixed-film treatment to degrade either organic and/or nitrogenous (ammonia-nitrogen) constituents present in aqueous wastestreams. Fixed-film RBC reactors provide a surface to which microorganisms can adhere. Treatment typically is achieved as the surfaces rotate through the wastewater, enabling systems to acclimate biomass capable of degrading organic waste [EPA, 1992d]. RBCs are generally applicable to influents containing organic concentrations between 40 and 10,000 mg/L (one percent) of soluble biochemical oxygen demand (SBOD). (Note: SBOD measures the soluble fraction of the biodegradable organic content in terms of oxygen demand.)

5.4.2 Advantages

In situ bioremediation is a relatively inexpensive technology to implement since it attempts to optimize natural bioremediation and biotransformation processes. *In situ* bioremediation of aquifers can be used to treat contaminants that are sorbed to aquifer materials or trapped in pore spaces, although the treatment rate may be limited by the rate of contaminant desorption from aquifer materials or diffusion from pore spaces. In addition to treatment of the saturated zone, organic contaminants held in unsaturated, capillary, and smear zones can be treated when an infiltration gallery is used. The areal zone of treatment using bioremediation can be larger than with other remedial technologies because the treatment moves with the plume and can sometimes reach areas that would otherwise be inaccessible. The areal zone of treatment will, however, be limited by *in situ* transport issues such as preferential groundwater flow paths, aquifer clogging, and consumption of electron acceptors and nutrients.

RBCs and other *ex situ* bioremediation techniques offer the advantage of increased process control. Contaminant concentrations can be adjusted through the addition of clean water. Temperature, pH, and nutrient loading also can be modified to optimize microbial activity. Contaminant monitoring additionally is simplified by the presence of readily accessible sampling points for treated water and sludge.

5.4.3 Limitations

Bioremediation systems do not effectively remove most inorganics or non-biodegradable organics. Wastes containing high concentrations of heavy metals and certain pesticides, herbicides, or highly chlorinated organics can resist treatment by inhibiting microbial activity. Wastestreams containing toxic concentrations of these compounds may require pretreatment to remove or dilute these materials prior to biological treatment. Extremes in pH can limit the diversity of the microbial population an may suppress specific microbes capable of degrading the contaminants of interest. (In gen-

eral, organic degradation is optimal a pH between 6.0 and 8.5; nitrification requires the pH to be greater than 6.) Temperatures below 55°F also reduce biological activity. [EPA, 1992d]

In situ bioremediation of contaminated groundwater is often limited by the ability to deliver nutrients and electron acceptors into the aquifer. The presence of NAPLs will greatly limit the effectiveness of bioremediation due to the physical effects of the NAPL phase and the very high, generally toxic, concentrations of the contaminants [Huling, 1997]. Bioremediation in aquifers with saltwater intrusion may be inhibited due to high salinity. Additionally, treatment monitoring is difficult due to spatial and temporal heterogeneity.

Some *ex situ* bioremediation systems are susceptible to excessive biomass growth, particularly when organic loadings are elevated. As an example, if the biomass for an RBC fails to slough off and a blanket of biomass forms which is thicker than 90 to 125 millimeters, the resulting weight may damage the shaft and discs. Also, general care must be taken to ensure that organic pollutants do not volatilize into the atmosphere. To control their release, gaseous emissions require offgas treatment. Additionally, nutrient and oxygen deficiencies can reduce microbial activity, causing significant decreases in biodegradation rates.

5.4.4 Technology Costs

Treatment costs using *ex situ* bioremediation techniques have been estimated to be as low as $2.94 per 1,000 gallons treated (1991 dollars) [EPA, 1991a]. Another EPA document presents a range of $50 to $90 per 1,000 gallons treated [EPA, 1992a]. Table 5-6 presents treatment costs for a bioremediation study using fixed-film bioreactors.

Table 5-6. Estimated Treatment Costs for MacGillis and Gibbs Site Case Study [EPA, 1991a]

Unit Type and Capacity	5 gpm Mobile		5 gpm Stationary		30 gpm Stationary	
Cost Category	$/1,000 gal	%	$/1,000 gal	%	$/1,000 gal	%
Capital Equipment (amortized over 10 years)	11.11	76	1.16	25	0.51	17
Labor	1.49	10	1.49	32	0.50	17
Consumables & Supplies						
Nutrient	0.042	0.31	0.042	1	0.017	1
Caustic	0.24	2	0.24	5	0.24	8
Utilities						
Electricity	0.216	1	0.216	5	0.216	7
Heat	1.46	10	1.46	32	1.46	50
Total ($/1,000 gal)[1]	**14.56**	**100**	**4.61**	**100**	**2.94**	**100**

[1] These cost estimates do not include costs associated with site preparation, permitting and regulatory activities, startup, effluent treatment and disposal, residuals management, analytical services, maintenance/modification, and demobilization.

The estimated treatment cost for the fixed-film biological treatment is in the range of $2.94 to $14.56 per 1,000 gallons, depending on system size. Major contributors to cost are labor, which decreases significantly as scale increases, and heat requirements. Factors affecting the cost of bioremediation systems include the type and size of the bioremediation system, the type and concentration of organics present, hydraulic residence time, treatment location (*in situ* or *ex situ*), nutrient and oxygen requirements, and pre- and post-treatment activities.

5.4.5 Treatability Study - ACW Site

Background/Waste Description: In March of 1995, a treatability study using chemical oxidation to augment bioremediation was conducted using groundwater from the ACW site in Jackson, TN [IT Corp., 1996b]. Contaminants, including PAHs, PCDDs/PCDFs, PCP, and other phenolic compounds, were apparently spread by drippings/pillage, leakage from tanks, and leaching from pits. A waste consisting of an oil/water emulsion was prepared by mixing groundwater composited from 5-feet-deep pits.

Summary of Study: Fenton's Reagent was chosen as the augmentation chemical for the study. Fenton's Reagent (H_2O_2 and ferrous sulfate) acts as a chemical oxidizing agent by generating hydroxyl radicals. The hydroxyl radicals in turn react with organic compounds such as petroleum hydrocarbons, oxidizing them more quickly than ozone or H_2O_2 alone [IT Corp., 1996b].

Samples were analyzed for PCDDs/PCDFs during an initial characterization of treatability study water. (These compounds are known to be recalcitrant; therefore, additional pretreatment analyses were not requested by EPA.) SVOC analysis and TPH analysis were conducted on the pretreatment sample in order to establish new baseline concentrations for these parameters. The TPH analysis was conducted on the sample in order to provide a quick, inexpensive means of tracking the progress of the study.

The experimental design for this study involved setting up five test conditions:

1.	Conventional Biological Treatment	Slurry in nutrient media.
2.	Fenton's Reagent Treatment	Slurry in nutrient media with 10 millimolar (mM) concentration of ferrous ions and 0.5 molar (M) concentration of H_2O_2.
3.	Fenton's Reagent Using Chelated Ferric Iron Treatment	Slurry in nutrient media with 10 mM concentration of chelated ferric iron and 0.5 M concentration of H_2O_2. Chelated ferric iron was added as a ferric iron/EDTA complex in solution.
4.	Abiotic Control	Slurry in deionized water and 0.1 percent mercuric chloride ($HgCl_2$).
5.	Biotic Control	Slurry in deionized water.

For each treatment condition, a slurry was prepared using 50 mL of the ACW water (sludge) sample, 25 g of sterile soil, and 25 mL of sterile deionized water for each treatment condition. The controls were set up in the same manner. The initial total organic carbon (TOC) concentration of the water sample was determined to be 227 mg/L. Nutrient amendment was applied to each treatment by adding 0.04 g of Restore™. Restore™ is a proprietary blend of nutrients including: 5 percent ammonium chloride; 20 percent disodium phosphate; 12.5 percent monosodium phosphate; and 12.5 percent sodium tripolyphosphate. No nutrients were added to the abiotic or biotic controls. The abiotic control was established by adding 0.4 g of mercuric chloride ($HgCl_2$) to the treatment vessel.

Four replicates of the first three treatments were established so that one replicate could be sacrificed at each of four time points for TPH analysis. The treatments and the biotic control were placed on a shaker set at 120 revolutions per minute (rpm) and incubated at 25°C. The abiotic control was placed in a refrigerator at 4°C.

The treatments were sampled for TPH after 5, 10, 15, and 30 days. The treatments and controls were analyzed for SVOCs and PCDDs/PCDFs at the end of the study (Day 30). The abiotic and biotic controls were

sampled only for TPH measurements at the end of the study.

Performance: The results for the treatability study are presented in Table 5-7. Biotreatment without Fenton's Reagent reduced total PAH concentrations by 96 percent, and B(a)P potency estimates were reduced by 95 percent. PCP concentrations, however, were reduced by only 38 percent. When biotreatment was augmented with Fenton's Reagent plus ferric iron, the percent removal for total PAH was 93 percent, and the B(a)P potency estimate was reduced by greater than 93 percent. PCP was reduced by 85 percent.

Cost: Cost information was not presented in this study.

5.4.6 Treatability Study - MacGillis and Gibbs Superfund Site

Background/Site Description: In 1986, a treatability study on bioremediation was conducted at the MacGillis and Gibbs Company in Minneapolis, MN [EPA, 1991a]. Both MacGillis and Gibbs Company facilities have been used for wood preserving for several decades. Originally, creosote was used in the treatment; in the 1950s, PCP in oil was substituted. Also, for a period in the 1950s, waste PCP solution was used for weed control on the site.

A section of the MacGillis and Gibbs property, where disposal had frequently taken place, collected water and formed a pond. In the 1970s, MacGillis and Gibbs replaced PCP with the CCA process and substituted closed reactors for the open troughs, thus reducing the opportunities for inadvertent spills and leaks. As the result of an RI/FS, it was concluded that the soil and groundwater at the sites were contaminated with PCP and lesser concentrations of PAHs. Both sites were placed on the EPA NPL in 1984.

Summary of Study: A 30-gallon, packed-bed reactor was used in the 9-month pilot-plant study. The system was activated using indigenous microflora and later amended with inoculations of a *Flavobacterium* acclimated to PCP. The unit operated in a continuous mode for the duration of the study. Air was continuously injected to maintain aerobic conditions, and adjustments in pH and nutrients were made as necessary.

Performance: The results of this pilot-scale study are presented in Table 5-8. The packed-bed system was reported to have effectively removed PCP, PAHs, and other constituents that were found to be present. The specific rate of PCP degradation was as high as 70 mg of PCP/L of reactor volume/hr, well beyond the values normally reported in the literature. All PCP analyses were carried out using a HPLC method developed by the vendor. Extensive removal of PAHs was also confirmed. While substantial reductions in chemical oxygen demand (COD) also occurred, the levels in the effluent indicate the presence of considerable refractory material.

Cost: Cost information was not presented in this study.

Table 5-7. Selected Results - ACW Conventional Biological , Fenton's Reagent Augmented, and Fenton's Reagent Plus Ferric Iron Augmented Treatment [IT Corp. 1996b]

	Influent Results	Effluent Results					
		Biological		Fenton's Reagent		Fenton's Reagent + Ferric Iron	
Parameter	Conc.	Conc.	% Change[4]	Conc.	% Change[4]	Conc.	% Change[4]
PAHs, ppb							
Acenaphthene	77,625	10,000	-87	19,000	-76	9,000	-88
Acenaphthylene	2,377	420	-82	430	-82	160	-93
Anthracene	29,594	860	-97	4,400	-85	2,000	-93
Benz(a)anthracene[1]	18,436	1,100	-94	1,700	-91	730	-96
Benzo(b)fluoranthene[1]	10,188	550	-95	880	-91	380	-96
Benzo(k)fluoranthene[1]	4,852	250	-95	430	-91	190	-96
Benzo(ghi)perylene	1,844	120	-93	<3,200	NC	78	-96
Benzo(a)pyrene[1]	6,792	340	-95	560	-92	240	-96
Chrysene[1]	17,466	1,000	-94	1,700	-90	730	-96
Dibenz(a,h)anthracene[1]	631	40	-94	<3,200	NC	<330	>-48
Fluoranthene	121,289	6,500	-95	10,000	-92	4,600	-96
Fluorene	53,367	1,200	-98	13,000	-76	5,000	-91
Indeno(1,2,3-cd)pyrene[1]	2,329	140	-94	<3,200	NC	110	-95
2-Methylnaphthalene	82,476	<330	>-99	22,000	-73	9,900	-88
Naphthalene	44,634	36	~-100	15,000	-66	3,800	-91
Phenanthrene	194,062	220	~-100	28,000	-86	14,000	-93
Pyrene	58,219	3,900	-93	7,400	-87	2,800	-95
Total PAHs[2]	726,000	27,000	-96	130,000	-82	54,000	-93
B(a)P Potency Estimate[2]	10,600	560	-95	<4,300	>-59	<690	>-93
Other SVOCs, ppb							
Dibenzofuran	58,219	2,700	-95	12,000	-79	4,700	-92
Pentachlorophenol	77,625	48,000	-38	52,000	-33	12,000	-85
Phenol	631	530	-16	<3,200	NC	<330	>-48
2-Methylphenol	582	58	-90	<330	>-43	<330	>-43
4-Methylphenol	1,019	<330	>-67	440	-57	<330	>-67
2,4-Dimethylphenol	1,455	<330	>-77	<3,200	NC	<330	>-77
TCDD-TEQ, ppq[3]	NR	3,125,600	NC	3,883,000	NC	3,508,000	NC

1 Used in calculation of B(a)P potency factor [EPA, 1993a].
2 For nondetected (i.e., less than) results, the detection limit was used to calculate total PAHs and the B(a)P potency estimate.
3 TCDD-TEQ by I-TEFs/89 [EPA, 1989a]. Results reported in ppq.
4 Percent change is stated as a decrease (-) or increase (+).
NC = Not calculated

Table 5-8. Selected Results - MacGillis and Gibbs Packed-Bed Reactor Treatment [EPA, 1991a]

Parameter	Influent Concentration	Effluent Concentration	% Change[3]
PAHs, ppb			
Acenaphthene	2,041	140	-93
Acenaphthylene	4,402	ND	~-100[4]
Anthracene	252	20	-92
Benz(a)anthracene[1]	292	9	-97
Benzo(b)fluoranthene[1]	448	8	-98
Bezno(k)fluoranthene[1]	178	7	-96
Benzo(ghi)perylene	315	4	-99
Benzo(a)pyrene[1]	211	5	-98
Chrysene[1]	171	8	-95
Dibenz(a,h)anthracene[1]	296	33	-89
Fluoranthene	466	153	-67
Fluorene	545	ND	~-100[4]
Indeno(1,2,3-cd)pyrene[1]	203	ND	~-100[4]
2-Methylnaphthalene	NR	NR	NC
Naphthalene	1,932	81	-96
Phenanthrene	264	38	-86
Pyrene	232	15	-94
Total PAHs[2]	12,200	520	-96
B(a)P Potency Estimate	603	40[a]	-93
Other SVOCs, ppb			
Pentachlorophenol	93,000	ND	~-100[4]

1 Used in calculation of B(a)P potency estimate [EPA, 1989a]
2 Total PAHs does not include 2-methylnaphthalene. Since no detection limits were provided for nondetected results, a value of zero was assigned.
3 Percent change is stated in a decrease (-) or increase (+).
4 Detection limits were not presented for these compounds. The % change, therefore, is considered to approach 100.
a No detection limit was provided for the nondetected dibenz(a,h)anthracene in this sample; therefore, a value of zero was assigned for the ND in the calculation of the B(a)P potency estimate.

NC = Not calculated
ND = Not detected
NR = Not reported
Shaded row contains only NR and NC designations.

CHAPTER 6
SOURCES OF ADDITIONAL INFORMATION

6.1 Documents

EPA has published a series of Engineering Bulletins on topics that discuss most of the technologies included in this document. Table 6-1 lists these Engineering Bulletin sources for each of the 10 treatment categories and the EPA reference number that may be used to obtain the documents.

EPA has also published a series of "Innovative Site Remediation Technology" volumes that provide more detailed information regarding some of the technologies included in this document. Table 6-2 lists the volumes that are relevant to the technologies discussed in this document. This series was also published by the American Academy of Environmental Engineers®, 130 Holiday Court, Suite 100, Annapolis, Maryland 21401. In addition, the American Academy of Environmental Engineers® is currently publishing a second series that expands upon the information provided in the first set. The new series also addresses innovative technologies not included in the original series.

Table 6-1. Engineering Bulletin Sources

Treatment Category	Bulletin Subject	EPA Reference No.
Water Treatment		
Photolytic Oxidation	Chemical Oxidation	EPA/540/2-91/025, October 1991
Carbon Adsorption	Granular Activated Carbon	EPA/540/2-91/024, October 1991
Hydraulic Containment	Landfill Covers	EPA/540/5-93/500, February 1993
	Slurry Walls	EPA/540/5-92/500, October 1992
Bioremediation	Rotating Biological Contactors	EPA/540/5-92/007, October 1992
Soil Treatment		
Soil Washing	Soil Washing	EPA/540/2-90/017, September 1990
S/S Treatment	Solidification/Stabilization	EPA/540/5-92/015, July 1993
Thermal Desorption	Thermal Desorption	EPA/540/5-94/501, February 1994
Incineration	Mobile/Transportable Incineration	EPA/540/2-90/014, September 1990
Solvent Extraction	Solvent Extraction	EPA/540/5-94/503, April 1994
Base-Catalyzed Decomposition	Chemical Dehalogenation	EPA/540/2-90/015, September 1990
Bioremediation	*In Situ* Biodegradation	EPA/540/5-94/502, April 1994
	Slurry Biodedegradation	EPA/540/2-90/016, September 1990
	Composting	EPA/540/5-96/502, October 1996

Table 6-2. Innovative Site Remediation Technology Volumes

Treatment Category	Volume Number and Title	EPA Reference No.
Water Treatment		
Bioremediation	Vol. 1, Bioremediation	EPA/542/B-94/006
Soil Treatment		
Soil Washing	Vol. 3, Soil Washing/Soil Flushing	EPA/542/B-93/012
S/S Treatment	Vol. 4, Solidification/Stabilization	EPA/542/B-94/001
Thermal Desorption	Vol. 6, Thermal Desorption	EPA/542/B-93/011
Incineration	Vol. 7, Thermal Destruction	EPA/542/B-94/003
Solvent Extraction	Vol. 5, Solvent/Chemical Extraction	EPA/542/B-94/005
Base-Catalyzed Decomposition	Vol. 2, Chemical Treatment	EPA/542/B-94/004
Bioremediation	Vol. 1, Bioremediation	EPA/542/B-94/006

The Federal Remediation Technologies Roundtable, a consortium of Federal agencies, has compiled technology-specific case studies into a series of documents. These documents contain a number of studies conducted at wood preserving sites. Table 6-3 lists the documents and EPA reference numbers. Additional information on the development of these documents is available from the Technology Innovation Office within EPA'sOffice of Solid Waste and Emergency Response.

Other relevant EPA publications include treatability study guidance documents (including a general guide and several technology-specific guides) and Fact Sheets that accompany each of the technology-specific guides. Table 6-4 lists the Treatability Study Guidance Documents and Fact Sheets that are relevant to technologies discussed in this document.

Table 6-3. Technology-Specific Remediation Case Studies

Treatment Category	Title	EPA Reference No.
General	Abstracts of Remediation Case Studies	EPA/542/R-95/001
	Abstracts of Remediation Case Studies, Volume 2	EPA/542/R-97/010
Water Treatment		
Groundwater Treatment	Remediation Case Studies: Groundwater Treatment	EPA/542/R-95/003
Soil Treatment		
Bioremediation	Remediation Case Studies: Bioremediation	EPA/542/R-95/002
Soil Vapor Extraction	Remediation Case Studies: Soil Vapor Extraction	EPA/542/R-95/004
Thermal Desorption/Soil Washing/*In Situ* Vitrification	Remediation Case Studies: Thermal Desorption, Soil Washing, and *In Situ* Vitrification	EPA/542/R-95/005
Bioremediation/Vitrification	Remediation Case Studies: Bioremediation and Vitrification	EPA/542/R-97/008
Soil Vapor Extraction/Other *In Situ* Technologies	Remediation Case Studies: Soil Vapor Extraction and Other *In Situ* Technologies	EPA/542/R-97/009

Table 6-4. Treatability Study Guidance Sources

Treatment Category	Guide Subject	EPA Reference No.
General	Conducting Treatability Studies Under CERCLA	EPA/540/R-92/071a, October 1992
Soil Treatment		
Soil Washing	Soil Washing	EPA/540/2-91/020A, September 1991 (guide) EPA/540/2-91/020B, September 1991 (fact sheet)
Thermal Desorption	Thermal Desorption Remedy Selection	EPA/540/R-92/074A, September 1992 (guide) EPA/540/R-92/074B, September 1992 (fact sheet)
Solvent Extraction	Solvent Extraction	EPA/540/R-92/016a, August 1992 (guide) EPA/540/R-92/016b, August 1992 (fact sheet)
Base Catalyzed Decomposition	Chemical Dehalogenation	EPA/540/R-92/013a, May 1992 (guide) EPA/540/R-92/013b, May 1992 (fact sheet)
Bioremediation	Aerobic Biodegradation Remedy Screening	EPA/540/2-91/013A, July 1991 (guide) EPA/540/2-91/013B, July 1991 (fact sheet)
	Biodegradation Remedy Selection	EPA/540/R-93/519a, August 1993 (guide) EPA/540/R-93/519b, August 1993 (fact sheet)

Additional documents containing potentially useful information are as follows:

- U.S. Environmental Protection Agency. Presumptive Remedies for Soils, Sediments, and Sludges at Wood Treater Sites. Directive: 9200.5-162. EPA/540/R-95/128. 1995.
- U.S. Environmental Protection Agency. Contaminants and Remedial Options at Wood Preserving Sites. EPA/600/R-92/182. 1992.
- U.S. Environmental Protection Agency. Technology Screening Guide for Treatment f CERCLA Soils and Sludges. EPA/540/2-88/004. 1988.
- U.S. Environmental Protection Agency. Users Guide to the Presumptive Remedies for Soils, Sediments, and Sludges at Wood Treater Sites. EPA/540/R-96/024. In Press.

6.2 Databases

The databases in Table 6-4 contain information that may be relevant to the remediation of wood preserving sites. Most are operated by EPA and are accessible through the World Wide Webb.

Table 6-5. Databases Containing Additional Remediation Information

Database	Description	Access
Alternative Treatment Technology Information Center (ATTIC)	Contains information about uses of treatment technologies in Superfund actions	- Modem access: (513) 569-7610 - Telnet access: CINBBS.CIN.EPA.GOV - Voice assistance: (513) 569-7272
Cleanup Information (CLU-IN) Bulletin Board System (BBS)	Includes bulletins, downloadable databases, regulatory updates, and messages	- Modem access: (301) 589-8366 - Internet access: http://www.clu-in.com - Voice assistance: (301) 589-8368
Hazardous Waste Superfund Collection Data Base (HWSFD)	Contains bibliographic references and abstracts for documents in the Hazardous Waste Superfund Collection at EPA Headquarters Library	- Voice assistance: (800) 334-2405
National Technical Information Service (NTIS) Bibliographic Data Base	The largest single source for public access to Federally-produced information	- Available to the public through a number of commercial vendors, including the following: BRS, (800) 345-4277 CISTI (Canada), (800) 668-1222 DATA-STAR, (800) 221-7754 DIALOG, (800) 334-2564 ORBIT, (703) 442-0900 or (800) 456-7248 STN International, (800) 848-6533
Records of Decision System (RODS)	Contains the full text of the Superfund RODs for NPL sites nationwide	- To obtain a user ID through the National Data Processing Division, contact Mike Cullen: (703) 603-8881
Research and Development Electronic Bulletin Board	Includes on-line bibliography, public domain software and databases, and bulletins	- Modem access: (513) 569-7610 - Voice assistance: (513) 569-7272
Superfund Treatability Database, Version 5.0	Contains data from numerous treatability studies conducted under CERCLA	- Download from ORD BBS: (513) 569-7700 - Will be available from ORD home page: http://www.epa.gov/docs/ORD/BBS.html - contact: Glenn Shaul, (513) 569-7408
Vendor Field Analytical and Characterization Technology System (Vendor FACTS), Version 1.0	Contains vendor-supplied information regarding innovative technologies for hazardous waste characterization and analysis	- Download from Vendor FACTS home page: http://www.prcemi.com/VFACTS - Vendor FACTS hotline, (800) 245-4505
Vendor Information System for Innovative Treatment Technologies (VISITT), Version 5.0	Contains vendor-supplied information regarding innovative technologies for hazardous waste site remediation	- Download from VISITT home page: http://www.prcemi.com/VISITT - VISITT hotline, (800) 245-4505

CHAPTER 7
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APPENDIX A

LIST OF WOOD PRESERVING SITES

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
A.B. Carroll Lumber Co., Inc.	Hurtsboro	Alabama	IV	Unknown	Unknown	RCRA
Ala-Tenn Wood Preservers (McKinney Lumber)	Sheffield	Alabama	IV	W	Yes	Other (4)
Alabama-Georgia Wood Preserving Co.	LaFayette	Alabama	IV	W	Yes	RCRA
Alabama Wood Treating Site (ASD)	Mobile	Alabama	IV	Unknown	Unknown	RCRA
Allstate Treating & Lumber Mfgr.	Tuscumbia	Alabama	IV	W	Yes	RCRA
Baldwin Pole & Piling Company, Inc.	Bay Minette	Alabama	IV	W,P	Yes	RCRA
Birmingham Wood, Inc.	Warrior	Alabama	IV	Unknown	Unknown	RCRA
Birmingham Wood Preserving, Inc.	Birmingham	Alabama	IV	Unknown	Unknown	RCRA
Brown Wood Preserving Company, Inc.	Kennedy	Alabama	IV	W	Yes	RCRA
Brown Wood Preserving Company, Inc.	Northport	Alabama	IV	C,P	Yes	RCRA (5)
Cahaba Pressure Treated Forest Products	Brierfield	Alabama	IV	W,C,P	Yes	RCRA
Cavenham Forest Industries, Inc.	Mobile	Alabama	IV	Unknown	Unknown	RCRA
Centreville Lumber Co./ Hampton Lumber	Centreville	Alabama	IV	W	Yes	Other (4)
Crosby Lumber Co., Inc.	Bay Minette	Alabama	IV	W	Yes	Other (4)
Diamond Wood Treating Inc.	Decatur	Alabama	IV	W	Yes	RCRA
Everwood Treatment	Irvington	Alabama	IV	Unknown	Unknown	RCRA
Everwood Treatment Co.	Spanish Fort	Alabama	IV	W	Yes	RCRA
Free State Lumber Co.	Haleyville	Alabama	IV	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Fullco Lumber Company, Inc.	Haleyville	Alabama	IV	Unknown	Unknown	RCRA
Great Southern Forest Products	Haleyville	Alabama	IV	W	Yes	RCRA
Great Southern Wood Preserving, Inc.	Abbeville	Alabama	IV	W, FRT	Yes	RCRA
Great Southern Wood Preserving, Inc.	Irvington	Alabama	IV	W	Yes	RCRA
Gulf Lumber Co., Inc.	Mobile	Alabama	IV	W	Yes	RCRA
Huntsville Wood Products	Huntsville	Alabama	IV	W	Yes	Other (4)
Huxford Pole & Timber Co.	Huxford	Alabama	IV	C,P	Yes	RCRA
Kennedy Processing, Inc.	Kennedy	Alabama	IV	Unknown	Unknown	RCRA
Koppers Industries, Inc.	Montgomery	Alabama	IV	W,C,P	Yes	RCRA
Lee Lumber Co.	Centreville	Alabama	IV	W	Yes	Other (4)
Littrell Brothers Lumber Co.	Vinemont	Alabama	IV	W	Yes	RCRA
Louisiana-Pacific Corp.	Evergreen	Alabama	IV	W	Yes	Other (4)
Louisiana-Pacific Corp.	Lockhart	Alabama	IV	W	Yes	RCRA
McShan Lumber Co., Inc.	McShan	Alabama	IV	W	Yes	RCRA
Mellco Inc.	Athens	Alabama	IV	W	Yes	Other (4)
Olon Belcher Lumber Co., Inc.	Brent	Alabama	IV	Unknown	Unknown	RCRA
Rafter King, Inc.	Lynn	Alabama	IV	W	Yes	Other (4)
Richardson Brothers Wood Preserving	Northport	Alabama	IV	Unknown	Unknown	RCRA
Scotch Lumber Company, Inc.	Fulton	Alabama	IV	Unknown	Unknown	RCRA

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Seaman Timber Co., Inc.	Montevallo	Alabama	IV	W,C	Yes	RCRA
Sillavan Lumber Co.	Saginaw	Alabama	IV	W	Yes	Other (4)
Southeast Wood Treating	Jasper	Alabama	IV	W	Yes	RCRA
Southeast Wood Treating	Louisville	Alabama	IV	W	Yes	Other (4)
Southeast Wood Treating	Nauvoo	Alabama	IV	W	Yes	RCRA
Southern Lumber Sales Co.	Saginaw	Alabama	IV	W	Yes	Other (4)
Springer Lumber Co./Treatment Div.	Millport	Alabama	IV	Unknown	Unknown	RCRA
Stallworth Timber Co., Inc.	Beatrice	Alabama	IV	W,C,P	Yes	RCRA
Swift Lumber Inc.	Atmore	Alabama	IV	W	Yes	Other (4)
T.R. Miller Mill Co., Inc.	Brewton	Alabama	IV	W,P	Yes	RCRA
Valley Lumber Co.	Hackleburg	Alabama	IV	W	Yes	Other (4)
W.T. Vick Lumber Company, Inc.	Hamilton	Alabama	IV	Unknown	Unknown	RCRA
Walker-Williams Lumber Co.	Falkville	Alabama	IV	W	Yes	Other (4)
Walker-Williams Lumber Co.	Hatchechubbee	Alabama	IV	W	Yes	RCRA
Weyerhaeuser Co.	Millport	Alabama	IV	W	Yes	Other (4)
Willamina Lumber Company	Certreville	Alabama	IV	Unknown	Unknown	RCRA
Willis Gerald Lumber Co.	Piedmont	Alabama	IV	Unknown	Unknown	RCRA
Arizona Pacific Wood Preserving	Eloy	Arizona	IX	W,C,FRT	Yes	RCRA
Ponderosa Timber Co.	Stanfield	Arizona	IX	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Southwest Forest Ind.	Prescott	Arizona	IX	Unknown	Unknown	RCRA
Anthony Wood Treating	Hope	Arkansas	VI	W	Yes	Other (4)
Arkwood, Inc.	Omaha	Arkansas	VI	C,P	No	NPL,RCRA
Commercial Lumber Sales	N. Little Rock	Arkansas	VI	W	Yes	Other (4)
Curt Bean Lumber Co.	Amity	Arkansas	VI	W	Yes	Other (4)
Curt Bean Lumber Co.	Glenwood	Arkansas	VI	W	Yes	Other (4)
Durapost	Rogers	Arkansas	VI	W	Yes	Other (4)
Fordyce Wood Preservers, Inc.	Fordyce	Arkansas	VI	Unknown	Unknown	RCRA
Hatfield Lumber Co.	Hatfield	Arkansas	VI	W	Yes	Other (4)
Hermitage Wood Prod.	Hermitage	Arkansas	VI	Unknown	Unknown	RCRA
Hixson Lumber Sales Co.	Pine Bluff	Arkansas	VI	W	Yes	Other (4)
Hixson Lumber Sales Co.	Plumerville	Arkansas	VI	W	Yes	Other (4)
Hoover Treated Wood Products, Inc.	Pine Bluff	Arkansas	VI	W,FRT	Yes	RCRA
Koppers Industries, Inc.	N. Little Rock	Arkansas	VI	C	Yes	RCRA
Lewis Lumber & Mfg. Co.	Cove	Arkansas	VI	W	Yes	Other (4)
M.M. Barksdale Lumber Co., Inc.	Amity	Arkansas	VI	W	Yes	Other (4)
Mid-South Wood Products	Mena	Arkansas	VI	W,C,P	No	NPL
Mountain Pressure Pine Treating	Plainview	Arkansas	VI	W,P	No	RCRA (5)
Old Midland Products	Ola	Arkansas	VI	C,P	No	NPL

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Ozark Timber, Inc.	St. Joe	Arkansas	VI	Unknown	Unknown	RCRA
Plainview Lumber Company	Plainview	Arkansas	VI	Unknown	Unknown	RCRA
Popile, Inc.	El Dorado	Arkansas	VI	C,P	No	NPL, RCRA
Rison Wood Products, Inc.	Rison	Arkansas	VI	W	Yes	Other (4)
Scott Lumber	Unknown	Arkansas	VI	C	No	Non-NPL (5)
Sentinel Industries, Inc.	Herber Springs	Arkansas	VI	W	Yes	Other (4)
Sentinel Industries, Inc./ Banner Properties	Calico Rock	Arkansas	VI	W	Yes	RCRA
Skyes Flooring Products	Warren	Arkansas	VI	Unknown	Unknown	RCRA
Thompson Industries, Inc.	Russellville	Arkansas	VI	W,C	Yes	Other (4)
Weyerhauser Company	DeQueen	Arkansas	VI	P	Yes	RCRA
B.J. Carney & Co.	Madera	California	IX	Unknown	Unknown	RCRA
California Cascade Industries	Fontana	California	IX	W	Yes	Other (4)
California Cascade Industries	Woodland	California	IX	W	Yes	Other (4)
Coast Wood Preserving	Ukiah	California	IX	W	No	NPL,RCRA
Fontana Wood Preserving, Inc.	Fontana	California	IX	W	Yes	Other (4)
J.H. Baxter & Co.	Long Beach	California	IX	W,P	Yes	RCRA
J.H. Baxter & Co.	Weed	California	IX	W,C,P, FRT	Yes	NPL,RCRA
Koppers Company, Inc.	Ontario	California	IX	Unknown	Unknown	RCRA

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Koppers Industries, Inc.	Oroville	California	IX	W,C, CuNap, P	Yes	NPL,RCRA
Louisiana-Pacific Corp.	Oroville	California	IX	W,C,P	No	NPL
Louisiana-Pacific Corp.	Ukiah	California	IX	W	Yes	Other (4)
Marley Cooling Tower Co.	Stockton	California	IX	W	No	RCRA (5)
McCormick & Baxter Creosoting Co.	Stockton	California	IX	C,P	No	NPL,RCRA
Pacific Wood Pres. of Bakersfield	Bakersfield	California	IX	W,C	Yes	Other (4)
San Diego Wood Preserving Co.	National City	Calfornia	IX	W,P	Yes	Other (4)
Selma Pressure Treating Co.	Selma	California	IX	W,P	No	NPL,RCRA
Sequoia Wood Products	Elmira	California	IX	Unknown	Unknown	RCRA
Southern California Edison Co. (Visalia Poleyard)	Visalia	California	IX	C,P	No	NPL
Thunderbolt Wood Treating Co.	Riverbank	California	IX	W	Yes	Other (4)
Valley Wood Preserving, Inc.	Turlock	California	IX	W	No	NPL
Western Wood Treating, Inc.	Woodland	California	IX	--	Yes	Other (4)
Broderick Wood Products	Denver	Colorado	VIII	W,C,P	No	NPL
Colorado Pacific Industries, Inc.	Loveland	Colorado	VIII	W	Yes	Other (4)
Colorado Wood Products	Ft. Collins	Colorado	VIII	W	Yes	Other (4)
Koppers Industries, Inc.	Denver	Colorado	VIII	W,C,FRT	Yes	RCRA
Ponderosa Timber Co., Inc.	Dolores	Colorado	VIII	--	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Universal Forest Products	Windsor	Colorado	VIII	W	Yes	Other (4)
Bauer Aerospace	Avon	Connecticut	I	Unknown	Unknown	RCRA
Ensign Bickford Co.	Simsbury	Connecticut	I	Unknown	Unknown	RCRA
Perma Treat Corp.	Durham	Connecticut	I	C	Yes	Other (4)
Koppers Co., Inc.	Newport	Delaware	III	Unknown	No	NPL
Seaboard Lumber	Bridgeville	Delaware	III	Unknown	Unknown	RCRA
Sealand Ltd., and Oil Industry	Mount Pleasant	Delaware	III	C	No	NPL
Aljoma Lumber Inc.	Miami	Florida	IV	W	Yes	Other (4)
American Creosote Works, Inc.	Pensacola	Florida	IV	C,P	No	NPL
Anchor Fence Wholesalers	Hialeah	Florida	IV	W	Yes	Other (4)
Apalachee Pole Co., Inc.	Bristol	Florida	IV	W	Yes	RCRA
Arnold Lumber Co.	Bonifay	Florida	IV	W	Yes	RCRA
Beazer East, Inc.	Gainesville	Florida	IV	Unknown	Unknown	RCRA
Brown Wood Preserving	Live Oak	Florida	IV	C,P	No	Deleted from NPL, 9/22/95
Coastal Lumber Co.	Havana	Florida	IV	W	Yes	RCRA
Coleman Evans Wood Preserving Co.	Jacksonville	Florida	IV	P	No	NPL,RCRA
Cook Lumber & Treating	Lake Worth	Florida	IV	W	Yes	RCRA
Cook Lumber & Treating	Tampa	Florida	IV	W	Yes	RCRA
Creosote Tanks/Tallyrand Road	Jacksonville	Florida	IV	C,P	No	Non-NPL (5)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Dantzler Lumber & Export, Co., Inc.	Jacksonville	Florida	IV	W	Yes	RCRA
Dantzler Lumber Co.	Pompano Beach	Florida	IV	Unknown	Unknown	RCRA
E.D. Cook Lumber Co.	Orlando	Florida	IV	W	Yes	RCRA
Escambia Wood	Pensacola	Florida	IV	C	No	NPL,RCRA
Florida DEP SE District	West Palm Beach	Florida	IV	Unknown	Unknown	RCRA
Florida Fence Post Co., Inc.	Ona	Florida	IV	W	Yes	RCRA
Florida Perma-Wood Treaters, Inc.	Hialeah	Florida	IV	W	Yes	RCRA
Florida Steel	Unknown	Florida	IV	C	No	Non-NPL (5)
Foley Timber & Land Co.	Perry	Florida	IV	Unknown	Unknown	RCRA
Georgia Pacific Corp.	Palatka	Florida	IV	Unknown	Unknown	RCRA
Georgia Pacific Corp.	Lake Placid	Florida	IV	Unknown	Unknown	RCRA
Georgia Pacific Corp.	Chiefland	Florida	IV	Unknown	Unknown	RCRA
Georgia Pacific Corp. Chip N Saw	Cross City	Florida	IV	Unknown	Unknown	RCRA
Great Southern Wood Preserving, Inc.	Bushnell	Florida	IV	W	Yes	RCRA
ITT Rayonier Bunnell Lumber Div.	Bunnell	Florida	IV	Unknown	Unknown	RCRA
Koppers Industries	Gainesville	Florida	IV	W	Yes	NPL
Lindsley Lumber	Dania	Florida	IV	P	No	Non-NPL (5)
Longleaf Forest Products, Inc.	DeLand	Florida	IV	W	Yes	RCRA

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Louisiana-Pacific Corp.	Cypress	Florida	IV	W	Yes	RCRA
Mar Ked Inc.	Tallahassee	Florida	IV	Unknown	Unknown	RCRA
North Florida Lumber, Inc.	Graceville	Florida	IV	W	Yes	Other (4)
O.S. Bailey Wood Preserving, Inc.	Graceville	Florida	IV	Unknown	Unknown	RCRA
Pensacola Wood Treating, Inc.	Pensacola	Florida	IV	Unknown	Unknown	RCRA
Perry Lumber Co., Inc.	Perry	Florida	IV	Unknown	Unknown	RCRA
Post & Lumber Preserving Co., Inc.	Quincy	Florida	IV	Unknown	Unknown	RCRA
Ridge Lumber & Treating, Inc.	Lakeland	Florida	IV	W	Yes	RCRA
Robbins Manufacturing Co.	Ft. Myers	Florida	IV	W	Yes	RCRA
Robbins Manufacturing Co.	Lockhart	Florida	IV	W	Yes	RCRA
Robbins Manufacturing Co.	Tampa	Florida	IV	W	Yes	RCRA
Southeast Wood Treating, Inc.	Rockledge	Florida	IV	W	Yes	Other (4)
Southern Wood Piedmont Co.	Baldwin	Florida	IV	Unknown	Unknown	RCRA
Southern Lumber & Treating Co., Inc.	Jacksonville	Florida	IV	W	Yes	Other (4)
Sunbelt Forest Products Corp.	Bartow	Florida	IV	W	Yes	RCRA
Total Distribution Systems, Inc.	Jacksonville	Florida	IV	Unknown	Unknown	RCRA
Unisys Corp.	Oldsmar	Florida	IV	Unknown	Unknown	RCRA
Universal Forest Products	Auburndale	Florida	IV	W	Yes	RCRA
USN Navy Public Works Center	Pensacola	Florida	IV	Unknown	Unknown	RCRA

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Wood Protection of Jacksonville, Inc.	Jacksonville	Florida	IV	Unknown	Unknown	RCRA
Wood Treaters, Inc.	Jacksonville	Florida	IV	W	Yes	Other (4)
A.B.C. Wood Treating	Suwanee	Georgia	IV	W	Yes	Other (4)
Ace Pole Company	Waycross	Georgia	IV	W	Yes	Other (4)
Atlanta Pressure Treated Lumber Co.	College Park	Georgia	IV	W	Yes	Other (4)
Atlantic Wood Industries, Inc.	Port Wentworth	Georgia	IV	Unknown	Unknown	RCRA
Atlantic Wood Industries, Inc.	Savannah	Georgia	IV	C,P	Yes	Other (4)
Atlantic Wood Industries, Inc.	Vidalia	Georgia	IV	W	Yes	RCRA
Augusta Wood Preserving Co., Inc.	Augusta	Georgia	IV	Unknown	Unknown	RCRA
B&M Wood Products, Inc.	Manor	Georgia	IV	W,C	Yes	Other (4)
Babb Lumber Co., Inc.	Ringgold	Georgia	IV	W	Yes	Other (4)
Baxley Creosoting Co., Inc.	Baxley	Georgia	IV	W,C	Yes	RCRA
Brunswick Wood Preserving	Brunswick	Georgia	IV	C,P	No	Proposed NPL
Carribean Lumber Co.	Pollen	Georgia	IV	W	Yes	Other (4)
Champion International Corp.	East Point	Georgia	IV	Unknown	Unknown	RCRA
Cleveland Wood Preserving	Cleveland	Georgia	IV	W	Yes	Other (4)
Continental Forest Industries	Statesboro	Georgia	IV	Unknown	Unknown	RCRA
Cook County Wood Preserving	Adel	Georgia	IV	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Cox Wood Preserving Co. (Augusta Wood)	Augusta	Georgia	IV	W	Yes	Non-NPL (5)
D&D Wood Preserving, Inc.	Albany	Georgia	IV	W	Yes	RCRA
Dickerson Post Treating	Homeville	Georgia	IV	C,P	No	Non-NPL (5)
Escambia Wood	Camilla	Georgia	IV	P	No	RCRA (5)
Escambia Treating Company, Inc.	Brunswick	Georgia	IV	Unknown	Unknown	RCRA
Georgia Lumber Co.	Covington	Georgia	IV	W	Yes	Other (4)
Georgia Pacific Corp.	Durand	Georgia	IV	Unknown	Unknown	RCRA
Georgia Pacific	Pearson	Georgia	IV	Unknown	Unknown	RCRA
Georgia Wood Preserving Co., Inc.	Crawfordville	Georgia	IV	W	Yes	RCRA
Georgia Pacific Corp. Timber Div.	Clyo	Georgia	IV	Unknown	Unknown	RCRA
Georgia Pacific Corp. Timber	Milledgeville	Georgia	IV	Unknown	Unknown	RCRA
Glennville Wood Preserving Co., Inc.	Glennville	Georgia	IV	C	Yes	RCRA
Great Southern Wood Preserving, Inc.	Conyers	Georgia	IV	W	Yes	Other (4)
Hogan Lumber Company	Athens	Georgia	IV	W	Yes	RCRA
Hoover Treated Wood Products, Inc.	Thomson	Georgia	IV	W,FRT	Yes	Other (4)
Keadle Treating Co., Inc.	Thomaston	Georgia	IV	W	Yes	Other (4)
Langdale Forest Products Co.	Valdosta	Georgia	IV	W	Yes	RCRA
Lawrence Smith Planning Mill, Inc.	Atlanta	Georgia	IV	W	Yes	Other (4)
Louisiana-Pacific Corporation	Statesboro	Georgia	IV	W	Yes	RCRA

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Louisiana-Pacific Corporation	Waynesboro	Georgia	IV	W	Yes	RCRA
Manor Timber Co, Inc.	Manor	Georgia	IV	W,C	Yes	RCRA
Moultrie Wood Preserving Co.	Moultrie	Georgia	IV	Unknown	Unknown	RCRA
Mt. Airy Wood Preserving, Inc.	Clarkesville	Georgia	IV	W	Yes	RCRA
Narjoe Timber and Supply Co.	Atlanta	Georgia	IV	W	Yes	Other (4)
Piedmont Building Products	Warner Robins	Georgia	IV	W	Yes	Other (4)
Pine Wood Products, Inc.	Gainesville	Georgia	IV	W	Yes	Other (4)
Pollard Lumber Co., Inc.	Appling	Georgia	IV	W	Yes	Other (4)
Randall Bros.	Atlanta	Georgia	IV	Unknown	Unknown	RCRA
S.I. Storey Lumber Co., Inc.	Armuchee	Georgia	IV	W	Yes	Other (4)
Savannah Wood Preserving, Inc.	Savannah	Georgia	IV	W	Yes	RCRA
Shearouse Lumber Co.	Pooler	Georgia	IV	W	Yes	Other (4)
Simco Wood Preserving Co.	Commerce	Georgia	IV	W	Yes	Other (4)
Smith-Evans Lumber Co.	Rome	Georgia	IV	Unknown	Unknown	RCRA
Southern Wood Piedmont Company	Augusta	Georgia	IV	Unknown	Unknown	RCRA
Southern Wood Piedmont Company	East Point	Georgia	IV	Unknown	Unknown	RCRA
Southern Wood Piedmont Company	Macon	Georgia	IV	Unknown	Unknown	RCRA
St. Beaumill Corporation	Milnrt	Georgia	IV	Unknown	Unknown	RCRA
St. Regis Allied Operations	Woodbine	Georgia	IV	Unknown	Unknown	RCRA

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Tolleson Lumber Co., Inc.	Fitzgerald	Georgia	IV	Unknown	Unknown	RCRA
Tolleson Lumber Co., Inc.	Perry	Georgia	IV	W	Yes	RCRA
Top Notch Wood Preserving	Eatonton	Georgia	IV	W	Yes	RCRA
Union Camp Corp. DBA Thomas Treating Co.	Folkston	Georgia	IV	Unknown	Unknown	RCRA
Union Timber Corp.	Homerville	Georgia	IV	C	Yes	RCRA
Universal Forest Products	Union City	Georgia	IV	W	Yes	RCRA
Varn Wood Products	Hoboken	Georgia	IV	W	Yes	Other (4)
W.C. Meredith Co.	East Point	Georgia	IV	P	Yes	RCRA
W.F. Harris & Sons Wood Preserving Co.	Thomaston	Georgia	IV	Unknown	Unknown	RCRA
Wilkes Wood Products	Washington	Georgia	IV	W	Yes	Other (4)
Hawaii Wood Preserving Co. (D.A. Enterprises)	Kahului, Maui	Hawaii	IX	W	Yes	RCRA
Hilo Wood Treating Co., Ltd.	Hilo	Hawaii	IX	W	Yes	RCRA
Honolulu Wood Treating Co., Ltd.	Ewa Beach	Hawaii	IX	W	Yes	RCRA
HPM Building Supply	Hilo	Hawaii	IX	W	Yes	Other (4)
Maui Wood Treating Co., Ltd.	Puunene, Maui	Hawaii	IX	Unknown	Unknown	RCRA
MIDPAC Lumber Co., Ltd.	Honolulu	Hawaii	IX	W	Yes	Other (4)
Wood Protection Co.	Hilo	Hawaii	IX	Unknown	Unknown	RCRA
B.J. Carney Industries, Inc.	Sandpoint	Idaho	X	Unknown	Unknown	RCRA

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Fulton & Lighty, Inc.	Hayden Lake	Idaho	X	W	Yes	Other (4)
L.D. McFarland Co., Ltd.	Sandpoint	Idaho	X	P	Yes	Other (4)
North Idaho Wood Preserving Co.	Rathdrum	Idaho	X	W	Yes	Other (4)
Penta Post & Training Co., Inc.	Tuttle	Idaho	X	P	Yes	Other (4)
Pressure Treated Lumber Co.	Boise	Idaho	X	W	Yes	Other (4)
Union Pacific Railroad Co.	Pocatello	Idaho	X	Unknown	No	NPL
Beazer East, Inc.	Carbondale	Illinois	V	Unknown	Unknown	RCRA
Beazer East, Inc.	Galesburg	Illinois	V	Unknown	Unknown	RCRA
Chicago Flameproof & Wood Preserving	Chicago	Illinois	V	W	Yes	Other (4)
Hager Wood Preserving Co., Inc.	Forrest	Illinois	V	W	Yes	Other (4)
Illinois Wood Preserving, Inc.	Hillsboro	Illinois	V	W	Yes	Other (4)
Jennison-Wright Corp. Site	Granite City	Illinois	V	C,P	No	Non-NPL (5)
John A. Biewer Co./Illinois	Seneca	Illinois	V	W	Yes	Other (4)
Joslyn Mfg. Co	Franklin Park	Illinois	V	Unknown	Unknown	RCRA
Kerr-McGee Chemical Corp.	Madison	Illinois	V	C	Yes	RCRA
Koppers Industries, Inc.	Galesburg	Illinois	V	C,P	Yes	NPL
Northern Illinois Lumber Specialties	Montgomery	Illinois	V	W	Yes	Other (4)
Perma-Treat of Illinois, Inc.	Marion	Illinois	V	W	Yes	Other (4)
Rocky Top Wood Preservers, Inc.	Streator	Illinois	V	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Carter Lee Lumber Co.	Indianapolis	Indiana	V	W,C	No	Unclear (6)
Culpeper Wood Preservers	Shelbyville	Indiana	V	W	Yes	Other (4)
Foster Wood Products	Winslow	Indiana	V	Unknown	Unknown	RCRA
Hoosier Treating Co.	Indianapolis	Indiana	V	C,P	Yes	RCRA
Indiana Wood Treating	Unknown	Indiana	V	Unknown	Unknown	Other (4)
Kerr-McGee Chemical Corp.	Indianapolis	Indiana	V	C	Yes	RCRA
Peters Revington Furniture	Delphi	Indiana	V	Unknown	Unknown	RCRA
Reilly Tar & Chemical Corp.	Indianapolis	Indiana	V	Unknown	No	NPL
Southern Indiana Treating	Huntingburg	Indiana	V	W	Yes	Other (4)
Universal Forest Products	Granger	Indiana	V	W	Yes	Other (4)
Walker-Williams Lumber Co., Inc.	Westville	Indiana	V	W	Yes	Other (4)
Western Tar Products Corp.	Terre Haute	Indiana	V	C	Yes	Other (4)
City of Muscatine, Orange Street Site	Muscatine	Iowa	VII	Unknown	Unknown	RCRA
Indiana Wood Preserving, Inc.	Oskaloosa	Iowa	VII	W	Yes	Other (4)
Musser Storage Area (DSA)	Muscatine	Iowa	VII	Unknown	Unknown	RCRA
Shimek Forest HQ Wood Treat.	Farmington	Iowa	VII	Unknown	Unknown	RCRA
St. Regis Paper Co.	Des Moines	Iowa	VII	Unknown	Unknown	RCRA
Timmons Storage Area	Muscatine	Iowa	VII	Unknown	Unknown	RCRA
Tri-State Forest Products, Inc.	Dubuque	Iowa	VII	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Washington Storage Area	Muscatine	Iowa	VII	Unknown	Unknown	RCRA
Appalachian Timber Svcs., Inc.	White Plains	Kentucky	IV	Unknown	Unknown	RCRA
Brown Wood Preserving Co., Inc.	Louisville	Kentucky	IV	Unknown	Unknown	RCRA
Burke-Parsons-Bowlby Corp.	Stanton	Kentucky	IV	W,C	Yes	Other (4)
Easterday Tie & Timber Co., Inc.	Mayfield	Kentucky	IV	C	Yes	RCRA
Escue Wood Products	Millwood	Kentucky	IV	W	Yes	RCRA
Kentucky Wood Pres. Of Winchester	Winchester	Kentucky	IV	W	Yes	RCRA
Kermit Lumber Company	Warfield	Kentucky	IV	Unknown	Unknown	RCRA
Koppers Industries, Inc.	Guthrie	Kentucky	IV	C	Yes	RCRA
Nell Banks Campton Site	Campton	Kentucky	IV	Unknown	Unknown	RCRA
Pioneer Wood Preserving	Leitchfield	Kentucky	IV	W	Yes	Other (4)
Quality Forest Products, Inc.	Walton	Kentucky	IV	W	Yes	RCRA
Southern Wood Treatment Co.	Winchester	Kentucky	IV	W	Yes	RCRA
Tri-Co Wood Preserving	Corbin	Kentucky	IV	Unknown	Unknown	RCRA
Wood Treatment Co., Inc.	Mt. Sterling	Kentucky	IV	Unknown	Unknown	RCRA
American Creosote	Winnfield	Lousiana	VI	C,P	No	NPL
Arnold Forest Products Corp.	Shreveport	Louisiana	VI	W	Yes	RCRA
Bayou Bonfouca	Slidell	Louisiana	VI	C,P	No	NPL
Benton Creosoting Works/Kennedy Saw Mills, Inc.	Benton	Louisiana	VI	C	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Cavenham Forest Ind., Inc., Treated Wd. Div.	Urania	Louisiana	VI	Unknown	Unknown	RCRA
Central Wood Preserving, Inc.	Slaughter	Louisiana	VI	Unknown	Unknown	RCRA
Clemons Bros. Lumber Co., Inc.	Amite	Louisiana	VI	Unknown	Unknown	RCRA
Colfax Creosoting Co.	Pineville	Louisiana	VI	C,P	Yes	RCRA
Dis-Tran Wood Products, Inc.	Pineville	Louisiana	VI	P	Yes	RCRA
Dura-Wood Treating Co.	Alexandria	Louisiana	VI	C	Yes	RCRA
Elco Forest Products (Silco)	Opelousas	Louisiana	VI	W	Yes	RCRA
Elder Wood Preserving Co., Inc.	Mansura	Louisiana	VI	W	Yes	RCRA
EVR Wood Treating Co., Inc.	Jennings	Louisiana	VI	Unknown	Unknown	RCRA
Hill-Behan Lumber Company	Harahan	Louisiana	VI	Unknown	Unknown	RCRA
International Paper Co.	DeRidder	Louisiana	VI	C	Yes	RCRA
International Paper Co.	Jena	Louisiana	VI	Unknown	Unknown	RCRA
Kerr McGee Chemical Corp.	Bossier City	Louisiana	VI	Unknown	Unknown	RCRA
Koppers Industries, Inc.	Logansport	Louisiana	VI	C	Yes	Other (4)
L.L. Brewton Lumber Co., Inc.	Winnfield	Louisiana	VI	W	Yes	Other (4)
Louisiana Treated Lumber, Inc.	Kenner	Louisiana	VI	W	Yes	Other (4)
Madisonville Creosote Works	Madisonville	Louisiana	VI	C	Yes	NPL,RCRA
Manville Products Co., Inc., Treat. Plant 94	Shreveport	Louisiana	VI	Unknown	Unknown	RCRA

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Marion Pressure Treating Co.	Marion	Louisiana	VI	Unknown	Unknown	RCRA
Maurin Wood Preserving Co.	Hammond	Louisiana	VI	Unknown	Unknown	RCRA
Mid-States Wood Preservers,Inc.	Simsboro	Louisiana	VI	W	Yes	RCRA
Oliver Treated Products, Inc.	Hammond	Louisiana	VI	Unknown	Unknown	RCRA
Olivier-Celcure Wood Preserving	New Orleans	Louisiana	VI	W	Yes	Other (4)
Reddell Creosoted Forest Products	Reddell	Louisiana	VI	Unknown	Unknown	RCRA
Standard Wood Preservers, Shreveport	Shreveport	Louisiana	VI	Unknown	Unknown	RCRA
Superior Tie & Timber	Vivian	Louisiana	VI	C	Yes	RCRA
Zytech, Inc.	Pine Grove	Louisiana	VI	Unknown	Unknown	RCRA
Industrial Box and Lumber	Parson Field (Kezar Falls)	Maine	I	P	No	Non-NPL (5)
Maine Wood Treaters, Inc.	Mechanic Falls	Maine	I	W,CuNap	Yes	Other (4)
Atlantic Wood Industries, Inc.	Fruitland	Maryland	III	W	Yes	RCRA
Cropper Bros. Lumber	Willards	Maryland	III	Unknown	Unknown	RCRA
F. Smith Bowie & Son, Inc.	Baltimore	Maryland	III	Unknown	Unknown	RCRA
Koppers Co., Inc.	Salisbury	Maryland	III	Unknown	Unknown	RCRA
Long Life Treated Wood, Inc.	Hebron	Maryland	III	W	Yes	Other (4)
Maryland Wood Preservers Corp.	Rockville	Maryland	III	W	Yes	Other (4)
Mid-Atlantic Wood Preservers	Harmans	Maryland	III	W	No	NPL,RCRA
Reliance Wood Preserving Co., Inc.	Federalsburg	Maryland	III	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Rocky Top Wood Preservers, Inc.	Hagerstown	Maryland	III	W	Yes	Other (4)
Southern Maryland Wood Treating Corp.	Hollywood	Maryland	III	C	No	NPL
Universal Forest Products	North East	Maryland	III	W	Yes	Other (4)
Bestway Enterprises, Inc./New England	S. Lancaster	Massachusetts	I	W	Yes	Other (4)
Cabot Samuel, Inc.	Chelsea	Massachusetts	I	Unknown	Unknown	RCRA
Charleston Navy Yard	Boston	Massachusetts	I	C	Unknown	Other (4)
Hatheway & Patterson Co., Inc.	Mansfield	Massachusetts	I	Unknown	Unknown	RCRA
Hocomonco Pond	Westborough	Massachusetts	I	C	No	NPL
Northeast Treaters, Inc.	Belchertown	Massachusetts	I	W	Yes	Other (4)
Saloom Furniture, Inc.	Gardner	Massachusetts	I	Unknown	Unknown	RCRA
Universal Forest Products	Belchertown	Massachusetts	I	W	Yes	Other (4)
Continental Wood Preservers, Inc.	Detroit	Michigan	V	W,FRT	Yes	Other (4)
Forest Waste Products	Otisville	Michigan	V	Unknown	No	NPL
Gilbert & Bennett Co.	Carney	Michigan	V	W	Yes	Other (4)
Hager Wood Preserving Co., Inc.	Grand Rapids	Michigan	V	W	Yes	Other (4)
Hydrolake Leasing & Service Co.	McBain	Michigan	V	W	Yes	Other (4)
John A. Biewer Co./Michigan	Schoolcraft	Michigan	V	W	Yes	Other (4)
John A. Biewer Co./Michigan	St. Clair	Michigan	V	W	Yes	Other (4)
Lake States Wood Preserving	Munishing	Michigan	V	P	No	RCRA (5)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Midwest Timber, Inc.	Edwardsburg	Michigan	V	W	Yes	Other (4)
Quality Wood Treating Co., Inc.	Lansing	Michigan	V	W	Yes	Other (4)
Straits Wood Treating, Inc.	Tawas City	Michigan	V	W	Yes	Other (4)
Weyerhauser Co.	Westland	Michigan	V	W	Yes	Other (4)
Woodstock, Inc.	West Branch	Michigan	V	W	Yes	Other (4)
Bell Lumber & Pole Co.	New Brighton	Minnesota	V	P	Yes	NPL,RCRA
Boise Cascade/Onan Corp/ Medtronic, Inc.	Fridley	Minnesota	V	C	No	Removed from the proposed NPL 2/15/95
Burlington Northern	Brainerd/ Baxter	Minnesota	V	C	No	NPL,RCRA
Champion International Corp.	Cass Lake	Minnesota	V	Unknown	Unknown	RCRA
G.M. Stewart Lumber Co., Inc.	Minneapolis	Minnesota	V	Unknown	Unknown	RCRA
Joslyn Manufacturing & Supply Co.	Brooklyn Center	Minnesota	V	C,P	No	NPL,RCRA
Land O Lakes Wood Preserving Co.	Tenstrike	Minnesota	V	W	Yes	Other (4)
MacGillis & Gibbs Co.	New Brighton	Minnesota	V	W,C,P,FRT	Yes	NPL,RCRA
Page & Hill Forest Products, Inc.	Big Falls	Minnesota	V	W,P	Yes	Other (4)
Quality Wood Treating Co., Inc.	White Bear Lake	Minnesota	V	W	Yes	Other (4)
Reilly Tar & Chemical Corp.	St. Louis Park	Minnesota	V	C	No	NPL

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Ritari Post and Pole	Sebeka	Minnesota	V	P	No	NPL
Robinson Lumber Co.	McGrath	Minnesota	V	W	Yes	Other (4)
St. Regis Paper Co.	Cass Lake	Minnesota	V	W,C,P	No	NPL
Timber Wholesalers, Inc.	Willmar	Minnesota	V	W	Yes	RCRA
Turtle River Wood Treating	Bemidji	Minnesota	V	W	Yes	Other (4)
American Creosote Works	Louisville	Mississippi	IV	C,P	No	Non-NPL (5)
American Wood Co. (Powe Timber Co)	Hattiesburg	Mississippi	IV	C	Yes	RCRA
Brookhaven Wood Preserving Co.	Brookhaven	Mississippi	IV	C,P	No	Other (4)
Cavenham Forest Industries, Inc.	Gulfport	Mississippi	IV	Unknown	Unknown	RCRA
Central Miss Crosstie Company, Inc.	Edwards	Mississippi	IV	Unknown	Unknown	RCRA
Columbus Lumber Co.	Brookhaven	Mississippi	IV	W	Yes	Other (4)
Copiah County Mfg./Treatment Company	Hazlehurst	Mississippi	IV	Unknown	Unknown	RCRA
Deforest Wood Preservers	Bolton	Mississippi	IV	W	Yes	Other (4)
Escambia Wood	Brookhaven	Mississippi	IV	C,P	No	RCRA (5)
Fernwood Industries, Inc.	Fernwood	Mississippi	IV	Unknown	Unknown	RCRA
Follen Wood Preserving Co.	Jackson	Mississippi	IV	W	Yes	Other (4)
Gautier Oil Co., Inc.	Gautier	Mississippi	IV	C	No	NPL
Gordon Redd Treating Plant	Brookhaven	Mississippi	IV	Unknown	Unknown	RCRA
Gulf State Creosote	Hattiesburg	Mississippi	IV	C,P	No	Non-NPL (5)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Hinds Wood Preserving Co.	Learned	Mississippi	IV	C	No	Non-NPL (5)
International Paper Co.	Wiggins	Mississippi	IV	W,P	Yes	Other (4)
Jack's Wood Preserving Co.	Byhalia	Mississippi	IV	--	Yes	Other (4)
Kemper Pressure Treated Forest Products	Scooba	Mississippi	IV	P	Yes	Other (4)
Kenson Wood Preserving Corp.	Picayune	Mississippi	IV	Unknown	Unknown	RCRA
Kerr-McGee Chemical Corp.	Columbus	Mississippi	IV	C	Yes	RCRA
Kerr-McGee Chemical Corp.	Meridian	Mississippi	IV	Unknown	Unknown	RCRA
Koppers Industries, Inc.	Tie Plant	Mississippi	IV	C,P	Yes	RCRA
Laurel Lumber Company	Laurel	Mississippi	IV	Unknown	Unknown	RCRA
Louisiana-Pacific Corp.	Grenada	Mississippi	IV	W	Yes	Other (4)
Memphis Wood Preserving Corp.	Horn Lake	Mississippi	IV	W	Yes	Other (4)
Newsom Brothers Old Reichold Site	Columbia	Mississippi	IV	P	No	NPL
Pearl River Wood Preserving Corp.	Picayune	Mississippi	IV	C	Yes	Other (4)
Penick Forest Products	Macon	Mississippi	IV	Unknown	Unknown	RCRA
Pine Belt Wood Preserving Company	Laurel	Mississippi	IV	Unknown	Unknown	RCRA
Prentiss Creosote & Forest Products	Prentiss	Mississippi	IV	C,P	No	Non-NPL (5)
Southeastern Wood Preserving	Canton	Mississippi	IV	C,P	No	Non-NPL (5)
Southern Lumber Co.	Crosby	Mississippi	IV	C,P	No	RCRA (5)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Southern Pine Wood Preserving Company	Wiggins	Mississippi	IV	Unknown	Unknown	RCRA
Southern Wood Preserving	Palmers Crossing	Mississippi	IV	Unknown	Unknown	RCRA
Southern Wood Pres. Of Hattiesburg	Hattiesburg	Mississippi	IV	W	Yes	Other (4)
Thomas Wood Preserving Co., Inc.	Elliott	Mississippi	IV	W	Yes	Other (4)
Thomasson Lumber Co.	Philadelphia	Mississippi	IV	W	Yes	Other (4)
Thomasson Lumber Co. (Laurel Lbr.)	Laurel	Mississippi	IV	W	Yes	Other (4)
Timco, Inc.	Wiggins	Mississippi	IV	C	Yes	RCRA
Treat-All Wood Products	Louisville	Mississippi	IV	Unknown	Unknown	RCRA
Treated Materials Co., Inc.	Gulfport	Mississippi	IV	W	Yes	Other (4)
Tri State Lumber Co., Inc.	Fulton	Mississippi	IV	W	Yes	Other (4)
Tri State Pole & Piling Co.	Lucedale	Mississippi	IV	W	Yes	Other (4)
Wood Treating, Inc.	Picayune	Mississippi	IV	C	Yes	RCRA
A.K. Gibbon Lumber Co.	Kansas City	Missouri	VII	W	Yes	Other (4)
A&R Oak Fencing, Inc.	Long Lane	Missouri	VII	Unknown	Unknown	RCRA
Arneson Timber Co.	Steelville	Missouri	VII	P	Yes	RCRA
Beazer East, Inc. (Prev. Koppers)	Kansas City	Missouri	VII	Unknown	Unknown	RCRA
International Paper Co.	Joplin	Missouri	VII	P	Yes	RCRA
International Paper Co.	Pleasant Hill	Missouri	VII	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Kerr-McGee Chemical Corp.	Kansas City	Missouri	VII	Unknown	Unknown	RCRA
Kerr-McGee Chemical Corp.	Springfield	Missouri	VII	C	Yes	RCRA
Massie Pole Yard, Inc.	VanBuren	Missouri	VII	CuNap	Yes	Other (4)
Rogers Post & Lumber Co.	Steelville	Missouri	VII	Unknown	Unknown	RCRA
Scott Lumber Co.	Alton	Missouri	VII	C	No	RCRA (5)
Smith Flooring, Inc.	Cabool	Missouri	VII	Unknown	Unknown	RCRA
Sullens Lumber & Treated Post	Richland	Missouri	VII	Unknown	Unknown	RCRA
St. Louis Flameproof & Wood Pres.	St. Louis	Missouri	VII	W	Yes	Other (4)
Thomasville Wood Products	Thomasville	Missouri	VII	Unknown	Unknown	RCRA
Timber Industries, Inc.	Salem	Missouri	VII	Unknown	Unknown	RCRA
Universal Forest Products	Slater	Missouri	VII	W	Yes	Other (4)
Winona Post Co., Inc.	Winona	Missouri	VII	P	Yes	RCRA
Beaver Wood Products	Columbia Falls	Montana	VIII	P	No	Non-NPL (5)
Blackfeet Post & Pole	Browning	Montana	VIII	P	No	Non-NPL (5)
Burlington Northern Paradise Tie Plant	Paradise	Montana	VIII	Unknown	Unknown	RCRA
Champion International Corp. (Libby Groundwater)	Libby	Montana	VIII	W,C,P	No	NPL
Chippewa Pole	Unknown	Montana	VIII	C,P	No	Non-NPL (5)
Creston Post & Pole Yard	Kalispell	Montana	VIII	P	No	Non-NPL (5)
Evans Post & Pole	Browning	Montana	VIII	P	No	Non-NPL (5)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Kalispell Pole & Timber Co. (Burlington Northern Railroad)	Kalispell	Montana	VIII	W,P	No	RCRA (5)
L.D. McFarland Co., Ltd. (Idaho Pole)	Bozeman	Montana	VIII	C,P	Yes	NPL,RCRA
Larry's Post & Treating Co.	Columbia Falls	Montana	VIII	Unknown	No	Non-NPL (5)
Marks-Miller Post & Pole, Inc.	Clancy	Montana	VIII	W	Yes	Other (4)
Montana Pole and Treating	Butte	Montana	VIII	C,P	No	NPL,RCRA
Rocky Boy Post & Pole	Box Elder	Montana	VIII	C,P	No	Non-NPL (5)
Somers Tie-Treating Plant (Burlington Northern Railroad)	Somers	Montana	VIII	W,C	No	RCRA
Central Nebraska Wood Preservers	Sutton	Nebraska	VII	W	Yes	Other (4)
Hughes Brothers, Inc.	Seward	Nebraska	VII	P	Yes	RCRA
Nevada Wood Preserving	Silver Springs	Nevada	IX	W,P,CuNap	Yes	Other (4)
Beazer East, Inc.	Nashua	New Hampshire	I	Unknown	Unknown	RCRA
Littleton Lumber & Supply Co., Inc.	Bethlehem	New Hamsphire	I	W	Yes	RCRA
Atlantic Wood Industries, Inc.	Hainesport	New Jersey	II	C	Yes	RCRA
Beazer East, Inc. at Koppers Industries	Port Newark	New Jersey	II	Unknown	Unknown	RCRA
New Jersey Wood Treating Corp.	Burlington	New Jersey	II	W	Yes	Other (4)
Radiation Technology, Inc.	Rockaway	New Jersey	II	Unknown	Unknown	RCRA
Shollenbarger Wood Treating Co.	Bernalillo	New Mexico	VI	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Springer Wood Treater	Springer	New Mexico	VI	C,P	No	Non-NPL (5)
A.C. Dutton Lumber Corp.	Poughkeepsie	New York	II	W	Yes	Other (4)
Atlantic Wood Industries, Inc.	Athens	New York	II	W	Yes	Other (4)
Bestway Enterprises, Inc.	Cortland	New York	II	W,FRT	Yes	Other (4)
Colonie Wood Treating & Staining Co.	Albany	New York	II	W	Yes	Other (4)
G.C.L. Tie & Treating Corp.	Village of Sidney	New York	II	C	Yes	NPL
Northeast Treaters of New York LLC	West Athens	New York	II	Unknown	Unknown	RCRA
Wood Treaters of Buffalo, Inc.	Buffalo	New York	II	W,FRT	Yes	RCRA
Albemarle Wood Preserving Plant, Inc.	Albemarle	North Carolina	IV	W	Yes	Other (4)
Brackett Brothers Corp.	Morganton	North Carolina	IV	W	Yes	Other (4)
C.A. Seaford & Sons Lumber Co.	Mocksville	North Carolina	IV	W	Yes	Other (4)
C.M. Tucker Lumber Corp.	Middleburg	North Carolina	IV	W	Yes	Other (4)
Cape Fear Wood Preserving	Fayetteville	North Carolina	IV	W,C	No	NPL
Carolina Creosoting Corp.	Leland	North Carolina	IV	Unknown	Unknown	RCRA
Carolina Wood Preserving Co., Inc.	Scotland Neck	North Carolina	IV	W	Yes	Other (4)
Coastal Lumber Co.	Weldon	North Carolina	IV	W	Yes	Other (4)
Cove City Wood Preserving, Inc.	Cove City	North Carolina	IV	W	Yes	Other (4)
Cox Wood Preserving Co. (Structural Wood)	Coleridge	North Carolina	IV	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Davensport Creosote	Pinetops	North Carolina	IV	C	No	Non-NPL (5)
Durable Wood Preservers, Inc.	Charlotte	North Carolina	IV	W	Yes	RCRA
E.W. Godwin's Sons, Inc.	Wilmington	North Carolina	IV	W	Yes	Other (4)
Everhart Lumber Co.	New Bern	North Carolina	IV	P	No	Non-NPL (5)
Fortress Wood Products, Inc.	Greensboro	North Carolina	IV	W	Yes	Other (4)
General Timber, Inc.	Sanford	North Carolina	IV	W,C	Yes	RCRA
General Wood Preserving Co., Inc.	Leland	North Carolina	IV	W,P	Yes	Other (4)
Gold Hill Wood Preservers, Inc.	Gold Hill	North Carolina	IV	W	Yes	Other (4)
Goldston Lumber, Inc.	Goldston	North Carolina	IV	W	Yes	Other (4)
Holcomb Creosote Co.	Yadkinville	North Carolina	IV	C	Yes	RCRA
Koppers Co., Inc.	Morrisville	North Carolina	IV	P	No	NPL
McRae Wood Treating, Inc.	Mt. Gilead	North Carolina	IV	W	Yes	Other (4)
Mellco, Inc.	Roanoke Rapids	North Carolina	IV	W	Yes	Other (4)
Pee Dee Timber Co.	Laurinburg	North Carolina	IV	W	Yes	Other (4)
Perry Builders, Inc.	Henderson	North Carolina	IV	W	Yes	Other (4)
Quality Forest Products, Inc.	Enfield	North Carolina	IV	W	Yes	Other (4)
South Atlantic Wood Preservers, Inc.	Elizabeth City	North Carolina	IV	W	Yes	Other (4)
South-East Lumber Co.	Kemersville	North Carolina	IV	W	Yes	Other (4)
Tarheel Wood Treating Co., Inc.	Morrisville	North Carolina	IV	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Universal Forest Products	Elizabeth City	North Carolina	IV	W	Yes	Other (4)
Universal Forest Products	Salisbury	North Carolina	IV	W	Yes	Other (4)
Weyerhaeuser Co.	Plymouth	North Carolina	IV	W	Yes	Other (4)
Woodtreaters, Inc.	Rocky Point	North Carolina	IV	W	Yes	Other (4)
Lavelle Co.	Fargo	North Dakota	VIII	W	Yes	Other (4)
Beazer East, Inc.	Orrville	Ohio	V	Unknown	Unknown	RCRA
Dayton Flameproof & Wood Pres. Co.	Dayton	Ohio	V	W,FRT	Yes	Other (4)
Great Northern Wood Preserving Co.	Lodi	Ohio	V	W	Yes	Other (4)
John A. Biewer Co./Ohio	Washington Courthouse	Ohio	V	W	Yes	Other (4)
John A. Biewer Co./Toledo	Perrysburg	Ohio	V	W	Yes	Other (4)
Manufacturers Wholesale Lumber	Cleveland	Ohio	V	W	Yes	Other (4)
Manufacturers Wholesale Lumber	London	Ohio	V	W	Yes	Other (4)
McArthur Lumber & Post Co., Inc.	McArthur	Ohio	V	W	Yes	Other (4)
Midwest Wood Treating, Inc.	Norwalk	Ohio	V	W	Yes	Other (4)
Quality Wood Treating Co., Inc.	Gahanna	Ohio	V	W	Yes	Other (4)
Reilly Tar & Chemical Corp.	Dover	Ohio	V	C	No	NPL
Southern Wood Piedmont Waverly	Waverly	Ohio	V	Unknown	Unknown	RCRA
Universal Forest Products	Hamilton	Ohio	V	W	Yes	Other (4)
Walker-Williams Lumber Co., Inc.	Youngstown	Ohio	V	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Cavenham Forest Industries, Inc.	Sallisaw	Oklahoma	VI	Unknown	Unknown	RCRA
Central Forest Products	Hugo	Oklahoma	VI	Unknown	Unknown	RCRA
Huffman Wood Preserving Co., Inc.	Broken Bow	Oklahoma	VI	Unknown	Unknown	RCRA
Julian Lumber Co.	Antlers	Oklahoma	VI	W,C	Yes	Other (4)
Mixon Brothers Wood Preserving, Inc.	Idabel	Oklahoma	VI	C	Yes	RCRA
Rab Valley Wood Preserving Co.	Panama	Oklahoma	VI	C,P	No	Other (4)
Thomason Lumber & Timber Co.	Broken Bow	Oklahoma	VI	C,P	Yes	RCRA
Allweather Wood Treaters	White City	Oregon	X	W	Yes	RCRA
Alta Timber Co., Operation of Weyerhaeuser	Eugene	Oregon	X	Unknown	Unknown	RCRA
Burlington Northern Railroad, Dant & Russ	North Plains	Oregon	X	Unknown	Unknown	RCRA
Cascade Pacific Industries, Inc.	Jasper	Oregon	X	Unknown	Unknown	RCRA
Conrad Wood Preserving Co.	North Bend	Oregon	X	W	Yes	RCRA
Coos Bay Lumber Co.	Hauser	Oregon	X	Unknown	Unknown	RCRA
Durawood Treating Co.	Coos Bay	Oregon	X	W	Yes	Other (4)
J.H. Baxter & Co.	Eugene	Oregon	X	W,C,P,FRT	Yes	RCRA
Joseph Forest Products	Joseph	Oregon	X	W	No	NPL,RCRA
Kerr-McGee Chemical Corp.	The Dalles	Oregon	X	C	Yes	RCRA
L.D. McFarland Co., Ltd.	Eugene	Oregon	X	P	Yes	RCRA

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
McCormick & Baxter Creosoting Co.	Portland	Oregon	X	C	No	NPL
Osmose Wood Preserving	Tangent	Oregon	X	Unknown	Unknown	RCRA
Pacific Wood Treating Corp.	Portland	Oregon	X	W,C	Yes	Other (4)
Permapost Products Co.	Hillsboro	Oregon	X	W,P	Yes	RCRA
Port of St. Helens	St. Helens	Oregon	X	Unknown	Unknown	RCRA
Puget Sound Plywood	Eugene	Oregon	X	Unknown	No	Non-NPL (5)
Rangerfund II	Westfir	Oregon	X	P	No	Non-NPL (5)
Royal Pacific Industries	McMinnville	Oregon	X	W	Yes	RCRA
Taylor Lumber & Treating, Inc.	Sheridan	Oregon	X	W,C,P	Yes	RCRA
Timber Engineering Co.	Eugene	Oregon	X	Unknown	Unknown	RCRA
Union Pacific Railroad Tie Treatment	The Dalles	Oregon	X	Unknown	No	NPL,RCRA
USDA FS Ochoco ND Crooked River Grassland	Prineville	Oregon	X	Unknown	Unknown	RCRA
Belfield Avenue Site	Philadelphia	Pennsylvania	III	P	No	Non-NPL (5)
Burke-Parsons-Bowlby Corp.	DuBois	Pennsylvania	III	C	Yes	RCRA
Champion Lumber Co.	Champion	Pennsylvania	III	W	Yes	Other (4)
Coastal Lumber Co.	Armagh	Pennsylvania	III	W	Yes	Other (4)
Coastal Lumber Co.	Uniontown	Pennsylvania	III	W	Yes	Other (4)
Commonwealth Wood Preservers, Inc.	Fairless Hills	Pennsylvania	III	W	Yes	Other (4)
Eager Beaver Lumber Co.	Townville	Pennsylvania	III	P	No	Non-NPL (5)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
H.M. Stauffer & Sons, Inc.	Leola	Pennsylvania	III	W	Yes	Other (4)
H.P. McGinley, Inc.	McAlisterville	Pennsylvania	III	C	Yes	Other (4)
Havertown PCP Site	Havertown	Pennsylvania	III	P	No	NPL
Helsel Wood Process, Inc.	Duncanville	Pennsylvania	III	W	Yes	Other (4)
H&M Stauffer & Sons, Inc.	Leola	Pennsylvania	III	Unknown	Unknown	RCRA
Kerr-McGee Chemical Corp.	Avoca	Pennsylvania	III	C	Yes	Other (4)
Keystone Wood Treating Corp.	Oxford	Pennsylvania	III	W	Yes	RCRA
Koppers Industries, Inc.	Montgomery	Pennsylvania	III	C	Yes	RCRA
Mellott Wood Preserving Co.	Needmore	Pennsylvania	III	C	Yes	Other (4)
Merrill Lumber Co., Inc.	Philadelphia	Pennsylvania	III	W	Yes	Other (4)
National Wood Preservers	Havertown	Pennsylvania	III	P	No	RCRA (5)
Quality Wood Treating Co., Inc.	Fombell	Pennsylvania	III	W	Yes	Other (4)
Rummel Brothers Lumber Co.	Ebensurg	Pennsylvania	III	W	Yes	Other (4)
Schroth Lumber Co.	Indiana	Pennsylvania	III	W	Yes	Other (4)
Universal Forest Products	Gordon	Pennsylvania	III	W	Yes	Other (4)
Universal Forest Products	Stockertown	Pennsylvania	III	W	Yes	Other (4)
Unknown	Westline	Pennsylvania	III	Unknown	No	Other (4)
West Elizabeth Lumber Company	West Elizabeth	Pennsylvania	III	Unknown	Unknown	RCRA
Whetsell Treating Co.	Addison	Pennsylvania	III	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Wood Treating Corp. of Philadelphia	Philadelphia	Pennsylvania	III	Unknown	Unknown	RCRA
Boricua Wood Processing	Toa Baja	Puerto Rico	II	Unknown	Unknown	RCRA
B.B. & S. Treated Lumber/ New England	Davisville	Rhode Island	I	W,FRT	Yes	Other (4)
Beazer Materials and Services	Florence	South Carolina	IV	Unknown	No	Other (4)
C.M. Tucker Lumber Corp.	Pageland	South Carolina	IV	W	Yes	Other (4)
Charleston Timber & Wood Pres., Inc.	Charleston	South Carolina	IV	W	Yes	Other (4)
Collum's Lumber Mill	Allendale	South Carolina	IV	W	Yes	Other (4)
Colwood Company, Inc.	Columbia	South Carolina	IV	W	Yes	RCRA
Colwood Company, Inc.	Greenville	South Carolina	IV	Unknown	Unknown	RCRA
Cox Wood Preserving Co.	Orangeburg	South Carolina	IV	W,FRT	Yes	RCRA
Davis Brothers Lumber Co.	Richland	South Carolina	IV	W	Yes	Other (4)
Edisto Wood Preserving	Olar	South Carolina	IV	W	Yes	Other (4)
Georgia-Pacific Corp. Chip-N-Saw	Prosperity	South Carolina	IV	Unknown	Unknown	RCRA
Kellwood Timber Products	Hardeeville	South Carolina	IV	W	No	Non-NPL (5)
Koppers Co., Inc.	Charleston	South Carolina	IV	Unknown	No	NPL
Koppers Industries, Inc.	Florence	South Carolina	IV	W,C,P	Yes	NPL,RCRA
Lakewood Treating, Inc.	Newberry	South Carolina	IV	W,C	Yes	Other (4)
Mellco, Inc.	Rock Hill	South Carolina	IV	W	Yes	Other (4)
New South, Inc.	Camden	South Carolina	IV	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
New South, Inc.	Conway	South Carolina	IV	W	Yes	Other (4)
North-South Wood Preserving Co.	North	South Carolina	IV	P	Yes	Other (4)
Palmetto Wood Preserving	Cayce/Dixiana	South Carolina	IV	W	No	NPL
S&W Wood Products, Inc.	Hardeeville	South Carolina	IV	W	Yes	Other (4)
Southern Wood Piedmont Co.	Inman	South Carolina	IV	Unknown	Unknown	RCRA
Sumter Wood Preserving Co.	Sumter	South Carolina	IV	W	Yes	RCRA
Thrift Brothers Lumber Co., Inc.	Westminister	South Carolina	IV	W	Yes	Other (4)
United Wood Treating Co., Inc.	Whitmire	South Carolina	IV	W	Yes	Other (4)
Forest Products Distributors, Inc.	Rapid City	South Dakota	VIII	W	Yes	Other (4)
Hills Materials Co.	Whitewood	South Dakota	VIII	W	Yes	Other (4)
Wheeler Consolidated, Inc.	Whitewood	South Dakota	VIII	W,C,P	Yes	Other (4)
Whitewood Custom Treaters, Inc.	Whitewood	South Dakota	VIII	W	No	Non-NPL (5)
American Creosote Works, Inc.	Jackson	Tennessee	IV	C,P	No	NPL,RCRA
Bulls Gap Forest Products, Inc.	Bulls Gap	Tennessee	IV	Unknown	Unknown	RCRA
Cherokee Wood Preservers, Inc.	Mosheim	Tennessee	IV	W	Yes	RCRA
Coastal Lumber Co.	Henry	Tennessee	IV	W	Yes	Other (4)
Conasauga River Lumber Co.	Conasauga	Tennessee	IV	W	Yes	RCRA
Danek Industries, Inc.	Chattanooga	Tennessee	IV	Unknown	Unknown	RCRA
East Tennessee Forest Products, Inc.	Greeneville	Tennessee	IV	W	Yes	RCRA

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Gulf Lumber Company - Tennessee	Nashville	Tennessee	IV	Unknown	Unknown	RCRA
Jerico Industries	Winchester	Tennessee	IV	Unknown	Unknown	RCRA
Langdale Forest Products Co.	Sweetwater	Tennessee	IV	W	Yes	RCRA
Miles R V	Sharon	Tennessee	IV	Unknown	Unknown	RCRA
Oneida Wood Products, Inc.	Oneida	Tennessee	IV	W	Yes	RCRA
Quantex Corp.	Memphis	Tennessee	IV	Unknown	Unknown	RCRA
Southern Wood Piedmont Company	Chattanooga	Tennessee	IV	Unknown	Unknown	RCRA
Sunbright Lumber	Sunbright	Tennessee	IV	W	Yes	RCRA
The Wood Shop	Nashville	Tennessee	IV	Unknown	Unknown	RCRA
Wrigley Charcoal Plant	Wrigley	Tennessee	IV	Unknown	No	NPL
Beazer East, Inc.	Houston	Texas	VI	Unknown	Unknown	RCRA
Bowie-Sims-Prange Treating Corp.	Dallas	Texas	VI	W	Yes	Other (4)
Cass County Treating Co.	Linden	Texas	VI	W	Yes	RCRA
Century Forest Industries, Inc.	Lufkin	Texas	VI	Unknown	Unknown	RCRA
Conroe Creosoting Company	Conroe	Texas	VI	W,C,P	Yes	RCRA
D&I Wood Products, Inc.	Center	Texas	VI	W	Yes	Other (4)
Dean Lumber Co., Inc.	Gilmer	Texas	VI	W,FRT	Yes	RCRA
Dittmar Lumber Co., Inc.	San Antonio	Texas	VI	W	Yes	Other (4)
Eastex Forest Products	Houston	Texas	VI	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Fowler Post Co., Inc.	Clarksville	Texas	VI	W	Yes	Other (4)
Garland Creosoting Co.	Longview	Texas	VI	C	Yes	RCRA
Hart Creosoting Co.	Jasper	Texas	VI	C	Yes	RCRA
Hicks Post Co.	Alto	Texas	VI	W,C	Yes	Other (4)
Houston Woodtech, Inc.	Houston	Texas	VI	Unknown	Unknown	RCRA
Hughes Wood Products, Inc.	Schertz	Texas	VI	W	Yes	Other (4)
International Paper Co.	Mineola	Texas	VI	W	Yes	Other (4)
International Paper Co.	Navasota	Texas	VI	Unknown	Unknown	RCRA
Jasper Creosoting Co.	Jasper	Texas	VI	Unknown	Unknown	RCRA
Kerr-McGee Chemical Corp.	Texarkana	Texas	VI	C	Yes	RCRA
Koppers Co.	Texarkana	Texas	VI	W,C,P	No	NPL
Koppers Industries, Inc.	Summerville	Texas	VI	C	Yes	Other (4)
L.L. Brewton Lumber Co., Inc.	Caddo Mills	Texas	VI	W	Yes	Other (4)
Louisiana-Pacific Corp.	New Waverly	Texas	VI	W	Yes	Other (4)
Louisiana-Pacific Corp.	Silsbee	Texas	VI	W	Yes	Other (4)
Lufkin Creosoting Co., Inc.	Lufkin	Texas	VI	C	Yes	RCRA
M G Building Materials	San Antonio	Texas	VI	W	Yes	Other (4)
McLeod Timber Products	Newton	Texas	VI	W	Yes	Other (4)
North Cavalcade Street Site	Houston	Texas	VI	C	No	NPL

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Powell Lumber of Texas, Inc.	Winona	Texas	VI	W	Yes	Other (4)
Santa Fe Centralized Tie Plant	Somerville	Texas	VI	C	Yes	Other (4)
South Cavalcade Street Site	Houston	Texas	VI	W,C	No	NPL
South Houston Lumber Co.	S. Houston	Texas	VI	W	Yes	Other (4)
Southwest Shelving Co., Inc.	Dallas	Texas	VI	Unknown	Unknown	RCRA
Temple Inland Forest Product Corp.	Diboll	Texas	VI	Unknown	Unknown	RCRA
Texarkana Wood Preserving Co.	Texarkana	Texas	VI	C,P	No	NPL,RCRA
Texas Electric Cooperatives, Inc.	Jasper	Texas	VI	C	Yes	RCRA
United Creosoting Co.	Conroe	Texas	VI	C,P	No	NPL
Universal Forest Products	Saginaw	Texas	VI	W	Yes	Other (4)
Walker Wood Preserving, Inc.	Livingston	Texas	VI	W	Yes	RCRA
W.J. Smith Wood Preserving Co.	Denison	Texas	VI	Unknown	Unknown	RCRA
Wood Protection Co.	Houston	Texas	VI	W	Yes	RCRA
Kilfoyle Krafts, Inc.	Price	Utah	VIII	W	Yes	Other (4)
Utah Wood Preserving	Salt Lake City	Utah	VIII	W	Yes	Other (4)
Pine Street Canal	Burlington	Vermont	I	Unknown	No	NPL
Anderson Brothers Lumber Co., Inc.	Amelia	Virginia	III	W	Yes	Other (4)
Atlantic Wood Industries, Inc.	Newsoms	Virginia	III	W	Yes	Other (4)
Atlantic Wood Industries, Inc.	Portsmouth	Virginia	III	C,P	No	NPL,RCRA

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Beazer Materials & Services, Inc.	Richmond	Virginia	III	Unknown	Unknown	RCRA
Blue Ridge Wood Preserving	Moneta	Virginia	III	W	Yes	Other (4)
Burke-Parsons-Bowlby Corp.	Goshen	Virginia	III	W,C	Yes	Other (4)
Commonwealth Wood Preservers, Inc.	Hampton	Virginia	III	W	Yes	RCRA
Cove Creek Industries	Covesville	Virginia	III	Unknown	Unknown	RCRA
Culpeper Wood Preservers	Culpeper	Virginia	III	W	Yes	NPL,RCRA
Gloucester Lumber Products, Inc.	Gloucester	Virginia	III	W	Yes	Other (4)
Eppinger & Russell Co., Inc.	Chesapeake	Virginia	III	Unknown	Unknown	RCRA
Everdure, Inc.	Orange	Virginia	III	Unknown	Unknown	RCRA
Hoover Treated Wood Products, Inc.	Milford	Virginia	III	W,FRT	Yes	RCRA
Koppers Industries, Inc.	Salem	Virginia	III	C	Yes	RCRA
L.A. Clarke & Sons, Inc.	Fredricksburg	Virginia	III	C	No	NPL,RCRA
L-Wood	Providence Forge	Virginia	III	W	Yes	Other (4)
Madison Wood Preservers, Inc.	Madison	Virginia	III	W	Yes	RCRA
McCready Lumber Co.	Pulaski	Virginia	III	W	Yes	Other (4)
Pitts Lumber Co., Inc.	Saluda	Virginia	III	W	Yes	Other (4)
Potomac Supply Corp.	Kinsale	Virginia	III	W	Yes	RCRA
Rentokil, Inc.	Richmond	Virginia	III	W,C,P	No	NPL
Rocky Top Wood Preservers, Inc.	Rocky Mount	Virginia	III	W	Yes	Other (4)

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Saunders Supply Co.	Chuckatuck	Virginia	III	W,P	No	NPL,RCRA
Southside Lumber, Inc.	Emporia	Virginia	III	W	Yes	Other (4)
Taylor-Ramsey Corp.	Lynchburg	Virginia	III	W	Yes	Other (4)
The Burruss Co.	Gladys	Virginia	III	W	Yes	Other (4)
Valley Timber Sales, Inc.	Troy	Virginia	III	W	Yes	Other (4)
Wood Preservers, Inc.	Warsaw	Virginia	III	W,C,FRT	Yes	Other (4)
Allweather Wood Treaters	Washougal	Washington	X	W	Yes	RCRA
American Crossarm & Conduit Co.	Chehalis	Washington	X	C,P	No	NPL,RCRA
Brooks Manufacturing Co.	Bellingham	Washington	X	P	Yes	Other (4)
Cascade Pole & Lumber Co.	Olympia	Washington	X	Unknown	Unknown	RCRA
Cascade Pole & Lumber Co.	Tacoma	Washington	X	Unknown	Unknown	RCRA
Chemco, Inc.	Ferndale	Washington	X	W	Yes	Other (4)
Colville Post & Poles, Inc.	Colville	Washington	X	Unknown	Unknown	RCRA
Exterior Wood, Inc.	Washougal	Washington	X	W,FRT	Yes	RCRA
Girard Custom Coaters, Inc.	Tacoma	Washington	X	Unknown	Unknown	RCRA
Inchelium Tribal Wood Treatment	Inchelium	Washington	X	W	Yes	Other (4)
International Paper Co., Wood Products	Longview	Washington	X	Unknown	Unknown	RCRA
J.H. Baxter & Co.	Arlington	Washington	X	P	Yes	RCRA
J.H. Baxter & Co.	Longview	Washington	X	Unknown	Unknown	RCRA

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
J.H. Baxter & Co.	Renton	Washington	X	Unknown	Unknown	RCRA
L.D. McFarland Co., Ltd. (Cascade Pole & Lbr.)	Tacoma	Washington	X	W,P,C	Yes	Other (4)
North American Wood Treating	Sumas	Washington	X	W	Yes	Other (4)
Oeser Co., Inc.	Bellingham	Washington	X	P	Yes	Proposed NPL, RCRA
Pacific Sound Resources	Seattle	Washington	X	W,C,P	Yes	NPL
Port of Ridgefield, Lake River Site	Ridgefield	Washington	X	Unknown	Unknown	RCRA
Port of Seattle, PSR Site Remediation	Seattle	Washington	X	Unknown	Unknown	RCRA
Quendall Terminals	Renton	Washington	X	Unknown	Unknown	RCRA
RDK Prefinish Specialists, Inc.	Everett	Washington	X	Unknown	Unknown	RCRA
R.G. Haley Int'l. Corp.	Bellingham	Washington	X	Unknown	Unknown	RCRA
Spokane Custom Wood Treating	Wellpinit	Washington	X	CuNap	Yes	Other (4)
Superior Wood Treating (Manke Lumber)	Sumner	Washington	X	W	Yes	Other (4)
WDOE ERO B.J. Carney	Spokane	Washington	X	Unknown	Unknown	RCRA
Western Wood Preserving Co.	Sumner	Washington	X	W	Yes	RCRA
Wyckoff Co./Eagle Harbor	Bainbridge Island	Washington	X	C,P	No	NPL,RCRA
Acme Wood Preserving, Inc.	Princeton	West Virginia	III	W,C	Yes	RCRA
Appalachian Timber Services, Inc.	Sutton	West Virginia	III	W,C	Yes	RCRA

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Browning Lumber Co.	Bald Knob	West Virginia	III	W	Yes	Other (4)
Burke-Parsons-Bowlby Corp.	Reedy	West Virginia	III	W,C	Yes	Other (4)
Coatal Lumber Co.	Belington	West Virginia	III	W	Yes	Other (4)
Kessel Lumber Supply, Inc.	Keyser	West Virginia	III	W	Yes	Other (4)
Koppers Industries, Inc.	Green Spring	West Virginia	III	C	Yes	RCRA
Messer Treating Plant	Fort Gay	West Virginia	III	W	Yes	Other (4)
Universal Forest Products	Ranson	West Virginia	III	W	Yes	Other (4)
John A. Biewer Co./Wisconsin	Prentice	Wisconsin	V	W	Yes	Other (4)
Koppers Industries, Inc.	Superior	Wisconsin	V	C	Yes	RCRA
Midwest Manufacturing Co.	Eau Claire	Wisconsin	V	W	Yes	Other (4)
Morgan Products, Ltd.	Oshkosh	Wisconsin	V	Unknown	Unknown	RCRA
Moss-American Co., Inc./ Kerr-McGee Oil Co.	Milwaukee	Wisconsin	V	C	No	NPL
Northern Crossarm Co., Inc.	Chippewa Falls	Wisconsin	V	W	Yes	Other (4)
Onalaska Municpal Landfill	Lacrosse County	Wisconsin	V	Unknown	Unknown	Other (4)
Penta Wood Products	Daniels	Wisconsin	V	Unknown	No	NPL
Peterson Wood Treating Co.	Superior	Wisconsin	V	W	Yes	Other (4)
Quality Wood Treating Co., Inc.	Janesville	Wisconsin	V	W	Yes	RCRA
Quality Wood Treating Co., Inc.	Prairie du Chien	Wisconsin	V	W,FRT	Yes	RCRA

Company Name	Plant Location (City)	State	EPA Region	Types of Preservative(s) Used (1)	Operating in 1995? (2)	Regulatory Status (3)
Richardson Wood Preserving	DePere	Wisconsin	V	W	Yes	Other (4)
Universal Forest Products	Janesville	Wisconsin	V	W	Yes	Other (4)
Webster Industries, Inc.	Bangor	Wisconsin	V	C	Yes	RCRA
Woods Run Forest Products, Inc.	Colfax	Wisconsin	V	W	Yes	Other (4)
Ayres & Baker Pole & Post Co.	Mountain View	Wyoming	VIII	W	Yes	Other (4)
Baxter/Union Pacific Tie Treating	Laramie	Wyoming	VIII	C,P	No	NPL
Cowboy Timber Treating, Inc.	Manderson	Wyoming	VIII	P	Yes	RCRA
Union Pacific Railroad	Laramie	Wyoming	VIII	Unknown	Unknown	RCRA

This list of wood preserving sites was compiled from the following sources:
- American Wood Preservers Institute. The 1995 Wood Preserving Industry Production Statistical Report. September 1996.
- U.S. Environmental Protection Agency. Contaminants and Remedial Options at Wood Preserving Sites. EPA/600/R-92/182. October 1992a.
- CERCLIS database query results (query executed February 1997)
- RCRIS database query results (query executed March 1997)
- Federal Register. Vol. 61, No. 247. 40 CFR Part 300. National Priorities List for Uncontrolled Hazardous Waste Sites (FRL-5668-3) and National Priorities List for Uncontrolled Hazardous Waste Sites, Proposed Rule No. 21 (FRL-5668-4). December 23, 1996.

Notes:

(1)
W	=	Waterborne preservatives (includes CCA, ACC, ACZA, *etc.*)
C	=	Creosote (all creosote solutions)
P	=	Pentachlorophenol
FRT	=	Fire Retardant (interior and exterior)
CuNAP	=	Copper Napthenate
NP	=	Non-pressure Treating Plants Only

(2) Wood preserving facilities that were not in the "1995 Wood Preserving Industry Production Statistical Report, " but were in CERCLIS or on the NPL were assumed to be not operating as of 1995. Wood preserving facilities that were in RCRIS but not found in any other sources are listed as "Unknown."

(3) For the purposes of this table, a "RCRA" regulatory status means that the site was identified by RCRIS as having an SIC code of 2491 (Manufacturing - Wood Preserving). This does not necessarily mean that the site is being addressed under the RCRA Corrective Action Program.

(4) This site was not listed in the CERCLIS or RCRIS databases or in the 12/23/96 NPL. It might be subject to remediation under another program or might not require remediation.

(5) This site was identified in "Contaminants and Remedial Options at Wood Preserving Sites" as being addressed under programs other than CERCLA.

(6) The regulatory status of this site is unclear. It was identified in CERCLIS as having been deleted from the NPL on 5/8/96; however, it was included in the NPL published in the Code of Federal Regulations on 12/23/96.

APPENDIX B

SOIL TREATMENT TECHNOLOGIES
ADDITIONAL TREATABILITY AND CASE STUDIES

B.1 Soil Washing

B.1.1 Case Study - Pilot Demonstration of OHM's Soil Washing Unit at Cape Fear Site

Background/Waste Description: OHM's 40-ton-per-hour pilot-scale soil washing unit was used in a demonstration at the Cape Fear Superfund site, Fayetteville, NC. Soil at the site is contaminated with arsenic, chromium, and PAHs.

Summary of Study: Approximately 1,200 tons of contaminated soil material were treated during the 5-day demonstration. The OHM soil washing system operated at 30 tons per hour for 8 hours each day.

Performance: Treatment goals for the cleaned soil were less than 100,000 ppb of PAHs; less than 2,500 ppb of carcinogenic PAHs; less than 94,000 ppb of arsenic; and less than 88,000 ppb of chromium. The contaminated fines left onsite were required to have less than 100 ppb of carcinogenic PAHs in the SPLP (SW-846 Method 1312) leachate.

Approximate levels of PAHs in the contaminated soil were as follows: acenaphthene, 200,000 ppb; acenaphthylene, 10,000 ppb; anthracene, 100,000 ppb; benz(a)-anthracene, 100,000 ppb; benzo(b)fluoranthene, 40,000 ppb; benzo(k)fluoranthene, 40,000 ppb; benzo(g,h,i)perylene, 5,000 ppb; benzo(a)pyrene, 30,000 ppb; chrysene, 100,000 ppb; dibenz(a,h)anthracene, 1,000 ppb; fluorene, 200,000 ppb; indeno(1,2,3-cd)pyrene, 5,000 ppb; phenanthrene, 500,000 ppb; and pyrene, 300,000 ppb. Initial chromium levels were approximately 80,000 ppb, and arsenic was not detected in the untreated soil.

All treatment goals were met with the exception of carcinogenic PAHs in the soil, which ranged from 4,500 to less than 2,000 ppb.

Cost: Capital expense/leasing costs were $40 per ton of soil treated. This included all equipment costs for excavation, attrition scrubbing, screening, fines dewatering, back-filling, and project support (e.g., decontamination trailers, office trailers and equipment, etc.). Annual consumable (e.g., chemicals) costs were $8.50 per ton of soil treated. This included all chemicals used for attrition scrubbing and fines dewatering. Annual utilities costs were $1.50 per ton of soil treated. The labor costs during treatment were $35 per ton of soil treated. This included all labor costs for excavation, attrition scrubbing, fines dewatering, backfilling, and project administration. This cost estimate does not appear to include costs associated with permitting and regulatory compliance; startup; effluent monitoring and disposal; residuals and waste shipping, handling, and transportation; analyses; or demobilization.

Source:

OHM Corporation. Personal Communication between Paul Lear, OHM Corporation, and Kurt Whitford, SAIC. March 25, 1997.

B.2 Solidification/Stabilization (S/S)

B.2.1 Process Design for the ACW Site in Jackson, TN

Background/Waste Description: The soil at the ACW site is contaminated with VOCs, PCP, PAHs, dioxins, and furans. Maximum contaminant concentrations in the soil are 200 ppm VOCs; 21,300 ppm PAHs; 2,500 ppm PCP; 15 ppm dioxins; and 2.6 ppm furans.

Summary of Study: OHM prepared a preliminary process design and cost estimate for the S/S treatment of 35,100 tons of contaminated soil at the ACW site. OHM proposed completing all onsite work within a 75-day period. OHM's S/S equipment proposed for the site included a soil screening plant and a pugmill unit. The screening plant was designed to screen out materials greater than 2 inches in diameter. The pugmill was designed to mix the screened soil with reagents designed to immobilize the contaminants, particularly the PAHs. The average operating capacity of this system is 150 tons of soil per hour; the maximum operating capacity is 200 tons of soil per hour.

Performance: This process design was not associated with a particular treatability study, and no performance results were included. OHM anticipated that the process would be able to achieve the proposed performance criteria for the SPLP leachate, which were as follows:

- B(a)P potency estimate of less than 10 ppb
- PCP concentration of less than 200 ppb
- TCDD-TEQ of less than 30 ppq

Cost: Based on the operating parameters described above, OHM estimates the following costs:

- Equipment costs of $13 per ton of soil treated (includes all equipment costs for excavation, screening, S/S treatment, stockpiling, backfilling, capping, and project support)
- Utilities costs of $0.10 per ton of soil treated
- Consumables costs of $93 per ton of soil treated (includes S/S reagents, clay and soil for capping, and analytical testing)
- Labor costs of $16 per ton of soil treated (includes all labor costs for excavation, screening, S/S treatment, backfilling, capping, and project administration)

The sum of these costs is approximately $122 per ton of soil treated. This cost estimate does not include costs associated with site preparation, startup, offsite disposal of residuals, or demobilization.

Source:

Personal Communication with OHM Corporation. Fax describing proposed S/S treatment system for ACW site in Jackson, TN. 1997.

B.2.2 Treatability Study - MCB Superfund Site in Stockton, CA

Background/Waste Description: In the summer of 1996, a solidification treatability study was conducted using soil from the MCB Superfund site in Stockton, CA. Soil samples used in this treatability study were collected at the MCB site on May 24, 1995. The soil was collected from a pile of soil that was excavated from the process area, screened, and homogenized in preparation for an unrelated treat-ability test. After collection, the soil was screened through new ½-inch by ½-inch wire cloth, placed in ten 5-gallon pails, and shipped to vendors.

Particle size analysis indicated that the sample was a silt or clay soil with 3 percent gravel and 38 percent sand. The soil used in the particle size analysis may not be entirely representative of the soil used in the treatability studies because it was not from the pails shipped to Vendors A or C (it was from one of the other pails of soil collected at the same time).

Results of chemical analyses of TCLP and SPLP leachates from the untreated soil are summarized in the performance section to facilitate comparison with the treated soil. Vendor A and Vendor C each collected a soil sample from the pail(s) of soil they received, and shipped the sample to the analytical laboratory. The analytical laboratory composited these samples and analyzed the composite only. Since this process may have introduced inaccuracies, the composite sample may not be completely representative of either sample, but is considered sufficiently representative.

Summary of Study: Each of the two vendors tested several mixes prior to the treatability study documented in the performance tables. Each vendor used the results of the preliminary tests to select one mix for the final treatability study. The mixes used in the final treatability study were as follows:

Vendor A added the following reagents to 1,600 g of soil:

120 g of carbon
120 g of cement
150 mL of water

Vendor C added the following reagents per 1,000 g of soil:

80 g of cement
120 g of proprietary reagent P-4
Unknown quantity of water

Performance: Results of chemical analyses are presented in Tables B.2-1 (TCLP leachates) and B.2-2 (SPLP leachates). Geophysical testing was also performed on soils treated by Vendor A and Vendor C. The soil treated by Vendor A had a hydraulic conductivity of 6.8 x 10^{-7} cm/sec and an unconfined compressive strength of 280 psi. The soil treated by Vendor

C had a hydraulic conductivity of 2.2 x 10^{-7} cm/sec and an unconfined compressive strength of 170 psi.

Cost (1997): The reagent cost for Vendor A's treatment is estimated to be $60 per ton of soil treated; the reagent cost for Vendor C's treatment is estimated to be $50 per ton of soil treated. These cost estimates are for reagents only and are based on unit costs provided by S/S vendors.

Sources:

IT Corporation. Description of Materials Tests. Prepared for the U.S. Environmental Protection Agency under EPA Contract No. 68-C2-0108, 1996.

SAIC. Wood Preserving Sites Treatability Study: Solidification/Stabilization. Prepared for the U.S. Environmental Protection Agency under EPA Contract No. 68-C5-0001, Work Assignment 0-03, Technical Directive F, and Work Assignment 1-04, Technical Directive B, March 1997a.

B.3 Thermal Desorption (TD)

B.3.1 Pilot-Scale TD of Creosote Contaminated Soil

Background/Waste Description: A Superfund soil from an unspecified site was tested in a pilot-scale desorber. The soil was a fine, sandy soil, 75 percent of which had a grain size diameter between 0.1 and 0.4 mm. The moisture content was only 10 percent and the heating value was below 500 BTU/lb.

Summary of Study: The TD pilot plant was a continuously rotating desorber tube partially enclosed within a gas-fired furnace shell. The tube has a 6½-inch internal diameter and is 14 feet, ⅞ inch long. The heated part of the tube is 6 feet, 8 inches long. Small baffles located within the tube provide soil mixing. The desorber is rated at 320,000 BTU/hr maximum heat duty. The estimated maximum heat that can be transferred to material in the desorber tube is 100,000 BTU/hr. Natural gas or propane is used to fire the 14 equally spaced burners. Soil is fed to the burner via a screw feeder. A stationary thermowell was extended into the tube with six thermocouples to measure soil temperature and three thermocouples to measure gas temperature along the tube length.

Based on previous bench-scale tests, an operating temperature of 555°C and a residence time of 10 minutes were used in the pilot-scale desorber. A nitrogen purge was continuously introduced into the desorber at a rate of 2 cubic feet per minute to help flush contaminants and to maintain an atmosphere that does not support combustion (i.e., <6 percent oxygen). Soil samples were taken before and after treatment. Six sets of temporally related soil samples (waste feed and treated residual) were collected to evaluate system performance. Each feed and residual sample comprised three composites. To allow for residence time, a treated sample was taken approximately 20 minutes after the corresponding feed sample.

Performance: Table B.3-1 gives the average concentration of SVOCs in the pre-treatment and post-treatment soil. Greater than 99.9 percent removal was accomplished for practically all of the SVOCs.

Cost: Costs were not provided with this study.

Source

Lauch, R.P., et al. Removal of Creosote from Soil by Thermal Desorption. Hazardous Materials Control/Superfund '91; Proceedings of the 12th National Conference, December 3-5, 1991, Washington, D.C.

Table B.2-1. Selected TCLP Results - MCB Solidification Treatment

Parameter	Concentration in TCLP Leachate			Change, Percent[a]			
				As Analyzed		Adjusted for Dilution	
	Before Treatment	After Vendor A Treatment	After Vendor C Treatment	Vendor A	Vendor C	Vendor A	Vendor C
PAHs, ppb							
Acenaphthene	52	ND (2.0)	ND (2.0)	>-96	>-96	>-96	>-95
Acenaphthylene	3.1	ND (2.0)	ND (2.0)	>-35	>-35	>-26	>-22
Anthracene	6.3	3.2	ND (1.0)	-49	>-84	-42	>-81
Benz(a)anthracene[1]	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Benzo(b)fluoranthene[1]	ND (5.0)	ND (5.0)	ND (5.0)	NC	NC	NC	NC
Benzo(k)fluoranthene[1]	ND (5.0)	ND (5.0)	ND (5.0)	NC	NC	NC	NC
Benzo(ghi)perylene	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Benzo(a)pyrene[1]	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Chrysene[1]	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Dibenz(a,h)anthracene[1]	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Fluoranthene	12	2.8	ND (1.0)	-77	>-91	-73	>-90
Fluorene	8.6	ND (1.0)	ND (1.0)	>-88	>-88	>-87	>-86
Indeno(1,2,3-cd)pyrene[1]	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
2-Methylnaphthalene	ND (2.0)	ND (2.0)	ND (2.0)	NC	NC	NC	NC
Naphthalene	1.1	ND (1.0)	ND (1.0)	>-9.1	>-9.0	NC	NC
Phenanthrene	11	ND (1.0)	ND (1.0)	>-90	>-90	>-90	>-89
Pyrene	8.8	2.4	ND (1.0)	-73	>-88	-69	>-86
Total PAHs[2]	121	33	ND (28)	-72	>-77	-69	>-72
B(a)P potency estimate	ND (2.8)	ND (2.8)	ND (2.8)	NC	NC	NC	NC
Other SVOCs, ppb							
Carbazole	18	1.3 J	ND (10)	-93	>-44	-92	>-33
Dibenzofuran	6.1	ND (2.0)	ND (2.0)	>-67	>-67	>-62	>-60
Pentachlorophenol, ppb	360	240	ND (1.0)	-33	>-99	-23	>-99
TCDD-TEQ, ppq[3]	110	25	26	-78	-77	-75	-73
Metals							
Arsenic	191	155	64.4	-18.8	-66.3	-66.8	-59.5
Chromium	ND (20.0)	45.5	ND (20.0)	NC	NC	NC	NC
Copper	610	186	62.0	-69.5	-89.8	-64.9	-87.8
Zinc	1,190	52.4	441	-95.6	-62.9	-94.9	-55.5
pH	5.0	10.8	5.9	NA	NA	NA	NA

[a] Percent change stated as a decrease (-) or increase (+).
[1] Used in calculation of B(a)P potency estimate [EPA, 1993a]
[2] For nondetected results, the detection limit has been used for calculating total PAHs.
[3] TCDD-TEQ by I-TEF/89 [EPA, 1989a] reported in parts per quadrillion (ppq)
J = Estimated value, detected above method detection limit but below reporting limit
NA = Not applicable
NC = Not calculated
ND = Not detected at the reporting limit stated in parentheses.
Shaded rows contain only ND and NC designations.

Table B.2-2. Selected SPLP Results - MCB Solidification Treatment

Parameter	Concentration in SPLP Leachate			Percent Change[a]			
				As Analyzed		Adjusted for Dilution	
	Before Treatment	After Vendor A Treatment	After Vendor C Treatment	Vendor A	Vendor C	Vendor A	Vendor C
PAHs, ppb							
Acenaphthene	47	2.3	ND (2.0)	-95	>-95	-94	>-94
Acenaphthylene	ND (10)	ND (2.0)	ND (2.0)	NC	NC	NC	NC
Anthracene	7.1	5.6	ND (1.0)	-21	>-85	-9.3	>-83
Benz(a)anthracene[1]	6.6	ND (1.0)	ND (1.0)	>-85	>-84	>-83	>-81
Benzo(b)fluoranthene[1]	ND (25)	ND (5.0)	ND (5.0)	NC	NC	NC	NC
Benzo(k)fluoranthene[1]	ND (25)	ND (5.0)	ND (5.0)	NC	NC	NC	NC
Benzo(ghi)perylene	ND (5.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Benzo(a)pyrene[1]	ND (5.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Chrysene[1]	6.7	ND (1.0)	ND (1.0)	>-85	>-85	>-83	>-82
Dibenz(a,h)anthracene[1]	ND (5.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Fluoranthene	63	3.9	ND (1.0)	-94	>-98	-93	>-98
Fluorene	ND (5.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Indeno(1,2,3-cd)pyrene[1]	ND (5.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
2-Methylnaphthalene	ND (10)	ND (2.0)	ND (2.0)	NC	NC	NC	NC
Naphthalene	ND (5.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Phenanthrene	ND (5.0)	1.6	ND (1.0)	NC	NC	NC	NC
Pyrene	63	3.5	1.3	-94	-98	-94	-97
Total PAHs[2]	300	38.9	28.3	-87	-91	-85	-89
B(a)P potency estimate	14	ND (2.8)	ND (2.8)	>-80	>-80	>-77	>-76
Other SVOCs, ppb							
Carbazole	5.7 J	7.6 J	ND (10)	+33	NC	+53	NC
Dibenzofuran	ND (10)	ND (2.0)	ND (2.0)	NC	NC	NC	NC
Pentachlorophenol, ppb	13,000	870	ND (1.0)	-93	>-99	-92	>-99
TCDD-TEQ, ppq[3]	9,800	9.7	11	>-99	>-99	>-99	>-99
Metals, ppb							
Arsenic	189	21.4	ND (20.0)	-88.7	>-89.4	-87.0	>-87.3
Chromium	27.0	32.8	26.0	+21.5	-3.70	+39.7	+15.6
Copper	211	121	27.2	-42.7	-87.1	-34.1	-84.5
Zinc	579	ND (50.0)	ND (50.0)	>-91.4	>-91.3	>-90.1	>-89.6
pH	6.8	11.3	11.2	NA	NA	NA	NA

[a] Percent change stated as a decrease (-) or increase (+).
[1] Used in calculation of B(a)P potency estimate [EPA, 1993a].
[2] For nondetected results, the detection limit has been used for calculating total PAHs.
[3] TCDD-TEQ by I-TEF/89 [EPA, 1989a] reported in ppq.
J = Estimated value, detected above method detection limit but below reporting limit
NA = Not applicable
NC = Not calculated
ND = Not detected at the reporting limit stated in parentheses.
Shaded rows contain only ND and NC designations.

Table B.3-1. Average Concentration of SVOCs in Treatment Soil

Parameter	Initial Concentration[5]	Final Concentration[5]	Percent Change[6]
PAHs, ppb			
Acenaphthene	340	<0.210	>-99
Acenaphthylene	38	<0.007	>-99
Anthracene	420	<0.073	>-99
Benz(a)anthracene[1]	170	<0.023	>-99
Benzo(b)fluoranthene[1,2]	160	<0.047	>-99
Benzo(k)fluoranthene[1,2]	NR	NR	NC
Benzo(ghi)perylene	<26	<0.320	NC
Benzo(a)pyrene[1]	77	<0.110	>-99
Chrysene[1]	160	<0.120	>-99
Dibenz(a,h)anthracene[1]	<4.0	<0.016	NC
Fluoranthene	670	<0.010	>-99
Fluorene	390	<0.020	>-99
Indeno(1,2,3-cd)pyrene[1]	<25	<0.035	NC
2-Methylnaphthalene	NR	NR	NC
Naphthalene	140	<0.016	>-99
Phenanthrene	1000	<0.034	>-99
Pyrene	580	<0.052	>-99
Total PAHs[3]	4,200	<1.09	>-99
B(a)P Potency Estimate[4]	120	<0.14	>-99

1 Used in calculation of B(a)P potency estimate [EPA, 1993a]
2 Benzo(b)- and benzo(k)fluoranthene were found to co-elute; therefore, a total amount is given as benzo(b)fluoranthene.
3 Total PAHs does not include benzo(k)fluorenthene and 2-methylnaphthalene. For nondetected results, the detection limit has been used for calculating total PAHs.
4 B(a)P potency estimates were calculated using the relative potency factor for benzo(b)fluoranthene, which is higher than the factor for benzo(k)fluoranthene. This results in conservative B(a)P potency estimates.
5 Average value based on six sets of temporally related samples (waste feed and treated residual).
6 Percent change is stated as a decrease (-) or increase (+).
NR = Not reported
NC = Not calculated
Shaded rows contain only contain only NR and NC designations.

B.4 Incineration

B.4.1 Case Study - Broderick Wood Products Superfund Site

Background/Waste Description: The Broderick Wood Products (BWP) Superfund site is a closed wood treating plant located near Denver, CO that has ceased operation. Two types of waste materials were present at the BWP site. The first type was K001 creosote sludge. Prior to treatment this highly toxic sludge was impounded in plastic-lined cells, and comprised an estimated 3,250 cubic yards of solids and liquids. The sludges contained "elevated concentrations" of PCP, PAHs, VOCs, and PCDDs/PCDFs. The second type of waste was 500 gallons of oil contained in 55-gallon drums [DeFeo, 1994].

Summary of Study: EPA Region VIII divided the remediation into two separate job functions.

The first job, designated as Operable Unit (OU) 1, involved removing the sludges from the temporary storage cells, liquefying them, transporting the sludges to a recycling facility to reclaim the creosote, and incinerating and dispensing of residues. (Residues from the recycling process were incinerated due to the presence of PCP and PCDDs [DeFeo, 1994].)

Performance: The remediation of the wood preserving waste was conducted by AlliedSignal Environmental Systems and Services (ES&S). To liquefy the sludges, a proprietary, mobile liquefication process (LP) unit, supplied by 7-7, Inc. of Wooster, OH, was used onsite. The LP's capacity of up to 100 tons of solidified coal tar per day, coupled with continuous operation, enabled completion of the actual processing within 60 days. Following liquefication, the creosote sludge was pumped into thirty-six 20,000-gallon railcars and ultimately off-loaded into a 2-million-gallon work tank at AlliedSignal's tar products facility. This facility holds a final Part B RCRA permit for storage and incineration of hazardous waste.

At the tar products facility, the K001 material was separated into three fractions: water, coal tar oil, and unusable solids. The water was biologically treated to meet the facility's NPDES wastewater effluent limits and was discharged with the plant's normal production wastewater. Recovered coal tar oil was used as a normal feedstock in plant operations (i.e., used to make products including refined tars, roofing pitch, and electrode-binder pitch for the aluminum industry). The residual solids from the separation process were managed as K001 waste, and were incinerated at AlliedSignal's facility to meet land disposal restriction (LDR) treatment standards prior to ultimate disposal at an approved RCRA Subtitle C landfill [DeFeo, 1994].

Cost: The total costs for the entire project, which was completed within 90 days, amounted to between $3.1 and $3.2 million. Originally, the project had been estimated to take 6 to 8 months at a cost of $11 million to incinerate all the waste material onsite. The cost breakdown was reported as follows:

- Site preparation — $300,000 (including rail siding, road construction, etc.)
- Onsite liquefication of sludge — $1,000,000
- Transportation to AlliedSignal's facility in Birmingham, AL — $550,000
- Reclamation of material — $1,300,000.

B.5 Solvent Extraction

B.5.1 Treatability Study - Bench-Scale Solvent Extraction for the MCB Site

Background/Waste Description: Soil samples used in this treatability study were collected at the MCB Superfund site in Stockton, CA on May 24, 1995. The soil was collected from a pile of soil that was excavated from the process area, screened, and homogenized in preparation for an unrelated treatability test. After collection, the soil was screened through ½-inch wire cloth and placed in pails. CF Systems received one pail of soil.

Particle size analysis indicated that the soil consisted of silt or clay with 3 percent gravel and 38 percent sand. However, the soil used in the particle size analysis may not have been entirely representative of the soil used in the treatability study since it was collected from a pail other than that which was shipped to CF Systems.

Prior to chemical analysis or treatment, the untreated soil was screened to 1/4 inch and homogenized. Results of chemical analyses of the untreated soil are summarized in Table B.5-1 to facilitate comparison with the treated soil.

Summary of Study: The treatability study utilized a bench-scale CF Systems solvent extraction system to treat soil from the MCB site. The main components of the bench-scale system are a heated extraction vessel with a mixer and a receiver vessel in which the organic extract is collected.

The CF Systems solvent extraction process utilizes a liquefied solvent, typically either propane or dimethyl ether (DME), for extracting organic contaminants. Both of these solvents are gases at standard temperature and pressure but are liquids at the operating conditions utilized in the solvent extraction process.

CF Systems selected DME as the preferred solvent for treating the MCB soil. The soil was treated in seven batches of approximately 1 kg each. The treatment of each batch consisted of two extraction stages. Each extraction stage used 1.5 L of DME, resulting in a solvent-to-soil ratio of approximately 1:1, on a weight basis. The solvent and soil mixture was mechanically agitated for 25 minutes during each extraction stage, with a target extraction temperature of 120°F.

The organic extract collected during the solvent extraction treatability study material was treated by BCD in subsequent BCD treatability studies.

Performance: Treatability study results are summarized in Table B.5-1. Percent reductions for SVOCs ranged from 67.6 percent to 98.5 percent. The B(a)P potency estimate for the treated soil was at least 82.4 percent lower than for the untreated soil. The TCDD-TEQ for the treated soil was 95.9 percent lower than for the untreated soil.

Cost: No cost estimate was developed for this treatability study.

Sources:

SAIC. Wood Preserving Sites Treatability Study--Solvent Extraction. Prepared for the U.S. Environmental Protection Agency under EPA Contract No. 68-C5-001, Work Assignment 0-03, Technical Directive F, and Work Assignment 1-04, Technical Directive B. March 1997b.

IT Corporation. Description of Materials Tests. Prepared for the U.S. Environmental Protection Agency under EPA Contract No. 68-C2-0108.

B.6 Base-Catalyzed Decomposition (BCD)

B.6.1 Treatability Study - Treatment of Soil from the MCB Superfund Site

Background/Waste Description: The soil used in this treatability study was collected from the Process Tank Area of the MCB site in Stockton, CA. This soil was contaminated with creosote compounds, PCP, PCDDs/PCDFs, and metals.

Summary of Study: This study evaluates a two-stage TD/BCD process. In the first stage, soil is placed in a TD/BCD reactor which is intended to remove the organic contaminants from the soil, with some simultaneous dechlorination and decomposition of the organics. In the second stage, the desorbed organics are condensed, collected, and then placed in a liquid BCD reactor.

Prior to the treatability study, the soil was screened through a 2-mm sieve. The first stage of treatment was conducted in a 1-L Hastelloy C metal reactor. The materials placed in the reactor were 200 g of soil, 30 g sodium bicarbonate, and 250 g of clean sand (to improve mixing). These materials were heated to 400°C, then allowed to react for 8 hours at 400 to 408°C with continuous mixing and a continuous flow of nitrogen. Materials that volatilized from the soil were condensed and collected. The residuals from the process were 453.46 g of solid residue, 18.17 g oil/organic condensate, and 28.65 g aqueous condensate. The condensate contained nearly all of the chlorophenols and PCDDs/PCDFs that were not destroyed during treatment.

Table B.5-1. Selected Results for the CF Systems MCB Treatability Study

Parameter	Concentration in Soil, Dry Weight Basis		Concentration in Organic Extract	Change in Soil Concentration, Percent[4]
	Before Treatment	After Treatment		
PAHs, ppb				
Acenaphthene	95,700	ND (5,430)	2,330,000	>-94.3
Acenaphthylene	ND (16,600)	ND (5,430)	ND (333,000)	NC
Anthracene	66,500	ND (5,430)	1,920,000	>-91.8
Benz(a)anthracene[1]	77,000	ND (5,430)	2,000,000	>-92.9
Benzo(b)fluoranthene[1]	62,100	ND (5,430)	1,780,000	>-91.2
Benzo(k)fluoranthene[1]	52,200	ND (5,430)	1,350,000	>-89.5
Benzo(ghi)perylene	ND (16,600)	ND (5,430)	ND (333,000)	NC
Benzo(a)pyrene[1]	38,900	ND (5,430)	847,000	>-86.0
Chrysene[1]	94,700	ND (5,430)	2,210,000	>-94.2
Dibenz(a,h)anthracene[1]	ND (16,600)	ND (5,430)	ND (333,000)	NC
Fluoranthene	306,000	5,430	6,910,000	-98.2
Fluorene	21,300	6,890	580,000	-67.7
Indeno(1,2,3-cd)pyrene[1]	ND (16,600)	ND (5,430)	ND (333,000)	NC
2-Methylnaphthalene	ND (16,600)	ND (5,430)	ND (333,000)	NC
Naphthalene	ND (16,600)	ND (5,430)	ND (333,000)	NC
Phenanthrene	95,300	ND (5,430)	2,870,000	>-94.3
Pyrene	406,000	6,260	9,300,000	-98.5
Total PAHs[2]	1,415,000	94,600	34,000,000	-93
B(a)P potency estimate	<71,700	ND (12,500)	<1,610,000	-82.6
Other SVOCs, ppb				
Carbazole	ND (16,600)	ND (5,430)	373,000	NC
Dibenzofuran	ND (16,600)	ND (5,430)	367,000	NC
Pentachlorophenol	1,490,000	72,400	12,900,000	-95.1
Phenol	ND (53,100)	ND (17,200)	ND (1,070,000)	NC
TCDD-TEQ, ppq[3]	29,200,000	1,190,000	470,000,000	-95.9

1 Used in calculation of B(a)P potency estimate [EPA, 1993a].
2 For nondetected results, the detection limit has been used for calculating total PAHs.
3 TCDD-TEQ by I-TER/89 [EPA, 1989a]. Results are reported in ppq.
4 Percent change is shown as decrease (-) or increase (+).
ND = Not detected at the reporting limit stated in parentheses.
NC = Not calculated
Shaded rows contain only ND and NC designations.

In the second stage of the study, the condensate was treated using liquid-phase BCD. The liquid-phase BCD treatability study consisted of batch treatment in a 500-mL glass reactor with heating mantles and a mixer. The materials placed in the reactor were 17.35 g of organic condensate, 71.55 g of LW-110 oil, 21.50 g of LW-104 oil, 30 g of sodium hydroxide, and 2 g of a proprietary solid catalyst. These materials were allowed to react at 320°C to 340°C for 5 hours.

Performance: Results for the first stage of treatment (solid-phase TD/BCD) are summarized in Table B.6-1. The removals of the various PCDD/PCDF congeners from the soil ranged from 93.6 percent to greater than 99.9 percent. Further examination of the results indicates that some of the PCDD/PCDF removed from the soil was collected in the condensate, and some of the PCDD/PCDF was destroyed. General conclusions regarding the fate of specific congeners can be made by comparing their total quantities in the untreated soil and condensate (since the quantities in the treated soil are so low). The total quantity of TCDFs, TCDDs, and PCDDs increased during treatment; the total quantity of each of the other congeners decreased during treatment. This indicates that TCDFs, TCDD, and PCDDs were formed by the dechlorination of the more highly chlorinated PCDD/PCDF compounds.

The results of the second stage of treatment (liquid-phase BCD) are presented in Table B.6-2. The concentration of OCDD was reduced by greater than 99.9 percent to 0.127 ppb; the concentrations of all other PCDD/PCDF congeners were reduced to below detection limits. The concentration of PCP was also reduced to below its detection limit.

Cost: Estimated treatment costs were not presented for this treatability study.

Source:

Tiernan, T.O. Bench-Scale BCD Treatability Tests on Contaminated Soils from a Wood-Preserving Site, the McCormick & Baxter Creosoting Co. Facility in Stockton, California. Prepared for the U.S. Environmental Protection Agency by Wright State University under EPA Contract Number 68-C0-0003. September 20, 1994.

B.6.2 Treatability Study - BCD for the MCB Site

Background/Waste Description: The organic material treated during the BCD treatability study was produced by a solvent extraction treatability study conducted by CF Systems at the University of Idaho in Moscow, ID. The extract consisted of two phases: an organic phase and an aqueous phase. The organic material was reserved for the BCD treatability study and contained numerous chlorinated compounds, including chlorinated phenols, PCDDs, and PCDFs. The aqueous material was not analyzed or subjected to BCD treatment, but was retained for possible analysis at a later date.

Summary of Study: The apparatus used for the BCD treatability study tests includes the following components:

- A three-neck round-bottom glass reaction flask
- Two separate heating mantles for the top and bottom of the reaction flask, with a thermocouple and digital temperature read-out for each of the mantles
- A water-cooled condenser and a recycling receiver fitted with a three-way stopcock for collecting, removing, or recycling condensable components that evolve from the reactor during heating
- A blade-type stirrer driven by a variable-speed motor; the stirrer shaft enters the center opening of the reaction flask through a lubricant-free Teflon Trubore bearing.
- A stainless steel-encased thermocouple and digital readout for monitoring the temperature of the reaction mixture
- An activated carbon trap which is attached to the exit of the condenser for trapping of any noncondensable components volatilized from the reaction flask

Table B.6-1. Selected Results from the First Stage of the MCB TD/BCD Treatability Study (Solid-Phase Treatment Stage)

Parameter	Untreated Soil		Treated Soil		Condensate Collected During First Stage		Change During First Stage, Percent[a]
	Total Quantity	Concentration	Total Quantity	Concentration	Total Quantity	Concentration	
PCDD/PCDF	ng	ppq	ng	ppq	ng	ppq	
Total TCDFs	1,000	5,020,000	ND (0.300)	ND (700)	5,770	260,000,000	>-99.9
Total TCDDs	250	1,250,000	16	37,400	51,300	2,313,000,000	-93.6
Total PeCDFs	19,100	95,400,000	ND (0.600)	ND (1,400)	4,600	207,000,000	>-99.9
Total PeCDDs	2,980	14,900,000	ND (4.29)	ND (10,000)	39,600	1,784,000,000	>-99.8
Total HxCDFs	156,000	782,000,000	ND (1.20)	ND (28,000)	5,860	264,000,000	>-99.9
Total HxCDDs	91,800	459,000,000	ND (4.33)	ND (10,100)	44,000	1,984,000,000	>-99.9
Total HpCDFs	682,000	3,408,000,000	ND (10.1)	ND (23,500)	11,000	494,000,000	>-99.9
Total HpCDDs	1,230,000	6,161,000,000	7.63	17,800	117,000	5,251,000,000	>-99.9
OCDF	701,000	3,505,000,000	ND (12.6)	ND (29,400)	5,970	269,000,000	>-99.9
OCDD	7,360,000	36,785,000,000	72.0	168,000	301,000	13,572,000,000	>-99.9
	mg	ppb	mg	ppb	mg	ppb	
Pentachlorophenol	1,270	6,350,000	ND (0.002)	ND (4.67)	17.0	766,100	>-99.9

[a] Percent change calculated by comparing the total quantities of a given contaminant in the treated and untreated soils. Percent change stated as an increase (+) or decrease (-).

ND = Not detected at the reporting limit stated in parentheses.

Table B.6-2. Selected Results from the Second Stage of the MCB TD/BCD Treatability Study (Liquid BCD Treatment of Condensate Collected During the First Stage)

Parameter	Condensate from First Stage (Solid-Phase TD/BCD)		Reaction Products from Second Stage (Liquid BCD Treatment)		Change in Quantity Due to Liquid BCD Treatment, Percent[a]
	Total Quantity	Concentration	Total Quantity	Concentration	
PCDDs/PCDFs	ng	ppq	ng	ppq	
Total TCDFs	4,510	260,000,000	ND (0.813)	ND (5,700)	>-99.9
Total TCDDs	40,100	2,313,000,000	ND (1.31)	ND (9,200)	>-99.9
Total PeCDFs	3,590	207,000,000	ND (0.685)	ND (4,800)	>-99.9
Total PeCDDs	31,000	1,784,000,000	ND (1.20)	ND (8,400)	>-99.9
Total HxCDFs	4,580	264,000,000	ND (3.67)	ND (25,700)	>-99.9
Total HxCDDs	34,400	1,984,000,000	ND (4.52)	ND (31,700)	>-99.9
Total HpCDFs	8,570	494,000,000	ND (6.93)	ND (48,600)	>-99.9
Total HpCDDs	91,100	5,251,000,000	ND (9.34)	ND (65,500)	>-99.9
OCDF	4,670	269,000,000	ND (13.6)	ND (95,000)	>-99.7
OCDD	235,000	13,572,000,000	18.1	127,000	>-99.9
	mg	ppb	mg	ppb	
Pentachlorophenol	13.3	766,100	ND (0.014)	ND (98.2)	>-99.8

[a] Percent change is shown as an increase (+) or decrease (-).
ND = Not detected at the reporting limit stated in parentheses.

- A motor-driven syringe pump that can be used to inject liquid materials into the reaction flask at an adjustable, controlled rate.

Three preliminary treatability studies using three separate formulations of reagents were conducted. After the preliminary studies were complete, one of the three formulations was selected for the final treatability study based on PCP analytical results and observations made during the studies. The reaction product from the selected formulation was then analyzed for PCDDs, PCDFs, SVOCs, and chlorophenols.

All of the treatability studies followed the same general procedure, except that two different protocols were used to add an aliquot of the organic phase to the system. The protocol selected for the addition of the organic phase depended on the catalyst being used. In all cases, the reagents were added to the reaction flask, then the flask was fitted into the remainder of the system. During the final test and the third preliminary test, the aliquot of the organic phase was placed in the reaction flask at the same time as the other reagents. During the first and second preliminary treatability studies, the other reagents were heated (in the reaction flask) to the reaction temperature before the aliquot of the organic phase was added to the mixture. When the organic phase was added after heating began, the aliquot of the organic phase was injected into the reaction flask by a motor-driven syringe pump. When the motor-driven syringe pump was used, it was subsequently recharged with a small amount of LW-110 oil, which was injected into the reaction flask in order to rinse the injection system.

During all of the treatability studies, the reaction mixture was stirred continuously as it was heated to the reaction temperature. The stirrer was operated at 125 rpm. After the reaction temperature was reached, mixing and heating continued for the specified time at reaction temperature. During the reaction period, organic components were collected in the receiver and slowly recycled back into the reaction flask. After the specified reaction time, the reaction mixture was cooled to ambient temperature. Six 1-g aliquots of the cooled reaction product were then collected and analyzed for SVOCs/chlorophenols (including PCP) and for PCDDs/PCDFs.

Performance: Table B.6-3 presents selected analytical results from the organic extract and from the reaction product collected after the treatability study. The TCDD-TEQ and PCP concentrations for the reaction product were greater than 99.9 percent lower than for the organic extract. Concentrations of nonhalogenated compounds, such as PAHs, were also measured. However, an evaluation of the nonhalogenated compounds as a group indicated that all apparent reductions were due to analytical variability or dilution inherent in the BCD process. A detailed analysis of the PAH results (not presented here) indicated that BCD treatment had no significant effect on the nonhalogenated compounds.

Table B.6-3. Selected Results for the BCD Treatability Study at the MCB Site

Parameter	Concentration in Organic Extract	Concentration in Reaction Product	Percent Change (%)[2]
Other SVOCs, ppb			
Pentachlorophenol	12,900,000	ND (20)	>-99.9
TCDD-TEQ, ppq[1]	<470,000	ND (9.96)	>-99.9

[1] TCDD-TEQ by I-TEF/89 [EPA,1989a], reported in ppq.
[2] Percent change is shown as an increase (+) or decrease (-).
ND = Not detected at the reporting limit stated in parentheses.

Cost: No cost estimate was developed for this treatability study.

Source:

SAIC. Wood Preserving Sites Treatability Study Base-Catalyzed Dechlorination. Prepared for the U.S. Environmental Protection Agency under EPA Contract No. 68-C5-0001. Work Assignment 0-03, Technical Directive F, and Work Assignment 1-04, Technical Directive B. March 1997c.

B.7 Bioremediation

B.7.1 Treatability Study - ACW Site Solid-Phase Bioremediation

Background/Waste Description: Bench-scale treatability studies were conducted on composite samples of contaminated surface soils and sediments from the ACW site located in Pensacola, FL. ACW is an abandoned wood-preserving facility which used creosote from 1902 to 1950 and a mixture of creosote, PCP, and CCA from 1950 until its closure in 1981. Surface soil and the shallow groundwater aquifer has been contaminated due to improper disposal of creosote-contaminated waste. There is also contamination in the form of PCP and other chemicals associated with its use (i.e., chlorinated dioxins).

Summary of Study: Solid-phase bioremediation of contaminated surface soils and sediments were carried out in specially designed "land-farming chambers." Landfarming chambers were specially designed as contained systems by placing large, porcelain Buchner funnels inside inverted vacuum chambers. Funnels were seated on top of 250-mL beakers to collect leachate, if any. An upstream, in-line carbon trap was used as the control for extraneous organics. About 3 kg of surface soils or sediments was placed in each of two Buchner funnels lined with Whatman No. 1 filter paper. Two treatments were established for each type of material: (1) unamended and (2) supplementation with aqueous inorganic nutrient solutions. At the time of loading, 50 mL of sterile, modified Bushnell-Haas (MBH) medium (1,000 mg/L K_2HPO_4, KH_2PO_4, and $(NH_4)_2NO_3$; 200 mg/L $FeCl_3$; pH adjusted to 7.1) was added to the chambers and mixed well using a small trowel. The unamended surface soils and sediments received 50 mL of sterile distilled water prior to mixing. Solid materials were mixed weekly and moisture was maintained at 8 to 12 percent using either water or nutrient solution. All of the cells were maintained at 23°C $\pm$ 3°C.

Performance: Samples were obtained from the chambers initially and after 1, 2, 4, 8, and 12 weeks of incubation and analyzed for PCP and 42 targeted creosote constituents. Results of chemical analyses are presented in Tables B.7-1 and B.7-2. Data reported are the average of duplicate values.

Table B.7-1 presents the results for unamended and nutrient-amended contaminated surface soils. Volatilization of creosote/PCP from surface soils during the 12 weeks of treatment was less than 0.1 percent of the total weight present, and no losses due to leaching or sorption were observed. The rate and extent of biodegradation was stimulated by the addition of inorganic nutrients.

Table B.7-2 presents data for the amended and nutrient-amended contaminated sediments. Volatilization was greater with sediment than with surface soil. While greater than 50 percent of the PCP was biodegraded from the surface soil, no biodegradation of PCP was evident with the sediment. Between weeks 8 and 12, a large amount of naphthalene and other more readily biodegradable compounds were biodegraded. This activity occurred only after the creosote phenolics, absent from inorganic supplements, were extensively degraded. In contrast to contaminated surface soils, the addition of inorganic nutrients to sediments did not significantly improve the rate of biodegradation.

Table B.7-1. Bench-Scale Solid-Phase Bioremediation of ACW Contaminated Surface Soils

Parameter	Solid-Phase Bioremediation of Contaminated Surface Soils from ACW: Unamended			Solid-Phase Bioremediation of Contaminated Surface Soils from ACW: Nutrient-Amended		
	Initial Concentration	Final Concentration	Percent Change[2]	Initial Concentration	Final Concentration	Percent Change[2]
PAHs, ppb						
Acenaphthene	7,100	1,100	-85	7,100	1,200	-83
Acenaphthylene	5,200	3,200	-38	5,200	2,800	-46
Anthracene	9,600	4,000	-58	9,600	1,100	-89
Benz(a)anthracene	11,900	8,400	-29	11,900	10,600	-11
Benzo(b/k)fluoranthene	37,600	36,600	-2.7	37,600	27,100	-28
Benzo(k)fluoranthene	NR	NR	NC	NR	NR	NC
Benzo(ghi)perylene	NR	NR	NC	NR	NR	NC
Benzo(a)pyrene	28,100	21,200	-25	28,100	15,900	-43
Chrysene	38,000	17,800	-53	38,000	15,400	-59
Dibenz(a,h)anthracene	NR	NR	NC	NR	NR	NC
Fluoranthene	34,700	20,400	-41	34,700	15,200	-56
Fluorene	3,100	ND	~100[b]	3,100	ND	~-100[3]
Indeno(1,2,3-cd)pyrene	9,900	9,700	-1.7	9,900	8,100	-18
2-Methylnaphthalene	700	ND	~100[b]	700	ND	~-100[3]
Naphthalene	1,000	600	-40	1,000	400	-60
Phenanthrene	11,200	7,200	-36	11,200	4,800	-57
Pyrene	49,400	23,200	-53	49,400	18,400	-63
Total PAHs	248,000	153,000	-38	248,000	121,000	-51
B(a)P potency estimate	NC	NC	NC	NC	NC	NC
Other SVOCs, ppb						
Carbazole	23,500	4,700	-80	23,500	3,300	-86
Dibenzofuran	6,700	400	-94	6,700	300	-96
Pentachlorophenol	88,400	24,800	-72	88,400	39,700	-55

[1] Total PAHs does not include benzo(k)fluoranthene, benzo(ghi)perylene, and dibenz(a,h)anthracene. Since detection limits were not provided for nondetected results, a value of zero was used in the calculation of total PAHs.
[2] Percent change is shown as a decrease (-) or an increase (+).
[3] Detection limits were not presented for these compounds. The percent change is, therefore, considered to approach -100.
NR = Not reported
NC = Not calculated
Shaded rows contain only ND and NC designations.

Table B.7-2. Bench-Scale Solid-Phase Bioremediation of ACW Contaminated Sediments

Parameter	Solid-Phase Bioremediation of Contaminated Sediments from ACW: Unamended			Solid-Phase Bioremediation of Contaminated Sediments from ACW: Nutrient-Amended		
	Initial Concentration	Final Concentration	Percent Change[2]	Initial Concentration	Final Concentration	Percent Change[2]
PAHs, ppb						
Acenaphthene	1,367,700	1,043,100	-24	1,367,700	962,600	-30
Acenaphthylene	49,400	33,500	-32	49,400	33,300	-33
Anthracene	3,037,100	2,484,400	-18	3,037,100	2,235,600	-26
Benz(a)anthracene	171,200	148,700	-13	171,200	92,800	-46
Benzo(b/k)fluoranthene	139,600	115,200	-17	139,600	117,200	-16
Benzo(ghi)perylene	NR	NR	NC	NR	NR	NC
Benzo(a)pyrene	82,200	61,200	-26	82,200	59,600	-27
Chrysene	481,200	382,200	-21	481,200	330,800	-31
Dibenz(a,h)anthracene	NR	NR	NC	NR	NR	NC
Fluoranthene	1,628,700	1,093,000	-33	1,629,000	1,277,600	-22
Fluorene	1,792,100	1,428,900	-20	1,792,100	1,312,800	-27
Indeno(1,2,3-cd)pyrene	22,600	18,000	-20	22,600	15,800	-30
2-Methylnaphthalene	1,452,300	891,000	-39	1,452,300	361,600	-75
Naphthalene	3,924,500	615,000	-84	3,911,200	126,800	-97
Phenanthrene	4,433,800	3,566,300	-20	4,433,800	3,350,200	-24
Pyrene	1,015,900	775,600	-24	1,015,900	772,000	-24
Total PAHs[1]	19,600,000	12,700,000	-35	19,600,000	11,000,000	-44
B(a)P potency estimate	NC	NC	NC	NC	NC	NC
Other SVOCs ppb						
Carbazole	1,730,600	966,700	-44	1,730,600	964,300	-44
Dibenzofuran	1,264,500	867,200	-31	1,264,500	973,500	-23
Pentachlorophenol	107,900	130,300	+21	107,900	97,400	-9.8

1 Total PAHs does not include benzo(ghi)perylene and dibenz(a,h)anthracene.
2 Percent change is shown as a decrease (-) or an increase (+).
NR = Not reported
NC = Not calculated
Shaded rows contain only NR and NC designations.

Cost: Costs were not provided with this study.

Lessons Learned: While landfarming may be useful for the treatment of materials contaminated with more readily biodegradable compounds, these data suggest that solid-phase bioremediation is of limited usefulness for restoration of creosote- and PCP-contaminated materials present at the ACW site.

Source:

Mueller, J.G., S. Lantz, B. Blattmann, P. Chapman. "Bench-Scale Evaluation of Alternative Biological Treatment Processes for the Remediation of Pentachlorophenol- and Creosote-Contaminated Materials: Solid-Phase Bioremediation". Environmental Science Technology, Vol. 25, No. 6., 1991.

B.7.2 Treatability Study - Laramie Tie Plant Bioremediation

Background/Waste Description: Samples of contaminated soil were collected from the Union Pacific Railroad (UPRR) Laramie Tie Plant Site in Laramie, WY for a series of pilot tests. Railroad tie treating operations began in 1886. Operations continued on an intermittent basis until the facility closed in 1983. The primary wood-preserving agent used, and the primary contaminant of concern, is creosote. PCP was also used, but in much smaller quantities. Most of the contamination at the site is in the form of a 6.5-million-gallon DNAPL layer which is located at the base of a highly permeable alluvial deposit. The layer is at an approximate depth of 10 feet and covers an area of approximately 90 acres. Initial concentrations of PAHs are presented in Table B.7-3.

Summary of Study: A series of bench-scale and field pilot tests were performed at the Laramie Tie Plant Site to evaluate several bioremediation treatment options. Each test used two soil types: 1) sands and gravels; and 2) clays and silts. Soil core samples collected before and after treatment were analyzed for PAHs.

Performance: Cleanup levels achieved using the various bioremediation approaches are summarized in Table B.7-3. Results are given for the sum of 2-3 ring PAHs and the sum of 4-6 ring PAHs. Treatment times varied for each treatment approach.

Cost: Costs were not provided with this study.

Lessons Learned: It may be possible to achieve low cleanup levels in soils of high permeability in reasonable time periods. To achieve similar levels in soils of lower but still moderate permeability such as fine sands will require extended treatment time. Some soils will receive little or no treatment (e.g., stringers of silts and clays, which make up about 5 percent by volume of the contaminated alluvium at the site) in full-scale bioremediation.

Source:

Keith R. Piontek, T. Simpkin. Factors Challeng-ng the Practicability of In Situ Bioremediation at a Wood Preserving Site. For Presentation at the 85th Annual Meeting & Exhibition, Kansas City, MO, June 21-26, 1992.

B.7.3 Treatability Study - Pilot-Scale Bioremediation at an Unidentified Site

Background/Waste Description: Samples of creosote-contaminated soil were collected from an unidentified site for treatment in a pilot-scale bioremediation plot simulating land treatment.

Summary of Study: The study involved the use of a 12-foot by 50-foot pilot-scale bioremediation plot to treat creosote-contaminated soil for an approximate 57-week period. This study evaluated the capability of soil biodegradation under optimal environmental conditions (e.g., pH, temperature, nutrients) without the aid of supplemental organics or surfactants.

Table B.7-3. Laramie Tie Plant Site Treatability Studies Results

Parameter	Treatment	Soil Type	Initial Concentration	Final Concentration	Percent Change[a]
PAHs, ppb					
Sum of 2-3 Ring	Subsurface Bioreclamation after Oil Recovery[b]	Sand and Gravel	1,100,000 - 2,000,000	4,000-14,000	-98.7 to -99.8
Sum of 4-6 Ring	Subsurface Bioreclamation after Oil Recovery[b]	Sand and Gravel	370,000 - 540,000	40,000 - 140,000	-62.1 to -92.6
Sum of 2-3 Ring	Subsurface Bioreclamation after Oil Recovery and Soil Flushing[c]	Sand and Gravel	400,000	2,000 - 20,000	-95.0 to -99.5
Sum of 4-6 Ring	Subsurface Bioreclamation after Oil Recovery and Soil Flushing[c]	Sand and Gravel	180,000	2,000 - 14,000	-92.2 to -98.9
Sum of 2-3 Ring	Surface Bioreclamation (land treatment)[d]	Clay and Silt	1,500,000 - 2,000,000	50,000 - 150,000	-90.0 to -97.5
Sum of 4-6 Ring	Surface Bioreclamation (land treatment)[d]	Clay and Silt	900,000 - 1,200,000	180,000 - 300,000	-66.7 to -85.0
Sum of 2-3 Ring	Slurry Batch Treatment of Surface Soils[e]	Clay and Silt	1,500,000 - 1,900,000	45,000 - 60,000	-96.0 to -97.6
Sum of 4-6 Ring	Slurry Batch Treatment of Surface Soils[e]	Clay and Silt	1,300,000 - 1,900,000	170,000 - 200,000	-84.6 to -91.1

a Percent change is shown as an increase (+) or decrease (-).
b 206 days of treatment
c 210 days of treatment
d 450 days of treatment
e 68 days of treatment

Contaminated soil was applied so that the initial benzene extractable content was about 4 percent by dry weight. Agricultural manure equivalent to 10 tons per acre and agricultural fertilizer equivalent to 2 tons per acre were initially applied giving a C:N ratio range of 25:1 to 50:1. After about 57 weeks of operation, the C:N ratio range was 15:1 to 20:1. The soil pH was maintained between 6 and 7 during the entire treatment period by initially applying agricultural lime equivalent to 2 tons per acre. Soil moisture was maintained at nearly 80 percent of the field capacity and tilling was performed to a depth of 8 inches bi-weekly. Triplicate samples were taken at the beginning and at weeks 5, 20, 31, 35, 42, 46, 51, and 57 during treatment.

The treatment period began September, 1985 and continued through October, 1985. Operation essentially ceased from November, 1985 through April, 1986 due to cold weather. Operation resumed in May, 1986 and continued through October, 1986.

Performance: Table B.7-4 presents a summary of the pilot-scale test plot results. PAHs were grouped according to the number of aromatic rings a particular compound comprises. Overall, PAHs were reduced by approximately 97 percent. In general, the extent of biodegradation decreased progressively for contaminant groups with higher ring numbers.

Cost: Costs were not provided with this study.

Lessons Learned: The observation of decreasing effectiveness with increasing ring number can be partially explained by the fact that the PAH aqueous solubilities decrease and the affinity for desorption from solids decreases as molecular weights (i.e. ring number) increase. The data in this study begin to support the premise that coal-tar related PAHs must first desorb from the solid matrix and exist in aqueous solution in order to degrade in soil systems.

Source:

Smith, J.R., D. Nakles, D. Sherman, E. Neuhauser, R. Loehr, D. Erickson. Environmental Fate Mechanisms Influencing Biological Degradation of Coal-Tar Derived Polynuclear Aromatic Hydrocarbons in Soil Systems. Proceedings Third International Conference on New Frontiers for Hazardous Waste Management, September 10-13, 1989, Pittsburgh, PA. EPA/600/9-89/072. August 1989.

B.7.4 Treatability Study - Biotreatment of Soil and Groundwater from the ACW and MCB Superfund Sites

Background/Waste Description: The groundwater and soil used in this treatability study were collected from the ACW and MCB Superfund sites, respectively. The groundwater and soil were primarily contaminated with PAHs, PCP, and PCDDs/PCDFs.

Summary of Study: The reagent used during the study was Fenton's Reagent (hydrogen peroxide and ferrous sulfate) which acts as a chemical oxidizing agent by generating hydroxyl radicals. One pretreatment sample of the ACW water (emulsion) and one pretreatment sample of the MCB soil were collected for analysis. The experimental design involved setting up five test conditions for each of the two samples for a total of ten tests. The test conditions consisted of:

1. Conventional Biological Treatment: Slurry in nutrient media

2. Fenton's Reagent Treatment: Slurry in nutrient media with 10 millimolar (mM) concentration of ferrous ions and 0.5 molar (M) concentration of hydrogen peroxide.

Table B.7-4. Results of Pilot-Scale Bioremediation Plot Treatability Study

Parameter	Initial Concentration	Final Concentration	Percent Change[a]
PAHs, ppb			
Sum of 2-3 Ring PAHs[b]	2,540,000	6,000	~ -100
Sum of 4 Ring PAHs[c]	374,000	45,000	-88
Sum of 5 Ring PAHs[d]	310,000	88,000	-72
Sum of 6 Ring PAHs[e]	70,000	37,000	-47
Total PAHs	6,660,000	176,000	-97

[a] Percent change is shown as a decrease (-) or an increase (+).
[b] Napththalene, acenaphthene, acenaphthylene, anthracene, fluorene, phenanthrene
[c] Benz(a)anthracene, chrysene, fluoranthene, pyrene
[d] Benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, dibenzo(a,h)anthracene
[e] Benzo(g,h,i)perylene, indeno(1,2,3-cd)pyrene

3. Fenton's Reagent Using Chelated Ferric Iron: Slurry in nutrient media with 10mM concentration of chelated ferric iron and 0.5 M concentration of hydrogen peroxide chelated ferric iron was added or a ferric iron/EDTA complex in solution.

4. Abiotic control: Slurry in deionized water and 0.1 percent mercuric chloride.

5. Biotic control: Slurry in deionized water.

A slurry was prepared with 50 mL of the ACW water sample (sludge), 25 g of sterile soil and 25 mL of sterile deionized water for each treatment condition. The controls were set up in the same manner. Nutrient amendment was applied to each treatment by adding approximately 0.04 g of Restore™ which is a proprietary blend of nutrients including: 5 percent ammonium chloride, 20 percent disodium phosphate, 12.5 percent mono-sodium phosphate, and 12.5 percent sodium tripolyphosphate. No nutrients were added to the abiotic or biotic controls. The abiotic control was established by adding 0.4 g of mercuric chloride to the treatment vessel. The treatments and the biotic control were placed on a shaker set at 120 rpm and incubated at 25°C. The abiotic control was placed in a refrigerator at 4°C. The treatments were analyzed for SVOCs and dioxins/furans at the end of the study (Day 30).

Performance: Table B.7-5 presents selected pretreatment and post-treatment analytical results of the MCB soil collected prior to and after the treatability study.

Cost: No cost estimate was developed for this treatability study.

Source:

IT Corporation. Section III (Results of soil biodegradation tests). Prepared for the U.S. Environmental Protection Agency under EPA Contract No. 68-C5-0108. 1996b.

Table B.7-5. Selected Results for the Biotreatment with Fenton's Reagent Treatability Study

Parameter	Pretreatment	Biological	Percent Change (%)	Fenton's	Percent Change (%)	Fenton's and Ferric Iron	Percent Change[3] (%)
PAHs, ppb							
Acenaphthene	87,000	51,000	-41	67,000	-23	110,000	+26
Acenaphthylene	5,300	2,900	-45	3,900	-26	5,600	+5.7
Anthracene	59,000	44,000	-25	59,000	0	120,000	+100
Benz(a)anthracene[1]	64,000	32,000	-50	50,000	-22	70,000	+9.4
Benzo(b)fluoranthene[1]	64,000	31,000	-52	52,000	-19	77,000	+20
Benzo(k)fluoranthene[1]	26,000	12,000	-54	21,000	-19	26,000	0
Benzo(ghi)perylene	32,000	14,000	-56	25,000	-22	28,000	-12
Benzo(a)pyrene[1]	41,000	19,000	-54	31,000	-24	42,000	+2.4
Chrysene	71,000	36,000	-49	67,000	-5.6	110,000	+55
Dibenz(a,h)anthracene[1]	6,500	2,800	-57	6,100	-6.2	6,800	+4.6
Fluoranthene	380,000	140,000	-63	210,000	-45	330,000	-13
Fluorene	27,000	13,000	-52	18,000	-33	27,000	0
Indeno(1,2,3-cd)pyrene[1]	29,000	12,000	-59	23,000	-21	28,000	-3.4
2-Methylnaphthalene	2,800	1,500	-46	2,600	-7.1	3,600	-28
Naphthalene	2,900	1,700	-41	2,800	-3.4	4,100	+41
Phenanthrene	75,000	39,000	-48	67,000	-11	70,000	-6.7
Pyrene	180,000	96,000	-47	200,000	+11	270,000	+50
Total PAHs	1,153,000	548,000	-52	905,000	-21	1,328,000	+15
B(a)P potency estimate	64,000	29,000	-55	50,000	-22	67,000	+4.7

Table B.7.5. Selected Results for the Biotreatment with Fenton's Reagent Treatability Study (continued)

Parameter	Pretreatment	Biological	Percent Change (%)	Fenton's	Percent Change (%)	Fenton's and Ferric Iron	Percent Change (%)
Other SVOCs, ppb							
Carbazole	NA	NA	NC	NA	NC	NA	NC
Dibenzofuran	14,000	11,000	-21	11,000	-21	15,000	+7.1
Pentachlorophenol	460,000	250,000	-46	480,000	+4.3	580,000	+26
Phenol	NA	NA	NC	NA	NC	NA	NC
TCDD-TEQ, ppq[2]	14,000	6,100	-56	7,600	-46	910	-35

1 Used in calculation of B(a)P potency estimate [EPA, 1993].
2 TCDD-TEQ by I-TEF/89 [EPA,1989a], reported in ppq.
3 Percent change is stated as a decrease (-) or an increase (+).
NC = Not calculated
NA = Not analyzed
Shaded rows contain only NA and NC designations.

APPENDIX C

WATER TREATMENT TECHNOLOGIES
ADDITIONAL TREATABILITY AND CASE STUDIES

C.1 Photolytic Oxidation

C.1.1 Treatability Study - Ultrox® System at Wood Processing Facility in Denver, CO

Background/Waste Description: The Ultrox® system was employed by Koppers Industries, Inc., Denver, CO at a wood processing facility.

Summary of Study: The unit, operating since December 1985, uses UV and ozone to treat wastewater contaminated with phenol and pentachlorphenol (PCP). The organic concentrations of the influent typically range between 150 to 200 mg/L for phenol and are about 1 mg/L for PCP. Effluent was tested between May, 1988 and March, 1989.

Performance: Results of effluent testing are presented in Table C.1-1. The range of effluent values is based on 1-day composites taken May, August, and November, 1988 and March, 1989. Average flows in March 1989 were reported to be 5,211 gallons per day (gpd), with a maximum daily flow of 16,047 gallons.

Cost: The O&M cost for the entire system is $10.92 per 1,000 gallons of treated wastewater. This unit cost does not include equipment costs. The capital cost of the entire treatment system was $550,000, of which $200,000 was for the Ultrox® UV radiation/oxidation portion. The cost estimate also excludes costs associated with site preparation, permitting and regulatory compliance, startup, analysis, effluent disposal, and demobilization.

Source:
Koppers Industries. Personal communication between Mr. Marvin Miller, P.E., Koppers Industries, and Dr. Gary Welshans, PRC. 1989.

C.2 Carbon Adsorption

C.2.1 Case Study - Activated Sludge and Carbon Treatment at an Unidentified Wood Preserving Site in Canada

Background/Waste Description: Aqueous effluent containing PCP was treated using activated sludge and activated carbon from November 1, 1977 to May 1, 1978 at an unidentified wood preserving site in Canada.

Summary of Study: The study was divided into three phases: (1) monitoring of existing full-scale activated sludge system; (2) activated sludge treatment followed by pilot-scale filter and granular activated carbon treatment in series; and (3) by-pass of activated sludge system and treatment of wastewater using oil separation and flow equalization followed by activated carbon treatment. Data in this document are for the second phase only.

The flow rate through the pilot-scale system (filter followed by granular activated carbon (GAC) system) was 0.6 m^3/day. The pilot-scale filter was 100 mm in diameter and contained 11 kg of anthracite filter media at a media depth of 1 m. The hydraulic loading for the filter was 76 m^3/m^2-day. The GAC system consisted of three carbon columns operated in a series. Each column was 100 mm in diameter and 3 m high. Each column contained 6.8 kg of Filtrasorb 400 at a carbon depth of 2.1 m.

Table C.1-1. Koppers Industries Treatment Results Using Ultrox System

Parameter	Initial Concentration	Final Concentration	Percent Change[a]
Pentachlorophenol, ppb	1,000	150 - 500	-50 to -85
Phenol, ppb	150,000 - 200,000	38,000 - 145,000	-3.3 to -81
pH	NR	7.0 - 12.2	NC

[a] Percent change is shown as an increase (+) or decrease (-).
NC = Not Calculated
NR = Not Reported

Performance: Results of treating effluent contaminated with PCP using filtration and GAC in series and using GAC alone are given in Table C.2-1.

Cost: Costs were not provided with this study.

Source:

Guo, P.H.M, P.J.Z. Fowlie, V.W. Cairns and B.E. Jank. "Activated Sludge and Activated Carbon Treatment of a Wood Preserving Effluent Containing Pentachlorophenol", Canadian Environmental Protection Service Report EPS 4-WP-80-2. June 1980.

column packed with 1-inch (2.54 cm) Pall rings. Water drawn from a source aquifer was circulated through the column. Nutrients and oxygen were added to the wastewater before it entered the column, and the overflow from the column was returned to the source aquifer. The retention time for the column was initially three days, but was decreased to one day. Acclimated bacteria were introduced to the system by seeding the column with Pall rings from another treatment system that was successfully treating creosote- and pentachlorophenol-contaminated wastewaters. Seven influent and effluent sampling events occurred during the study.

Table C.2-1. GAC Treatment of a Wood Preserving Effluent

	Filtration and GAC			GAC		
Parameter	Initial Concentration	Final Concentration	Percent Change[a]	Initial Concentration	Final Concentration	Percent Change[a]
Pentachlorophenol, ppb	455	20	-96	3,409	30	-99

[a] Percent change is shown as an increase (+) or decrease (-).

C.3 Bioremediation

C.3.1 Treatability Study - Biological Treatment of Creosote Contaminated Groundwater in Montana

Background/Waste Description: A railroad tie treating plant located in northwestern Montana was operated for over 80 years until its closure in 1982. During operation, creosote-contaminated wastewater was discharged to an abandoned river slough which served as a surface impoundment. The surface impoundment was used as a sedimentation basin for recovery and reuse of creosote. In order to evaluate bioremediation as a groundwater treatment alternative, treatment was simulated in a laboratory study using a submerged fixed-film column.

Summary of Study: The submerged fixed-film system had a three-inch (7.6 cm) diameter

Performance: Table C.3-1 summarizes the average initial and final concentrations for several polycyclic aromatic hydrocarbons (PAHs) and the benzo(a)pyrene [B(a)P] potency estimate. Very high removal efficiencies were observed for all PAHs. The results of the study indicate that a pump and treat system using fixed-film bioremediation may be able to successfully treat the contaminated groundwater.

Cost: Costs were not provided with this study.

Source:

Coover, J.R., B. Stone, B. Genes. Biological treatment of Creosote Contaminated Groundwater in Montana. Joint CSCE-ASCE National Conference on Environmental Engineering Vancouver, B.C., July 13-15, 1988.

Table C.3-1. Removal Rates of PAH Compounds from a Submerged Fixed Film System

Parameter	Initial Concentration[3]	Final Concentration[3]	Percent Change[4]
PAHs, ppb			
Acenaphthene	492,000	24,500	-93.0
Acenaphthylene	230,000	29,400	-88.4
Anthracene	76,000	4,400	-94.2
Benz(a)anthracene[1]	10,100	400	-95.9
Benzo(b)fluoranthene[1]	4,000	500	-87.5
Benzo(k)fluoranthene[1]	5,700	500	-91.1
Benzo(ghi)perylene	10,200	1,000	-89.8
Benzo(a)pyrene[1]	8,800	300	-96.4
Chrysene[1]	20,500	1,700	-92.0
Dibenz(a,h)anthracene[1]	4,300	400	-90.4
Fluoranthene	72,700	2,600	-96.4
Fluorene	150,000	2,900	-98.7
Indeno(1,2,3-cd)pyrene[1]	2,000	600	-69.0
2-Methylnaphthalene	NR	NR	NC
Naphthalene	3,468,000	24,100	-99.3
Phenanthrene	294,000	4,000	-98.7
Pyrene	50,000	3,700	-92.6
Total PAHs[2]	4,900,000	101,000	-97.9
B(a)P potency estimate	14,800	8,57	-94.2

1 Used in calculation of B(a)P potency estimate [EPA, 1993a]
2 Total PAHs does not include 2-methylnaphthalene.
3 Average value based on seven sampling events.
4 Percent change is shown as a decrease (-) or an increase (+).
NR = Not reported
NC = Not calculated
Shaded row contains only NR and NC designations.

C.3.2 *Treatability Study - Biodegradation of Creosote- and PCP-Contaminated Groundwater at the American Creosote Works (ACW) Site*

Background/Waste Description: Approximately 400-L of groundwater contaminated with creosote and pentachlorophenol were taken from an onsite sampling well at the ACW site, Pensacola, FL. Groundwater was transferred into 55-gallon steel drums from which five 1-L samples were collected and sent to a laboratory for biodegradation studies.

Summary of Study: Fifteen 125-mL Erlenmeyer flasks received 25 mL of groundwater medium (GWM) consisting of 12.5 mL of filtered groundwater from the ACW site and 12.5 mL of modified Bushnell-Hass medium. In addition, two 1.0-L Wheaton bottles received 200 mL of the same GWM. Each flask was inoculated with 1.0 mL of a microbial suspension prepared using soil from the ACW site. The GWM in the Wheaton bottles each received 8.0 mL of the same soil microbial suspension. Duplicate 25-mL samples were extracted from each Wheaton bottle and analyzed for the initial contaminant concentration. Five of the 125-mL flasks received 2.5 mL of a 37 percent formaldehyde solution and were used as killed-cell controls. On Days 1, 3, 5, 8, and 14, the entire contents from two inoculated flasks and one killed-cell flask were separately extracted and analyzed for the presence of creosote constituents.

Performance: Results given in Table C.3-2 show that soil microorganisms indigenous to the ACW site were able to degrade the majority of the PCP and 42 creosote contaminants in the GWM. Lower molecular weight compounds were degraded to a greater degree than the higher molecular weight compounds. PCP was not degraded. The killed-cell flasks showed little degradation, indicating minimal losses due to abiotic processes (sorption, volatilization).

Cost: Costs were not provided with this study.

Source:

Mueller, J.G., D. Middaugh, S. Lantz, P. Chapman. "Biodegradation of Creosote and Pentachlorophenol in Contaminated Groundwater: Chemical and Biological Assessment". Applied and Environmental Microbiology, pp. 1277-1285. May 1991.

Table C.3-2. Bioremediation of ACW Contaminated Groundwater

Parameter	Bioremediation of Contaminated Groundwater from ACW Site: Indigenous Microorganisms			Bioremediation of Contaminated Groundwater from ACW Site: Sterile Control		
	Initial Concentration	Final Concentration	Percent Change[1]	Initial Concentration	Final Concentration	Percent Change[1]
PAHs, ppb						
Acenaphthene	13,600	1,800	-87	13,600	11,900	-13
Acenaphthylene	600	200	-67	600	400	-33
Anthracene	4,700	500	-89	4,700	3,900	-17
Benz(a)anthracene	2,900	1,300	-55	2,900	2,700	-6.9
Benzo(b/k)fluoranthene	2,900	1,700	-41	2,900	2,800	-3.4
Benzo(k)fluoranthene	NR	NR	NC	NR	NR	NC
Benzo(ghi)perylene	NR	NR	NC	NR	NR	NC
Benzo(a)pyrene	2,100	900	-57	2,100	2,000	-4.8
Chrysene	2,700	1,200	-56	2,700	2,400	-11
Dibenz(a,h)anthracene	NR	NR	NC	NR	NR	NC
Fluoranthene	16,200	7,600	-53	16,200	14,400	-11
Fluorene	11,600	100	-99	11,600	9,900	-15
Indeno(1,2,3-cd)pyrene	1,900	900	-53	1,900	1,800	-5.3
2-Methylnaphthalene	4,700	ND	~-100[2]	4,700	4,500	-4.3
Naphthalene	28,700	ND	~-100[2]	28,700	25,600	-11
Phenanthrene	32,800	ND	~-100[2]	32,800	27,700	-16
Pyrene	10,400	4,700	-55	10,400	9,800	-5.8
Total PAHs	136,000	21,000	85	136,000	≥120,000	-12
B(a)P potency estimate	NC	NC	NC	NC	NC	NC
Other SVOCs, ppb						
Carbazole	2,900	1,000	-66	2,900	3,000	+3.4
Dibenzofuran	5,500	700	-87	5,500	6,100	+11
Pentachlorophenol	100	100	0	100	100	0

1 Percent change is shown as an increase (+) or decrease (-).

2 Detection limits were not presented for these compounds. The percent change is, therefore, considered to approach 100.

NR = Not recorded

NC = Not calculated

Shaded rows contain only NR and NC designations.

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