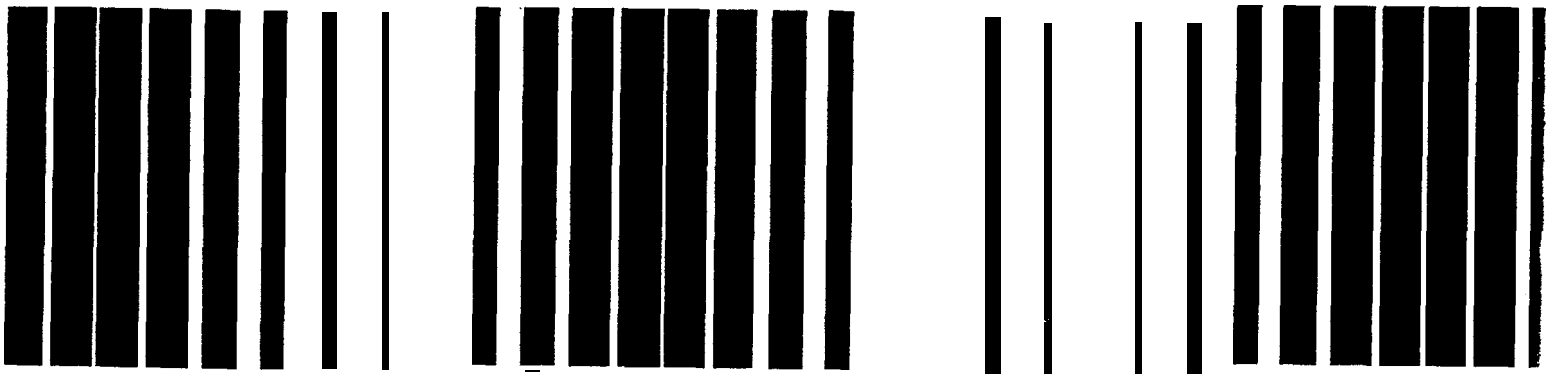


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Treatment Technology Performance and Cost Data for Remediation of Wood Preserving Sites



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October 1997

**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

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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-pdioxins 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
c o	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 ₂ O ₂	hydrogen peroxide
HpCDD	heptachlorodibenzo-pdioxin
HpCDF	heptachlorodibenzofuran
HPLC	high performance liquid chromatography
HWSFD	Hazardous Waste Super-fund Collection Database
HxCDD	hexachlorodibenzo-pdioxin

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	liquefaction process
LTU	land treatment unit
MCB	McCormick & Baxter
MCL	maximum contaminant level
mg/L	milligram per liter
m ² g	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
NRML	National Risk Management Research Laboratory
NTIS	National Technical Information System
O&M	operations and maintenance
O ₃	ozone
OCDD	octachlorodibenzo-pdioxin
OCDF	octachlorodibenzofuran
OHEA	Office of Health and Environmental Assessment
ORD	Office of Research and Development
o s c	On-Scene Coordinator
o u	operable unit
PAH	polycyclic aromatic hydrocarbon
PCDD	polychlorinated dibenzo-pdioxin
PCDF	polychlorinated dibenzofuran
PCP	pentachlorophenol
PeCDD	1,2,3,7,8-pentachlorodibenzo-<i>p</i>-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	Super-fund Innovative Technology Evaluation
SPLP	Synthetic Precipitation Leaching Procedure
STC	STC Remediation Inc.
SVE	soil vapor extraction
s v o c	semivolatile organic compound
TCDD	dioxin (tetrachlorodibenzo-pdioxin)
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
t Pd	tons per day
TPH	total petroleum hydrocarbons
u c s	unconfined compressive strength
UPRR	Union Pacific Railroad
μm	micrometers
u v	ultraviolet
UV/H ₂ O ₂	ultraviolet/hydrogen peroxide
Vendor FACTS	Vendor Field Analytical and Characterization Technology System
VISITT	Vendor Information System for Innovative Treatment Technologies
v o c	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 discusses 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 I-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

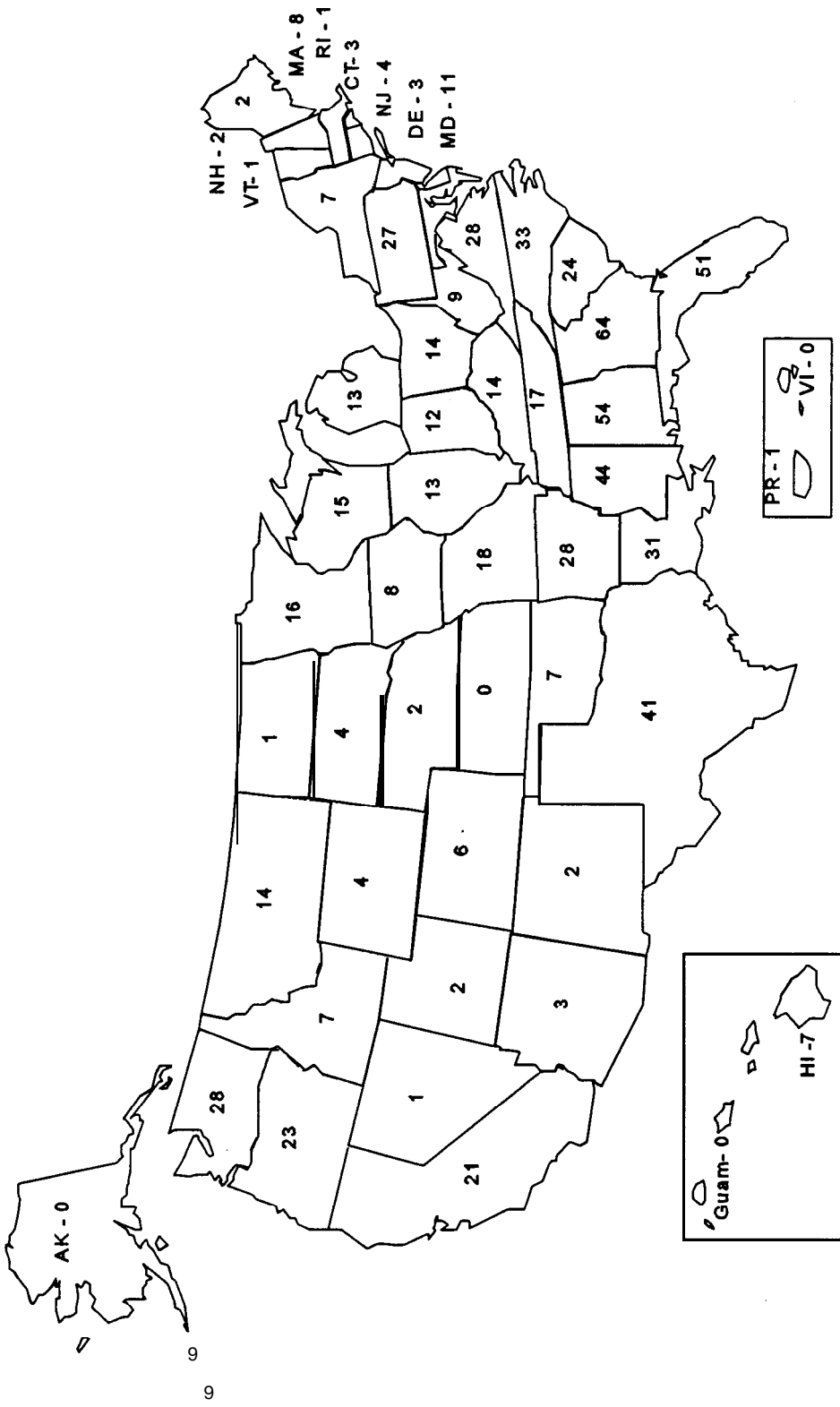


Figure 1-1. Distribution of wood preserving sites by state.

Table I-I. 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-pdioxins (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 Contaminants¹

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-I); 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)

2.5.7 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-pdioxin (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, 1991 c]. 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'

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	601 OA
	SVOCs ²	35408, 3541, 3550A	82708
	PAHs	3540B, 3541, 3550A	8100, 8310
	PCP	35408, 3541, 3550A	8040A
	Dioxins/Furans	NA ³	8280, 8290
Water/Leachate	Arsenic	3005A, 3010A, 3015	601 OA, 7060A ⁴
	Chromium	3005A, 3010A, 3015	6010A
	Copper	3005A, 3010A, 3015	6010A
	Zinc	3005A, 3010A, 3015	6010A
	SVOCs ²	351 OB, 35208	82708
	PAHs	351 OB, 35208	8100, 8310
	PCP	351 OB, 35208	8040A
	Dioxins/Furans	NA ³	8280, 8290
Organic-Phase Materials	Arsenic	3051	6 00A, 7060A ⁴
	Chromium	3051	6010A
	Copper	3051	6010A
	Zinc	3051	6010A
	SVOCs ²	3580A	82708
	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 (\$/yd³) 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 yd³) [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 Super-fund 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 B-99.9	>-99	B-97	-57	NR	Whiting, et al., 1992
Incineration	s-99.9	s-99	>-99	NR	+2 to -93	EPA, 1988
Solvent Extraction	-93 to >-99	-83	-61 to s-99	-96	NR	EPA, 1995c SAIC, 1997b ⁵
Base-Catalyzed Decomposition	N A	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'	Important Cost Factors	References
Soil Treatment				
<u>Soil Washing</u>				
Treatment'	30 - 200	1993	Residuals Disposal	Biogenesis Enterprises, Inc., 1993
Project ²	120-200	1994		EPA, 1994a
<u>Solidification/Stabilization</u>				
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
<u>Thermal Desorption</u>				
Treatment	NR		Residuals Disposal, Moisture Content	
Project	100-600	1992-93		EPA, 1994b Whiting, et al., 1992
<u>Incineration</u>				
Treatment	140 - 190	1989	Heating Value of Waste, Moisture Content	EPA, 1989b EPA, 1990b
Project	NR			
<u>Solvent Extraction</u>				
Treatment	94-112	1992	Residuals Disposal	EPA, 1993f
Project	75 - 400	1994		EPA, 1995c
<u>Base-Catalyzed Decomposition</u>				
Treatment	NR		Contaminant Media, Pretreatment Requirements	
Project	200 - 500	1990		EPA, 1990b EPA, 1994a
<u>Bioremediation</u>				
Treatment				
Slurry-Phase	49-105		Cleanup Levels	EPA 1993d
Cornposting	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, 19934 EPA, 1994a
Composting	187-310	1996	Cleanup Levels	EPA, 1996c
Landfarming	NR		Cleanup Levels	EPA, 1996b
Water Treatment				
<u>Photolytic Oxidation</u>				
Treatment	3.90 - 13.28	1993	Electricity	EPA, 1993b
Project	2.76 - 58.50	1993-94		EPA, 1994a Venkatadri and Peters, 1993
<u>Carbon Adsorption</u>				
Treatment	1.38	1995	Contaminant Concentration	IT Corp., 1996a
Project	1.20 - 6.30	1991		EPA, 1991b
<u>Hydraulic Containment</u>				
Treatment	NR	NR	NR	
Project	3 - 75⁴	1992	Depth of Contain- ment Required	EPA, 1992a
<u>Bioremediation⁶</u>				
Treatment	2.94 - 14.56	1991	Treatment Location <i>(In Situ vs. Ex Situ)</i>	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 \$/ft² 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 **estimates** 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 **afore-**mentioned site-specific factors, may greatly affect the actual cost of a specific remediation.

APPENDIX B

***SOIL TREATMENT TECHNOLOGIES
ADDITIONAL TREATABILITY AND CASE STUDIES***

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)anthracene¹	220,000	240,000	+9.1	58,000	-74
Benzo(b)fluoranthene¹	310,000	260,000	-16	71,000	-77
Benzo(k)fluoranthene¹	120,000	92,000	-23	24,000	-80
Benzo(ghi)perylene	57,000	54,000	-5.2	18,000	-68
Benzo(a)pyrene¹	130,000	120,000	-7.7	36,000	-72
Chrysene¹	350,000	350,000	0	84,000	-76
Dibenz(a,h)anthracene¹	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)pyrene¹	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 PAHs²	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, ppq³	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 8400,000 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)anthracene¹	115,000	19,000	-83	46,000	680
Benzo(b)fluoranthene¹	120,000	19,000	-84	47,000	720
Benzo(k)fluoranthene¹	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
Chrysene¹	75,000	12,000	-84	28,000	430
Dibenz(a,h)anthracene¹	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)pyrene¹	30,000	5,000	-83	12,000	200
2-Methylnaphthalene	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
Pvrene	300,000	44,000	-85	110,000	1,700
Total PAHs²	4,000,000	420,000	-90	1,200,000⁴	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-methylnaphthalene**.

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 yd³ (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 yd³, 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 ²	\$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 Handlina of Clean Soil	60,000	4

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

Activity	Project Cost (\$1)	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 yd³ 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 yd³ 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]

Formulation	Pounds of Reagent per Ton of Soil Treated				
	Portland Type 1 Cement	Class F Fly Ash	Activated Carbon	STC P-1'	STC P-4'
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'			
	Untreated Soil ⁵	After Mix 2 Treatment	After Mix 6 Treatment	As Analyzed		Adjusted for Dilution	
				Mix 2	Mix 6	Mix 2	Mix 6
PAHs, ppb							
Acenaphthene	100	ND (2.0)	ND (2.0)	r-98	a-98	a-97	>-97
Acenaphthylene	5.1	ND (2.0)	ND (2.0)	>-60	>-60	>-47	B-50
Anthracene	22	ND (1.0)	ND (1.0)	>-95	>-95	a-93	>-94
Benz(a)anthracene¹	1.3	ND (1.0)	ND (1.0)	a-21	>-21	>-0	a-3.1
Benzo(b)fluoranthene¹	ND (5.0)	ND (5.0)	ND (5.0)	NC	NC	NC	NC
Benzo(k)fluoranthene¹	ND (5.0)	ND (5.0)	ND (5.0)	NC	NC	NC	NC
Benzo(ghi)perylene¹	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Benzo(a)pyrene¹	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Chrysene'	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Dibenz(a,h)anthracene¹	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
Fluoranthene	11	1.2	ND (1.0)	-90	>-91	-86	a-89
Fluorene	55	ND (1.0)	ND (1.0)	>-98	>-98	>-97	a-97
Indeno(1,2,3-cd)pyrene¹	ND (1.0)	ND (1.0)	ND (1.0)	NC	NC	NC	NC
2-Methylnaphthalene	170	ND (2.0)	ND (2.0)	a-98	>-98	>-98	a-98
Naphthalene	240	ND (1.0)	ND (1.0)	>-99	>-99	>-99	>-99
Phenanthrene	65	ND (1.0)	ND (1.0)	a-98	>-98	a-97	B-98
Pyrene	6.4	ND (1.0)	ND (1.0)	>-	>-84	>-79	>-80
Total PAHs²	690	2.8	ND (28)	-96	>-96	-95	a-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	B-92
Dibenzofuran	52	ND (2.0)	ND (2.0)	>-96	a-96	>-94	>-95
Pentachlorophenol	8,200	120	12	-99	>-99	-98	>-99
Phenol³	ND (10)	71	37	>+610	>+270	>+840	>+370
TCDD-TEQ, ppq⁴	320	12	14	-96	-95	-95	-94
Metals, ppb							
Arsenic	ND (20)	ND (20)	ND (20)	NC	NC	NC	NC
Chromium³	ND (20)	60	70	>+200	>+250	>+300	>+340
Copper	22	ND (20)	ND (20)	s-7.7	B-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 $\frac{1}{4}$ -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 TCDPTEQ) 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)anthracene¹ (1,000)	ND (14)	180	+120
Benzo(b)fluoranthene¹ (1,000)	60,000	<1	~-100
Benzo(k)fluoranthene¹ (1,000)	27,000	50	-99.8
Benzo(ghi)perylene (1,000)	190,000	ND (4.7)	~ -100
Benzo(a)pyrene¹ (1,000)	400,000	ND (10)	~ -100
Chryene ¹	65,000	200	-99.7
Dibenzfa, hanthracene 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)pyrene¹ (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 (110,000)	220,000	350	-99.8
Total PAHs²	3,400,000	2,300	-99.9
B(a)P Potency Estimate³	410,000	ND (32)	~-
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, ppq⁴	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)anthracene¹ (1,000)	3,200	ND (14)	~-100
Benzo(b)fluoranthene¹ (1,000)	4,300	ND (1)	~-100
Benzo(k)fluoranthene¹ (1,000)	5,100	ND (0.4)	~-100
Benzo(ghi)perylene (1,000)	ND (4.7)	ND (4.7)	NC
Benzo(a)pyrene¹ (1,000)	9,500	ND (10)	~-100
Chrysene¹	3,500	ND (1)	~-100
Dibenz(a,h)anthracene¹	NR	NR	NC ²
Fluoranthene (10,000)	6,300	ND (0.7)	~-100
Fluorene (10,000)	1,800	ND (0.6)	~-100
Indeno(1,2,3-cd)pyrene¹ (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
4.40 Pyrene II (0.000)	-	ND (7.5)	~-100
Total PAHs²	54,000	ND (60)	a-99.9
B(a)P Potency Estimate³	11,000	ND (12)	~-
Other SVOCs, ppb			
Pentachlorophenol (500)	9,400	ND (300)	>-97
2,4,5-Trichlorophenol (500)	1,600	ND (110)	B-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
Benzo(a)anthracene¹ (1,000)	12,000	NR	NC
Benzo(b)fluoranthene¹ (1,000)	9,100	ND (1)	~-100
Benzo(k)fluoranthene¹ (1,000)	6,800	ND (4)	~-100
Benzo(ghi)perylene (1,000)	8,900	ND (4.7)	-100
Benzo(a)pyrene¹ (1,000)	18,000	ND (10)	~-100
Chrysene ¹	11,000	ND (1)	~-100
Dibenz(a,h)anthracene¹	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)pyrene¹ (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
Pvrene (10,000)	36,000	ND (2.51)	~-100
Total PAHs²	180,000	220	99.9
B(a)P Potency Estimate³	71,000	ND (10)	--
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 **benzo(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, 1991 b]:

- System capacity
- Types of feedstocks being fed
- Regime (i.e., slagging vs. ashing)
- Length-to-diameter (UD) 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 Super-fund 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	36.56	36.50
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 1969 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 $\frac{2}{3}$ 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-f 3. Selected Results - International Paper Company Incineration Treatment [EPA, f 989b]

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	NR.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	C39.99995	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	99.99666	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	99.99869	4,000	>99.99997	2,200	>99.99997	7,400	>99.99998
Total PAHs ²	34,000	299.99816	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/yr	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	B-99.98	co.01 0
Acenaphthylene	NR	---	---	---
Anthracene	8,500 - 13,000	<2.5	B-99.98	<0.050
Benz(a)anthracene¹	<2,500 - 3,400	<2.5	>-99.93	co.01 0
Benzo(b and/or k)fluoranthene ¹	940 - 2,300	<2.5	p-99.89	<0.050
Benzo(ghi)perylene	NR	---	---	---
Benzo(a)pyrene¹	<250 - 940	<2.5	s-99.73	co.050
Chrysene ¹	<2,500 - 3,600	<2.5	>-99.93	<0.050
Dibenz(a,h)anthracene¹	NR	---	---	---
Fluoranthene	13,000 - 21,000	<2.5	>-99.99	co.050
Fluorene	8,200 - 12,000	<2.5	B-99.98	co.050
Indeno(1,2,3-cd)pyrene¹	NR	---	---	---
2-Methylnaphthalene	NR	--	--	--
Naphthalene	26,000 - 43,000	<2.5	>-99.99	<0.050
Phenanthrene	28,000 - 42,000	<2.5	B-99.99	co.050
Pvrene	9,200 - 15,000	<2.5	>-99.98	<0.050
Total PAHs²	110,000 - 170,000	<28	---	co.47
B(a)P Potency Estimate³	600 - 1,500	<3.0	---	<0.056
Pentachlorophenol	920 - 3,000	<12.5	B-99.58	co.020
Metals				
Arsenic	1.1 - 2.9	0.4 - 0.8	-64 to -72	co.01 - 0.12
Chromium	1.5 - 2.7	1.1 - 8.2	-27 to +2.0	co.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 Cost²	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]

Material	PAH Concentration, ppb		
	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. PCB 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]

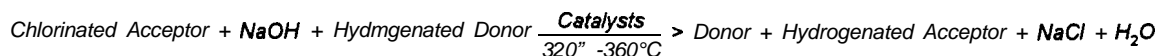
Parameter	Concentration ¹		Percent Change ²
	Before Treatment	After Treatment	
PAHs, ppb			
Acenaphthene	150,000 to 250,000	<1,000 to 1,750	>-98 to --100
Chrysene	75,000 to 120,000	<4,000 to 4,000	-95 to >-96
Fluorene	50,000 to 130,000	<1,000 to 900	-98 to -99
Pentachlorophenol, ppb	33,000 to 330,000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

ene 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]:



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].

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 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 polyethyl-

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 179891: 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)	(0 %)	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	(0 %)	ND (0.543)	ND (0.787)	ND (0.163)	ND (0.825)	ND (1.02)	a-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	(1 %)	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)	B-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)	(0 %)	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 **reinjecte**d 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 **bioavail**-ability. 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 **bioremed**-iation. 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 volatilization 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 20,000yd³ (22,000 tons, based on measured soil density of 1.1 tons/yd³) 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 Costs¹			
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	3,013,692	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	1,369,816	1,518,018	1,666,216
Contingency on Capital Costs	3,425,405	3,794,519	4,165,239
Total Capital Costs¹	24,521,000	27,172,000	29,825,000
<u>Annual Operating Costs</u>			
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	881,783	881,783	881,783
Total Operating Costs for Duration of Treatment, Present Value²	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 yd³, 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 \$1570,000 to treat 45,000 yd³ of soil. The unit treatment cost is therefore approximately \$35 per yd³, or approximately \$27 per ton of contaminated soil.

4.7.6 Case Study - Southeastern Wood Preserving

Background/Site Description: The Southeastern Wood Preserving Super-fund 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 yd³ (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'	Concentration (mg/kg)	Percent Change'	Concentration (mg/kg)	Percent Change'
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	40.12	-63	33.0	-66	41.0	-62
PCP	132.1	10.1	-92	20.7	-64	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'	Concentration (mg/kg)	Percent Change'
Naphthalene	1.1 ² 1	.0 ²	-9.1	2.0	+a2
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	-66

- 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 **waste-water 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 **acenap-**

there. 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 **yd³** (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)anthracene¹	280,000	12,000	-96
Benzofluoranthene ¹	321,000	209,000	-35
Benzo(ghi)perylene	92,000	18,000	-80
Benzo(a)pyrene¹	130,000	79,000	-39
Chrysene¹	296,000	36,000	-88
Dibenz(a,h)anthracene¹	92,000	9,000	-90
Fluoranthene	1,708,000	32,000	-98
Fluorene	630,000	14,000	-98
Indeno(1,2,3-cd)pyrene¹	94,000	31,000	-33
2-Methylnaphthalene	NR	NR	NR
Naphthalene	93,000	ND	NC
Phenanthrene	1,031,000	34,000	-97
Pvrene	1,148,000	33,000	-97
Total PAHs²	8,867,000	649,000	-93
B(a)P Potency Estimate³	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 benzo(a)fluoranthene 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 m²/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., $\geq 1,000$ 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 require-

ments. 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, 1991 c].

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-I). 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]

Parameter	Influent Results	Effluent Results			
	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-TEFs189 [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 (O₃), hydrogen peroxide (H₂O₂), or titanium dioxide (TiO₂) 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/H₂O₂ 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

Treatability Vendor	Recommended Treatment System	Cost		
		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 inter-technology 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 H₂O₂. This treatment used H₂O₂, 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/ ,000 gal.	\$13.28⁴	\$5.64⁵	\$5.14⁶

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 H₂O₂ 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 H₂O₂ was added. When H₂O₂ 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 H₂O₂; 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 Conc.	Effluent Results					
		Condition 1 ^a		Condition 2 ^b		Condition 3 ^c	
		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	13J	-32	<55	NC
Benzo(a)pyrene ¹	58 J	28	-52	34 J	-41	25 J	-57
Chrysene'	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	16J	-20	11 J	-45
2-Methylnaphthalene	130	40	-69	690	+430	490	+280
Naphthalene	17J	<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	140J	-99	1,200	-89
Phenol	36 J	38	+6	29 J	-19	19 J	-47
TCDD-TEQ. ppq ³	2.2 x 10 ⁴	N R	NC	4.8x10 ⁴	+118	2.8 x 10 ⁴	+27

^a Condition 1:
H₂O₂ = 0 ppm
UV lamp = 1.2 kW
Flow rate = 1 gpm
Treatment time = 10 min.

^b Condition 2:
H₂O₂ = 80 ppm
UV lamp = 10 kW
Flow rate = 1 gpm
Treatment time = 8 min.

^c Condition 3:
H₂O₂ = 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 580 and 577 percent.

J = Estimated Value

NC = Not calculated

NR = Not reported

Table 5-5. Estimated Treatment Costs for Cavitation/W 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 ₂ O ₂ dose = 300 mg/L Catalyst ² 270-kW system	0.74	7.53 ³	8.27
	b) UV type SX H ₂ O 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 420480,000 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-pureTM 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-pureTM 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. H₂O₂ 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-pureTM system treated maximum influent PCP concentrations of 15 mg/L to an average effluent concentration of 0.1 mg/L. The perox-pureTM system also reduced iron concentrations in the groundwater to acceptable levels.

Cost: The O&M costs for continuous operation of the perox-pureTM system installed at the Washington site were reported for a flow rate of 70 gpm. Included in the O&M costs were electricity, chemicals (H₂O₂ 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 H₂O₂ (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 and 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	
	\$/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)'	14.66	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-foot-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 reac-

tors for the open troughs, thus reducing the opportunities for inadvertent spills and leaks. As the result of an **RIFS**, 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 g-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: 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]

Parameter	Influent Results Conc.	Effluent Results					
		Biological		Fenton's Reagent		Fenton's Reagent + Ferric Iron	
		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 PAHs²	726,000	27,000	-96	130,000	-82	54,000	-93
B(a)P Potency Estimate²	10,600	560	95	<4,300	>-	<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	B-77	<3,200	NC	<330	>-77
TCDD-TEQ, ppq³	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)anthracene¹	292	9	-97
Benzo(b)fluoranthene¹	448	8	-98
Benzo(k)fluoranthene¹	178	7	-96
Benzo(ghi)perylene	315	4	-99
Benzo(a)pyrene¹	211	5	-98
Chrysene ¹	171	8	-95
Dibenz(a,h)anthracene¹	296	33	-89
Fluoranthene	466	153	-67
Fluorene	545	ND	~ -100 ⁴
Indeno(1,2,3-cd)pyrene¹	203	ND	~ -100 ⁴
2-Methylnaphthalene	NR	NR	NC
Naphthalene	1,932	81	-96
Phenanthrene	264	38	-86
Pyrene	232	15	-94
Total PAHs²	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	<i>in Situ</i> Biodegradation	EPA/540/5-94/502, April 1994
	Slurry Biodegradation	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 Tie	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's Office** 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	Tie	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-92/071 a, 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: 9200.5162. 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 of CERCLA Soils and Sludges. EPA/540/2-881004. 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	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - Modem access: (301) 589-8366 - Internet access: http://www.clu-in.com - Voice assistance: (301) 589-8368
Hazardous Waste Super-fund Collection Data Base (HWSFD)	Contains bibliographic references and abstracts for documents in the Hazardous Waste Superfund Collection at EPA Headquarters Library	<ul style="list-style-type: none"> - Voice assistance: (800) 334-2405
National Technical Information Service (NTIS) Bibliographic Data Base	The largest single source for public access to Federally-produced information	<ul style="list-style-type: none"> - 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) 8486533
Records of Decision System (RODS)	Contains the full text of the Superfund RODs for NPL sites nationwide	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - Modem access: (513) 569-7610 - Voice assistance: (513) 569-7272
Super-fund Treatability Database, Version 5.0	Contains data from numerous treatability studies conducted under CERCLA	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - 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	<ul style="list-style-type: none"> - Download from VISITT home page: http://www.prcemi.com/VISITT - VISITT hotline, (800) 245-4505

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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.	Haleville	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)
Duranost	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@ 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	V I	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)
Weyerhaeuser 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	California	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)
Dantzer Lumber & Export, Co., Inc.	Jacksonville	Florida	IV	W	Yes	RCRA
Dantzer 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 Corn.	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.	Clarksville	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	I 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)
Joslvn 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	Louisiana	VI	C,P	No	NPL
Arnold Forest Products Corp.	Shreveport	Louisiana	VI	W	Yes	RCRA
Bayou Bonfouca	Slide11	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	unlalown	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.	Federalburg	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)
Hatbeway & 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)
Weyerhaeuser 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 Crossstie 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) I
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	Palmer's 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 Hampshire	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-Bowlbv 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)