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Contaminants and Remedial Options at Wood Preserving Sites

CONTAMINANTS AND REMEDIAL OPTIONS
AT WOOD PRESERVING SITES

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. 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 resources to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, and Superfund-related activities. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

This document will provide information specific to wood preserving sites to assist federal and state remedial project managers, potentially responsible parties (PRPs), and remedial contractors in identifying remedial options, planning, treatment systems, and implementing remedies at sites contaminated by wood preserving operations. It is intended to facilitate remedy selection and so accelerate cleanup at these sites.

E. Timothy Oppelt, Director
Risk Reduction Engineering Laboratory

ABSTRACT

This document provides information that facilitates characterization of the site and selection of treatment technologies at wood preserving sites, to meet the regulations' acceptable cleanup levels. It does not provide risk-assessment information or policy guidance related to determination of cleanup levels. This document will assist federal, state, or private site removal and remedial managers operating under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Resource Conservation and Recovery Act (RCRA), or state regulations.

The wood preserving industry treats wood in pressurized cylinders, with one of the following types of preservatives:

- Pentachlorophenol in petroleum or other solvents
- Creosote
- Water or ammonia solutions of copper, chromium, arsenic, and zinc
- Fire retardants

Older wood preserver sites contain widespread soil, sediment, and sludge contamination generated by processes, practices, equipment leaks, storage, and waste treatment. Often, these primary sources lead to secondary contamination of underlying soil, which leads to groundwater pollution. Groundwater contamination is particularly difficult to remediate because wood preservative components form nonaqueous phase liquids (NAPLs), some of which are lighter than water and float on the groundwater surface; others are denser and settle.

The remedial manager faces the challenge of selecting remedial options that meet established cleanup levels. Two general options exist: destruction or immobilization. Separation/concentration technologies prepare wood preserving matrices for either destruction or immobilization. No single technology can remediate an entire wood preserving site. The remedial manager must combine pretreatment and posttreatment components to achieve the best performance by the principal technology.

This document is designed for use with other remedial guidance documents issued for RCRA, CERCLA, and/or state mandated cleanups to accelerate the remediation of wood preserving sites. The contaminant characterization section will assist the remedial manager to identify the areas of a site most likely to be heavily contaminated with toxic and mobile compounds. The section on remedial options stresses the arrangement of treatment trains to achieve performance levels. It also introduces the concept of high-energy destruction techniques to reach stringent contaminant residual levels versus lower energy techniques for less rigorous performance requirements. The technology performance data provided can then assist the remedial manager to narrow options to those most likely to succeed in achieving site-specific cleanup goals. The descriptions of remedial options cover innovative and emerging technologies, as well as proven treatments. However, the section on water-treatment options provides only an overview on these techniques because they have already been thoroughly examined in other documents.

Finally, this remedial aid provides a comprehensive bibliography, organized by the relevance to each section, to complement the information offered in these pages.

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ABBREVIATIONS

Al	aluminum
As	arsenic
BaP	benzo(a)pyrene
Ca	calcium
CCA	chromated copper arsenate
Cd	cadmium
CO_2	carbon dioxide
Cr	chromium
Cu	copper
FCAP	fluor chrome arsenate phenol
Fe	iron
gm	gram
GAC	granular activated carbon
H_2	hydrogen
H_2O_2	hydrogen peroxide
Kg	kilogram
L	liter
mg	milligram
ml	millliter
Mn	manganese
mm	millimeter
Na	sodium
NO_x	nitrogen oxides
Pb	lead
PCB	polychlorinated biphenyl
PCP	pentachlorophenol
psi	pounds per square inch
pH	a measure of acidity or alkalinity of a solution
ppb	parts per billion
ppm	parts per million
SO_x	sulfur oxides
TCDD	dioxin (tetrachlorodibenzo-p-dioxin)
UV	ultraviolet
yd^3	cubic yard
Zn	zinc

ACRONYMS

APC	air pollution control
APEG	alkali polyethylene glycol
ATTIC	Alternative Treatment Technology Information Center
BDAT	best demonstrated available technology
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFB	circulating fluidized bed
COE	U.S. Army Corps of Engineers
CPAH	carcinogenic PAH
DNAPL	dense non-aqueous phase liquid
DOE	Department of Energy
DOI	Department of Interior
ERT	Emergency Response Team
EPA	United States Environmental Protection Agency
FS	feasibility study
FR	Federal Register
FWEI	Foster Wheeler Enviresponse, Inc.
HSCD	Hazardous Sites Control Division
ISV	in situ vitrification
LNAPL	light non-aqueous phase liquid
NAPL	nonaqueous phase liquid
NPL	National Priority List
OERR	Office of Emergency and Remedial Response
ORD	Office of Research and Development
OTI	Office of Technology Innovation
PAH	polycyclic aromatic hydrocarbon
PNA	polynuclear aromatic hydrocarbon (see PAH)
RCRA	Resource Conservation and Recovery Act
RI	remedial investigation
ROD	record of decision
RO	reverse osmosis
RREL	Risk Reduction Engineering Laboratory
SITE	Superfund Innovative Technology Evaluation
S/S	stabilization/solidification
SVE	soil vapor extraction
TCLP	Toxicity Characteristic Leaching Procedure
TEO	total extractable organics
TPAH	total polycyclic aromatic hydrocarbons
USDA	U.S. Department of Agriculture
USEPA	United States Environmental Protection Agency
VOC	volatile organic compound

ACKNOWLEDGMENTS

SECTION 1

INTRODUCTION

PURPOSE

This reference document assists site removal and remedial managers in selecting treatment technologies at wood preserving sites. This information should prove useful to all remedial managers whether their efforts fall under federal, state, or private authority, and whether they are applying standards from RCRA, CERCLA, and/or state programs.

A recent listing of the wood treating industry indicated that nearly 1,400 wood preserving sites exist in the United States, of which more than 700 are inactive [1]. Fifty-six wood preserving sites appear on the National Priorities List; hundreds more may also have been abandoned. Table 1-1 lists the contaminants commonly found at these sites. It cross-references the Resource, Conservation, and Recovery Act (RCRA) best demonstrated available technology (BDAT) contaminant designations (e.g., W02, W03, etc.) with the RCRA classifications (e.g., halogenated phenols, creosols, ethers, and thiols), as well as terms commonly used in EPA Engineering Bulletins and other technical sources (e.g., halogenated semivolatiles).

The text emphasizes the identification of sources, both primary, such as a surface spill, and secondary, such as a subsurface migration from the primary source. "Source" in this sense can mean the following:

- Process or equipment generating the contamination,
- Contaminated soil, sludge, or sediment that could migrate, or
- Migrated surface/subsurface/groundwater contamination.

This approach allows the remedial manager to target remediation in terms of contaminated zones. For example, the remedial manager may consider the relative practicality of remediating a highly-contaminated surface zone versus a deeper, less contaminated zone. The manager may achieve a significant contaminant reduction at a lower cost by first remediating a more accessible zone versus another. This strategy should first mitigate the most toxic/mobile materials, and later deal with the less toxic/mobile ones.

ORGANIZATION

This reference document identifies the sources and types of contaminants at wood preserving sites, characterizes them, and evaluates the impact of media characteristics on technology selection and cost (Section 2).

TABLE 1-1. CROSS-REFERENCE OF CONTAMINANT DESIGNATIONS

BDAT class	Class description	Alternate description	Specific contaminants found at wood preserving sites
W02[1]	Dioxins/furans/PCBs and their precursors		Dioxin Dibenzofuran Furan
W03	Halogenated phenols, creosols, ethers and thiols	Halogenated semivolatiles	Pentachlorophenol Tetrachlorophenol
W07	Heterocyclics and simple non-halogenated aromatics	Non-halogenated volatiles	Benzene Toluene Ethylbenzene Xylene
W08	Polynuclear aromatics	Non-halogenated semivolatiles (PAHs)	2-Methylnaphthalene Chrysene Acenaphthene Fluoranthene Acenaphthylene Fluorene Anthracene Indeno(1,2,3-cd)pyrene Benzo(a)anthracene Naphthalene Benzo(a)pyrene Phenanthrene Benzo(b)fluoranthene Pyrene Benzo(k)fluoranthene
W09	Other polar organic compounds	Non-halogenated semivolatiles	2,4-Dimethylphenol 2-Methylphenol 4-Methylphenol Benzoic acid Di-n-octyl phthalate N-nitrosodiphenylamine
W10	Nonvolatile metals		(compounds of) Chromium Copper
W11	Volatile metals		(compounds of) Arsenic Cadmium Lead Zinc

[1] "W" codes obtained from *Summary of Treatment Technology Effectiveness for Contaminated Soil*, EPA/540/2-89/053 [2].

Remedial Options

Section 3 divides treatment into four principal groups:

- **Immobilization Technologies** contain contaminants either through construction of physical barriers to minimize migration, through occurrence of chemical reaction, or by physical/chemical means.

- **Destruction Technologies** employ thermal, chemical, or biological mechanisms to alter toxicity.

- **Separation/Concentration Technologies** use physical or chemical processes to separate contaminants from the associated media without altering the contaminant's toxicity.

- **Water Treatment Technologies** treat process residuals from the technology groups, surface water, and groundwater.

Treatment Trains

Generally no single technology can remediate an entire wood preserving site. Remediation of these sites often requires a combination of control and treatment options to achieve sufficient toxicity reduction and contaminant immobilization. This treatment train concept combines incremental or sequential control technologies to achieve site-specific objectives and acceptable residual contaminant levels.

The technical data and technology-specific considerations addressed in Sections 2 and 3 will aid decision-makers in selecting alternatives that will maximize the benefits of the treatment train approach at a particular site.

Performance Levels

The remedial options addressed in Section 3 focus on those technologies that are applicable to contaminants at wood preserving sites. Typical performance levels are given for these technologies. The performance levels can be used to match the technologies to the required site cleanup levels. Many factors can influence the cleanup level for a specific site: the toxicity of contaminants, future use of the site, location, and hydrogeology. Several criteria, such as feasibility, ease of implementation, and cost also influence the remedial choice.

Stages of Technology Development

The treatment options covered in this reference represent different stages of technological development: proven, innovative, and emerging. Some, such as incineration and biological treatment, have proven successful at the commercial scale and may not require treatability tests. Others, such as thermal desorption, require site-specific treatability tests to ensure they can meet established cleanup levels. The descriptions provided in Section 3 (Remedial Options) will familiarize the manager with newer technologies. Section 3 also offers performance data and treatability study results for contaminants found at wood preserving sites or for analogous compounds (where available).

Complementary Bibliography

To aid the remedial manager who wishes to delve more deeply into specific topics, the comprehensive bibliography at the end of this document has been organized to correspond with specific categories in Sections 2 and 3.

ESSENTIAL REFERENCES

This document assumes that the remedial manager is familiar with appropriate policy issues (RCRA, CERCLA, and state), risk assessment, and the determination of cleanup levels. Familiarity is assumed, as appropriate, with the references listed below.

Policy

Corrective Action for Solid Waste Management Units at Hazardous Waste Management Facilities; Proposed Rule. 55 FR 145, July 27, 1990 [3].

This is the proposed Subpart S rule which defines requirements for conducting remedial Investigations and selecting and implementing remedies at RCRA facilities.

New Rule for Wood Preserving Wastes [4]

Fact Sheet

Wood Preserving: Identification and Listing of Hazardous Wastes; Final Rule. 55 FR 50450, December 6, 1990 [5]

This rule finalizes portions of a proposed regulation published by EPA on December 30, 1988 (53 FR 53282). The finalized listings include wastewaters, process drippage, and spent preservatives from wood preserving processes at facilities that have used chlorophenolic formulations, and inorganic preservatives containing arsenic or chromium.

Technical

Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA [6]

This document provides the user with an overall understanding of the remedial Investigation/ feasibility study (RI/FS) process.

Guidance for Conducting Treatability Studies Under CERCLA [7]

This booklet (currently being revised) describes the necessary steps in conducting treatability studies that determine a technology's effectiveness in remediating a CERCLA site.

USEPA Guide for Conducting Treatability Studies Under CERCLA: Aerobic Biodegradation Remedy Screening Guide (EPA/540/2-91/13a) [8]

This document describes the necessary steps In conducting treatability studies specifically for aerobic biodegradation remedy screening.

Handbook on In Situ Treatment of Hazardous Waste Contaminated Soils [9]

This handbook provides state-of-the-art information on in situ technologies for use on contaminated soils.

Summary of Treatment Technology Effectiveness for Contaminated Soil [2]

This report presents information on a number of treatment options that apply to excavated soils, and explains the BDAT contaminant classifications.

Technology Screening Guide for Treatment of CERCLA Soils and Sludges [10]

This guide contains information on technologies which may be suitable for the management of soil and sludge containing CERCLA waste.

RCRA Facility Investigations (RFI) Guidance, Volumes 1-4 [11]

These documents recommend procedures for conducting an investigation, and for gathering and interpreting the data from the investigation.

In addition, EPA has also published engineering bulletins on topics that discuss single technologies, including the following:

Chemical Dehalogenation Treatment: APEG Treatment
Chemical Oxidation Treatment
Granular Activated Carbon Treatment
In Situ Soil Vapor Extraction Treatment
In Situ Steam Extraction Treatment
Mobile/Transportable Incineration Treatment
Soil Washing Treatment
Solvent Extraction Treatment
Slurry Biodegradation
Thermal Desorption Treatment

Much information is being collected on data bases for quick retrieval. Many of these can be found in the following documents:

The Federal Data Base Finder [12]

A comprehensive listing of federal data bases and data files.

Technical Support Services for Superfund Site Remediation [13]

Technical support services available to field staff.

Bibliography of Federal Reports and Publications Describing Alternative and Treatment Technologies for Corrective Action and Site Remediation [14]

References for documents and reports from USEPA, U.S. Army COE, U.S. Navy, U.S. Air Force, DOE, and DOI.

Bibliography of Articles from On-Line Databases Describing Alternative and Innovative Technologies for Corrective Action and Site Remediation [15]

Information for EPA remedial managers and contractors who are evaluating cleanup remedies.

Alternative Treatment Technology Information Center (ATTIC) [16]

A compendium of information from many available data bases. Data relevant to the use of treatment technologies in Superfund actions are collected and stored in ATTIC.

REFERENCES

1.   AEG Information Services. *Guide to the Wood Treating Industry.* AEG Company, Murrysville, PA. March 1990.

2.   USEPA. *Summary of Treatment Technology Effectiveness for Contaminated Soil.* EPA/540/2-89/053. 1989.

3.   Corrective Action for Solid Waste Management Units at Hazardous Waste Management Facilities; Proposed Rule. 55 FR 30798. July 27, 1990.

4. *New Rule for Wood Preserving Wastes* (Fact Sheet). EPA/530-SW-91-012. December 1990.

5. Wood Preserving; Identification and Listing of Hazardous Wastes; Final Rule. 55 FR 50450. December 6, 1990.

6. USEPA. *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA.* EPA/540/2-89/004. 1989.

7. USEPA. *Guidance for Conducting Treatability Studies Under CERCLA - Interim Final.* EPA/540/2-89/058. 1989.

8. USEPA. *Guide for Conducting Treatability Studies Under CERCLA: Aerobic Biodegradation Remedy Screening Guide.* EPA/540/2-91/13a. 1991.

9. *Handbook on In Situ Treatment of Hazardous Waste Contaminated Soils.*

10. USEPA. *Technology Screening Guide for Treatment of CERCLA Soils and Sludges.* EPA/540/2-88/004. 1988.

11. *RCRA Facility Investigation (RFI) Guidance (Volumes 1-4).* EPA 530/SW-89-031. May 1989.

12. *Information USA, The Federal Data base Finder - A Directory of Free and Fee-Based Data Bases and Files Available from the Federal Government, 3rd edition.* Kensington, MD. 1990.

13. USEPA. *Technical Support Services for Superfund Site Remediation.* Second Edition. EPA/540/8-90/011. Office of Solid Waste and Emergency Response, Washington, DC. 1990.

14. USEPA. *Bibliography of Federal Reports and Publications Describing Alternative and Innovative Treatment Technologies for Corrective Action and Site Remediation.* EPA/540/8-91/007. Center for Environmental Research Information, Cincinnati, OH. 1991.

15. USEPA. *Bibliography of Articles from Commercial Online Databases Describing Alternative and Innovative Technologies for Correction Action and Site Remediation.* Information Management Services Division, Washington, DC. 1991.

16. ATTIC Online System - Alternative Treatment Technology Information Center, computerized data base and electronic bulletin board on treatment of contaminated materials. Information: J. Perdek, EPA, (908) 321-4380; Modem Access: (301) 670-3808.

SECTION 2

CONTAMINANTS AT WOOD PRESERVING SITES

HISTORICAL USES OF WOOD PRESERVATIVES

Wood preserving in the United States is over a 100-year-old industry. The industry usually treats wood in cylinders, under pressure, with one of the following types of preservatives:

- Pentachlorophenol (penta, PCP) in petroleum or other solvents
- Creosote
- Water solutions of copper, chromium, arsenic and zinc
- Copper and zinc aqueous solutions in ammonia
- Fire retardants (combinations of phosphates, borates, boric acid, and/or zinc compounds)

Older processes used oil-based preservatives. However, the wood treating industry has gradually turned to water-soluble preservatives. Facilities using water-soluble preservatives tend to be more modern and practice better process control. Water-soluble processes produce little or no wastewater, except for small amounts of metal-containing sludges. Oil-based processes produce sludge wastes and significant quantities of process wastewater. The waste sludge has generally been landfilled.

Table 2-1 shows the 1988 production of treated wood in the United States and the relative volume of each preservative type used.

WOOD PRESERVING CHEMICALS AND WASTES

Organic Wood Preservatives

The United States wood preserving industry uses two major organic preservatives: PCP and creosote.

Pentachlorophenol--
Technical grade PCP, used to treat wood, contains the following:

- PCP 85% to 90%
- 2,3,4,6-tetrachlorophenol (4% to 8%)
- higher chlorophenols (2% to 6%)
- dioxins and furans (0.1%)

TABLE 2-1. PRODUCTION OF TREATED WOOD IN THE UNITED STATES, 1988[a]

Products	Volume of wood treated (1,000 cu ft)			
	Creosote solutions[b]	Pentachloro-phenol	Waterborne preservatives[c]	Fire retardants
Crossties	56,990	780	—	—
Switch and bridge ties	6,315	—	—	—
Poles	14,675	41,778	14,738	—
Crossarms	122	1,229	122	—
Piling	3,734	108	5,859	—
Fence posts	1,242	1,356	9,805	—
Lumber	3,113	1,251	350,220	5,283
Timbers	2,850	1,283	40,884	—
Plywood	—	17	8,732	3,956
Other products	1,441	68	20,206	991
Total products 1988	90,482	47,870	450,566	10,230
Total products 1987[d]	97,822	48,557	418,984	10,618

[a] Estimate based on reported production of 476 treating plants plus estimated production of 100 nonreporting plants. 1987 production data added for comparison.
[b] Creosote, creosote-coal tar, and creosote-petroleum.
[c] CCA, ASCA, ACC, and CZC.
[d] Wood Preservation Statistics, 1987.
Source: Proceedings of the American Wood Preservers Association, 1990 [1].

Additional contaminants form in technical-grade PCP during its manufacture. These side reactions add traces of trichlorophenol, chlorinated dibenzo-p-dioxins, chlorinated dibenzofurans, chlorophenoxy phenols, chlorodiphenyl ethers, and/or chlorohydroxydiphenyl ethers. Chlorodibenzodioxins and furans are the by-products of greatest concern. Analyses of PCP have revealed that the principal chlorodibenzodioxin and chlorodibenzofuran contaminants contain six to eight chlorines.

Analyses of PCP produced in the United States [2] have not found the highly toxic 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). Nevertheless, at high temperature PCP treatment of wood may produce traces of TCDD. This can affect cleanup decisions.

Table 2-2 shows the composition of a commercial PCP and a purified PCP. Table 2-3 is a representative distribution of dioxin isomers [3].

TABLE 2-2. COMPOSITION OF COMMERCIAL GRADE AND PURIFIED GRADE PENTACHLOROPHENOL[a]

Component	Analytical results	
	Commercial (Dowicide 7)	Purified (Dowicide EC-7)
Pentachlorophenol	88.4%	89.8%
Tetrachlorophenol	4.4%	10.1%
Trichlorophenol	0.1%	0.1%
Chlorinated phenoxyphenol	6.2%	---
Octachlorodioxin	2,500 ppm	15.0 ppm
Heptachlorodioxin	125 ppm	6.5 ppm
Hexachlorodioxin	4 ppm	1.0 ppm
Octachlorodibenzofuran	80 ppm	1.0 ppm
Heptachlorodibenzofuran	80 ppm	1.8 ppm
Hexachlorodibenzofuran	30 ppm	1.0 ppm

[a] USEPA, 1978 [3]

TABLE 2-3. CHLORODIOXIN ISOMER DISTRIBUTIONS IN COMMERCIAL GRADE PCP AND PCP-Na SAMPLES[a]

Chlorodioxin	PCP[b] (ppm)	PCP-Na[c] (ppm)
$1,2,3,6,7,9\text{-}Cl_6D$	1	0.5
$1,2,3,6,8,9\text{-}Cl_6D$	3	1.6
$1,2,3,6,7,8\text{-}Cl_6D$	5	1.2
$1,2,3,7,8,9\text{-}Cl_6D$	0	0.1
$1,2,3,4,6,7,9\text{-}Cl_7D$	63	16.0
$1,2,3,4,6,7,8\text{-}Cl_7D$	171	22.0
$1,2,3,4,6,7,8,9\text{-}Cl_8D$	250	110.0

[a] Buser, 1975, 1976, [5,6].
[b] Dowicide 7 (commercial PCP).
[c] Sodium salt of PCP.

2-3

Creosote--

Creosote is the other principal organic wood preservative used in the United States. It is an oily, translucent, brown to black liquid with a sharp smoky or tarry odor and a sharp, burning taste. It is applied either at full strength or diluted with petroleum oil or coal tar. Creosote, practically insoluble, is denser than water. This very complex mixture of organic compounds, produced from the high temperature carbonization of bituminous coal, contains approximately 85% polynuclear aromatic hydrocarbons (PAHs), 10% phenolic compounds, and 5% nitrogen-, sulfur- or oxygen-containing heterocycles [4]. Although the chemical composition of this material varies according to the production process, creosote can contain several thousand compounds, of which most are present in very small amounts. Table 2-4 lists the major components of creosote produced in the United States.

Inorganic Wood Preservatives

Metal Compounds--

Among inorganic arsenical wood preservatives, three are commonly used: chromated copper arsenate (CCA), ammoniacal copper arsenate (ACA), and ammoniacal copper-zinc-arsenate (ACZA). These mixtures derive, in part, from ammonium arsenic pentoxide, sodium arsenate, or sodium pyroarsenate.

Some physical properties of arsenic compounds are shown in Table 2-5.

Other Inorganic Preservatives--

Other inorganic or inorganic/organic formulations include Tanalith (a mixture of sodium fluoride, sodium dichromate, arsenate and dinitrophenol); FCAP (fluor chrome arsenate phenol); Minalith (a generic name for mixtures of diammonium phosphate, ammonium sulfate, sodium tetraborate, and boric acid); and Pyresote (a mixture of zinc chloride, sodium dichromate, ammonium sulfate, and boric acid). Minalith and Pyresote are fire retardants. Processes using these preservatives have not been widely used but contaminants from these processes may be found at some sites.

WOOD PRESERVING PROCESSES

Open-air drying is commonly used to prepare large stock such as cross ties and poles for treatment with organic preservatives, and to prepare any wood for treatment with inorganic preservatives. Kiln drying is used only for organic preservative treatments of lumber or large stock. Steam, combined with either an oil preservative or a hydrocarbon vapor, can season wood artificially in the cylinder. This method exposes the wood to live steam up to 245°F; a vacuum then removes water from the wood. Boulton drying, used for cross ties or western woods, employs preservative solution as a heat transfer medium, with temperatures up to 220°F and a vacuum of 14 to 24 inches of mercury, over a period of 20 to 60 hours to reduce wood moisture. The internal structure of trees from the western United States makes penetration of the preservative more difficult, requiring the different treatment procedure. Vapor drying, no longer used, exposed wood stock to hot vapors of organic solvents, such as xylene.

Pressure Treating Processes

Pressure treating processes (Figure 2-1) apply either air pressure or a vacuum to the wood before treating it with a preservative. Inorganic treatment processes use full-cell or modified full-cell processes. The modified full-cell process maintains pressure with added heat for an extended period after the initial pressure treatment. In the full-cell process, an initial vacuum removes air from the wood cells to permit maximum retention of the preservative. Empty cell processes maintain air at atmospheric pressure (Lowry Process) or at pressures of 15-75 psi (Rueping Process). This procedure allows air to remain in the wood

TABLE 2-4
MAJOR CHEMICAL COMPONENTS
OF
CREOSOTE PRODUCED IN THE UNITED STATES[a]

Compound or component	Percentage
Naphthalene	3.0
Methyl naphthalene	2.1
Diphenyl dimethylnaphthalene	---
Biphenyl	0.8
Acenaphthene	9.0
Dimethylnaphthalene	2.0
Diphenyloxide	---
Dibenzofuran	5.0
Fluorene-related compounds	10.0
Methyl fluorenes	3.0
Phenanthrene	21.0
Anthracene	2.0
Carbazole	2.0
Methylphenanthrene	3.0
Methyl anthracenes	4.0
Fluoranthene	10.0
Pyrene	8.5
Benzofluorene	2.0
Chrysene	3.0

[a] Lorenz and Gjovik, 1972 [7].

TABLE 2-5. ARSENIC COMPOUND PROPERTIES

Compound	Molecular wt.	Density	Comment
Ammonium arsenite	125	1.3	Colorless, hygroscopic rhombic prisms, very soluble in cold water, decompose in hot water.
Sodium arsenate	185.9	1.9	Grey-white powder, very soluble in water, slightly soluble in ethanol, effloresces in warm air.
Sodium pyroarsenate	353.8	2.2	White crystals, decompose at 1,000°C, very soluble in water.

cells, reducing preservative usage since the preservative will not fill a cell already filled with air. Organic treatments use empty cell processes, except for marine pilings which are first treated with inorganics, and then with creosote.

Oil-Based Treatments--

The oil-based wood-treating cycle begins with placement of either seasoned or green wood into a pressure cylinder. Most of the industry uses large cylinders (4 to 8 ft diameter, 40 to 150 ft long). Wood stock, loaded on special rail cars, moves into the treatment cylinder.

A pump feeds the oil-based preservative, heated to decrease its viscosity, into the cylinder until it covers the wood. The process applies hydrostatic or pneumatic pressures of 50 to 200 psi to the wood and preservative in the vessel and maintains them until the desired amount of preservative permeates the wood. When the vessel has slowly been returned to atmospheric pressure, a pump sends the excess preservative to a storage tank for reuse. A vacuum process, or steam and vacuum combined, can remove excess preservative from the surface layers of the wood. Some of the treating solution in the wood begins to flow out as the internal and external pressures equalize. The vessel captures some of this solution, but, in the past, treated wood often lay in an open area for several days, allowing preservative to drip. Current operations use lined and covered drip pads to collect the excess preservative.

Water-Based Treatments--

Air drying prepares wood for water-based treatments. Pressure treatment using water-based preservatives differs from oil-based processes: the preserving fluid is unheated and either empty-cell or modified empty-cell processes are used. The inorganic preservative solutions react with the wood to form a complex mixture of relatively insoluble precipitates. The water carrier evaporates after treatment, allowing the treated wood to be painted or stained.

Nonpressure Treating Processes

Nonpressure processes include thermal, diffusion, cold soak, vacuum, brush, dip, and spray methods.
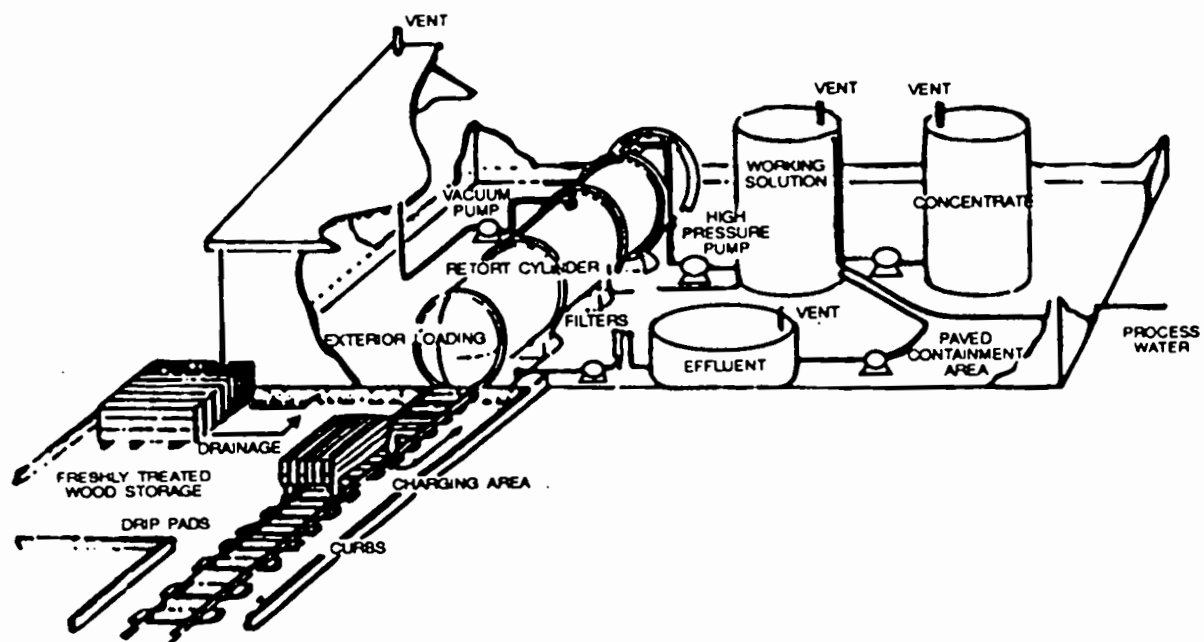
Figure 2-1. Wood preservative pressure-treating facility [8].

Thermal process	Wood is immersed in hot PCP or creosote preservative for several hours, followed by further soaking at ambient temperature.
Cold soaking	Wood is immersed in a PCP solution.
Diffusion	Waterborne salts, such as copper sulfate and zinc chloride, are applied to unseasoned wood.
Brush, dip and spray	Pentachlorophenol or copper naphthenate treatments are applied to wood surfaces.

SOURCES OF CONTAMINATION AT WOOD PRESERVING SITES

Wastewater

Wastewater from wood preserving facilities falls into two classes: process wastewater and surface runoff water.

Process wastewater includes wastewater from conditioning (retort condensate), kiln drying, treated wood washing, accumulations in doors or retort sumps, preservative formulation recovery, and rinsing of drums, storage tanks, and equipment.

Surface runoff water flows from process areas, drip pads, and treated wood storage areas.

Sludges and Residuals

Wastewater treatment processes, which generate sludges or residuals, include the following:

- Oil/water separation
- Filtration
- Biological treatment
- Spray irrigation

- Land spreading
- Thermal evaporation
- Wastewater injection into boilers
- Wastewater containment in tanks and impoundments

Oil/water separators recover reusable preservative and reduce the concentration of oil and grease in wastewater before further treatment or discharge. Pentachlorophenol treatment solutions rise to the top; creosote solutions sink. Sludges consisting of oil-water emulsions that do not separate polymerized oil, soil, and wood debris will accumulate at the bottom of the separator. Sometimes the addition of flocculants, dissolved air flotation, or filtration can remove the emulsified oils and particulates from wastewater.

Biological organisms can also treat wastewater. A mixture of biomass with some nonviable organisms as well as other solids from the biotreatment accumulate as a sludge, which must be removed. Biological treatment ponds and lagoons sometimes do not have wasting mechanisms to remove sludge; it simply accumulates at the bottom.

Wastewaters are sometimes sprayed on open fields, and sludge spread on land treatment areas. Spray irrigation fields and land treatment areas are sometimes combined as one unit.

Heating wastewater from wood preserving sites in pan evaporators, tanks, or ponds can evaporate the water, building up sludge residues in the bottom of the evaporation devices and must be removed

periodically. When wastewater is injected into industrial boilers, the resulting ash can contain elevated levels of wood preservative constituents.

Sludges containing sawdust, wood chips, sand, soil, stones, tar, and emulsified or polymerized oils accumulate in the bottom of wood treatment cylinders and tanks. Similar materials accumulate in holding, work, storage, or mixing tanks.

Drippage, spillage, accumulations of debris in sumps, and residues from treatment processes that employ filtration can generate solid wastes. Historically, these solid wastes were dumped in unlined, earthen pits. These pits have become major sources of groundwater contamination, since the wastes migrate through the soil into aquifers.

After wood is treated, some unabsorbed preservative adheres to the wood surface. Excess preservative from pressure-treated wood will exude slowly, dripping from the wood. Rain can carry off preservative from treated wood. Large volumes of soil in storage areas have been contaminated by drippage from treated wood.

Figure 2-2 shows common sources of PCP wood preserving contamination.

CONTAMINANT BEHAVIOR, FATE, AND TRANSPORT

Predicting Contaminant Behavior

Predicting contaminant fate requires the organization of complex site characterization data for each chemical of concern. This data will assist the remedial manager in determining where a specific waste compound is located, where it is going, how fast it is moving, and what types of transformation or degradation are occurring. It facilitates prioritizing remedial decisions by basing them on the contaminant's toxicity and rate of transport from a site, its persistence, and its migration pathways. The manager can then tailor the treatment evaluation and selection to the contaminant toxicity and mobility.

Figure 2-3 illustrates the behavior, fate, and transport mechanisms for contaminants at a specific site:

- Migration upward (volatilization);
- Migration downward (leaching);
- Migration laterally (aqueous plume and pure product);
- Degradation; and
- Residence on site as persistent chemicals.

Pentachlorophenol--
Pentachlorophenol does not decompose when heated to its boiling point for extended periods of time. Pure PCP is chemically rather inert [9]. The chlorinated ring structure tends to increase stability, but the polar hydroxyl group facilitates biological degradation [10]. Pentachlorophenol does not exhibit the easy oxidative coupling or electrophilic substitution common to most phenols. All monovalent alkali metal salts of PCP are very soluble in water. However, the protonated (phenolic) form is much less soluble (about 8 mg in 100 ml of water) -- a degree of solubility that is still environmentally important. Therefore, transport of PCP in water relates to the pH of the environment. PCP can also volatilize from soils [11]. It is denser than water, but the commonly used solution contains PCP and petroleum solvents in a mixture less dense than water. Therefore, technical grade PCP floats on top of groundwater as a light nonaqueous phase liquid (LNAPL).

PCP Solids
(Blocks or Bags)

Carrier Oil
(Bulk)

**POTENTIAL CHEMICAL
RELEASES**

Chemical Delivery

| (Pallets-Rail/Truck) | (Bulk tankers) |

• DRIPS, SPILLS.....to ground

oil spills, drips

Chemical Storage & Mixing
(Tankage/Oil)

• AEROSOLS, VAPORS.....to air
• SPILLS.....to ground

Recovered Oil Solution
(Tankage)

recovered oil

Solution Storage
(Tankage)

• AEROSOLS, VAPORS.....to air

oil

Filter
(If used)

Oil/water Separator

• SLUDGES.....to disposal

Pressure Treatment
(Retort Cylinder)

• AEROSOLS, VAPORS.....to air

water

Condenser

• CONDENSER COOLING WATER.....
to sewer

Wastewater treatment

• TREATED EFFLUENT.....to sewer
• SLUDGES
• SPENT CARBON.....to regeneration

Evaporation

• VAPORS.....to air
• CONCENTRATED LIQUID.....to reuse

oil drips

Sumps

• SLUDGES.....to disposal

**Freshly-treated
Wood Storage**

| Drip pads (If used) | Ground |

precipitation: oil spills, drips

• DRIPS.....to ground
• TRACKING.....to ground
• DUST.....to air

**Dry-treated
Wood Storage**
(Ground)

• DRIPS.....to ground
• DUST.....to air

Source: Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma

Figure 2-2.   Sources of wood preserving contamination.

Figure 2-3. Contaminant transport and fate mechanisms.
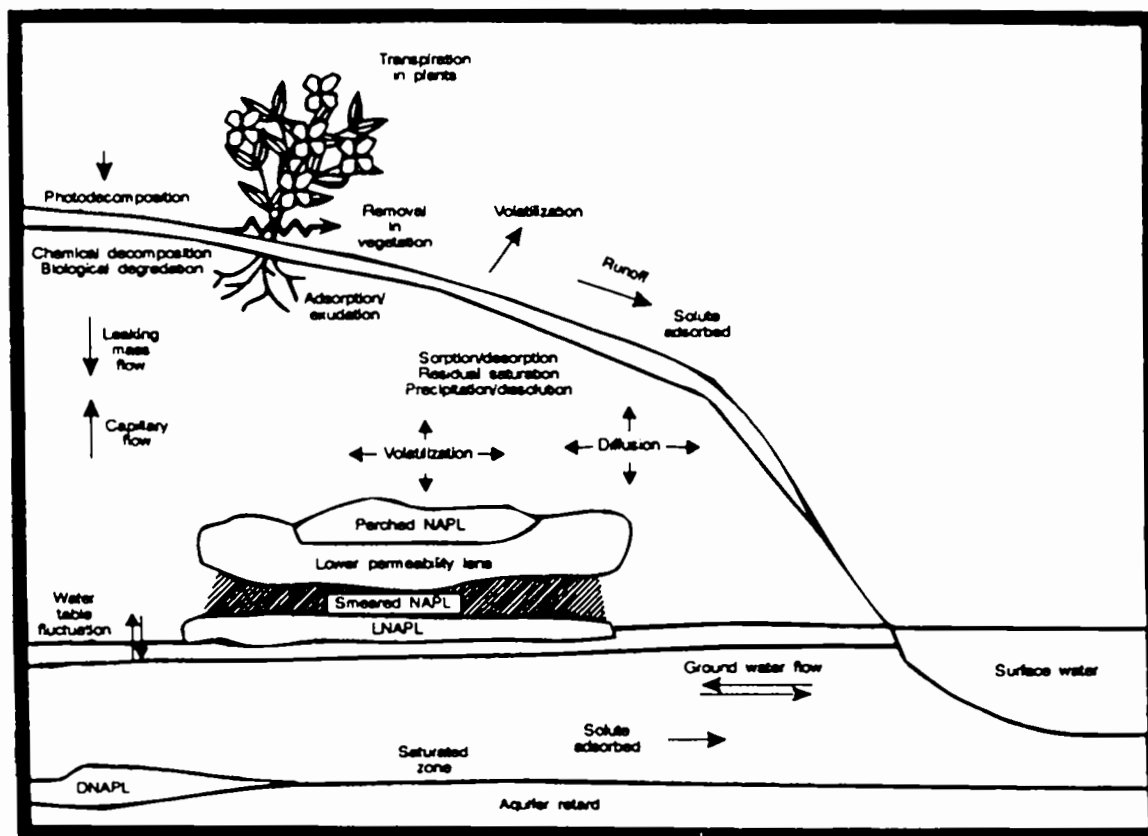
NAPL   = Non Aquaous Phase Liquid
LNAPL   = Light Non Aquaous Phase Liquid
DNAPL   = Dense Non Aquaous Phase Liquid

Source: Robert S Karr Environmental Research Laboratory
         Ada, Oklahoma

Biological effects--Biodegradation of PCP in soils has been the subject of extensive study. Kaufman [12] performed a thorough review of the parameters affecting PCP degradation in soil. Most data indicate that microbial activity plays an important part in its degradation. Biodegradation of PCP in soils has been documented under anaerobic as well as aerobic conditions.

Several types of bacteria and fungi can degrade PCP in pure and mixed cultures. These include strains of **Pseudomonas, Flavobacterium, Arthrobacter, Mycobacterium, Rhodococcus, Aspergillus, Trichoderma,** and **Phanerochaete.** Kirsch and Etzel [13] derived a microbial population capable of rapid PCP degradation from a soil sample obtained at a wood products factory. When fully acclimated, the organisms were used to degrade materials containing 100 mg/L of PCP. They degraded 68% of the PCP within 24 hours.

Aerobic decomposition of PCP occurs mainly through sequential dechlorination to a variety of partially dechlorinated products, such as 2,3,5,6-tetrachlorophenol [12, 14]. An oxidation step then forms substituted hydroquinones or catechols, such as 2,3,4,5-tetrachloro-catechol. These products undergo ring cleavage, ultimately forming carbon dioxide (CO_2) and inorganic chloride ions.

Degradation of PCP also occurs under anaerobic conditions. Reductive dechlorination forms (tetra-, tri-, and di-)chlorophenol intermediates [15,16] which may accumulate. However, complete anaerobic degradation of PCP to CH_4 has been reported [15]; and Bryant et al. [17] demonstrated complete anaerobic dechlorination of PCP to phenol.

Although biological transformations do not always reduce or eliminate toxicity, biological treatment has successfully reduced the toxicity of PCP in soils and leachates [18].

Factors affecting PCP degradation in soils--The presence of readily degradable carbon sources increases the rate of PCP degradation; the soil pH modifies the availability and toxicity of the PCP. However, PCP degradation may be inhibited when soils are also contaminated with creosote or CCA mixtures. The number of species and population levels of bacteria and fungi capable of degrading PCP may be limited. In most cases of rapid PCP degradation by microorganisms, the inoculum came from areas where PCP had been used for a long time.

Sometimes augmenting the existing population may enhance degradation. Edgehill and Finn [19] found that an **Arthrobacter sp.** added at the rate of a million cells per gram of soil (dry weight) greatly reduced the half-life of PCP in laboratory and field tests. Middledorp et al. [20] reported long term enhancement of PCP degradation in peat and sandy soils inoculated with **Rhodococcus chlorophenolicus** at 10^5 to 10^6 cells/gm of soil. However, the use of microbial inocula should be approached with caution.

Introduced organisms may fail to survive due to a variety of reasons, including predation [21,22,23] inhibition by other soil microbes [24,25], or starvation due to competition for essential nutrients by indigenous soil microbes. Few unequivocal, well-documented reports support the benefits of using such inocula. Full-scale bioaugmentation has not yet been successfully demonstrated.

Sorption/immobilization--Soil adsorption plays an active role in the transport of PCP. PCP adheres strongly to soils; the extent of sorption depends on organic content, pH, and the type of soil involved. The adsorption of PCP is comparable to other strongly sorbing contaminants such as PCBs, pyrene, and chlordane.

Choi and Aomine [26,27,28] studied the interaction of PCP and soil in detail. Adsorption and/or precipitation of PCP occurred to some extent in all soils tested. Soils containing humic material adsorb more PCP than soils from which organic matter was removed with hydrogen peroxide [27]. Later

investigations indicated that low concentrations of PCP are mostly adsorbed by humus. At higher PCP concentrations, adsorption by nonhumus soil fractions increases [28]. Different adsorption mechanisms dominate at different pH values. For example, PCP is an acid, which forms a salt at a higher pH. In the salt form, PCP is more soluble in water but also more polar.

Organic content of soils affects adsorption of PCP at all pH values. Schellenberg et al. [29] reported increased sorption of chlorophenols with increasing organic carbon content. Bellin et al. [30] increased sorption of PCP by raising the organic carbon content of soil through the addition of sewage sludge. In contrast, PCP may migrate in soils when partitioned in oil phases [31]. Since technical grade PCP solutions for treating wood consist of PCP dissolved in hydrocarbon solvents, PCP contamination will usually be associated with oily phases. However, the partitioning between soil, aqueous, and oily phases is a complex process, and difficult to predict.

Persistence--The persistence of PCP in soil depends on a number of environmental factors. Young and Carroll [32] and Kuwatsuka and Igarashi [33] found higher PCP degradation rates under flooded conditions than under unsaturated conditions. PCP breaks down more slowly in heavy clay than in sandy or sandy clay soils [34]. Adsorption to clays may decrease availability of PCP for degradation, and slow diffusion in clays may decrease reaction rates. An extensive study of soil variables by Kuwatsuka and Igarashi [33] indicated that the PCP degradation rate correlated with the clay mineral composition, free iron content, phosphate adsorption coefficients and cation exchange capacity of the soil. The most significant effect correlated with organic matter.

Creosote--

Biological effects--PAHs represent major components of creosote, supplemented by trace amounts of phenols and azaarenes. Mueller et al. [4] estimated that PAHs comprise about 85% of the creosote components. A wide range of soil organisms, including bacteria, fungi, cyanobacteria (blue-green algae), and eukaryotic algae, have the enzymatic capacity to oxidize PAHs. Tausson [35] first demonstrated that several PAHs, including naphthalene, anthracene, and phenanthrene, can serve as substrates for soil organisms by which they are completely metabolized. Prokaryotic organisms, bacteria, and cyanobacteria use different biodegradation pathways than the eukaryotes, fungi, and algae, but all involve molecular oxygen. Biochemical pathways for the degradation of a number of PAHs by soil microorganisms have been proposed by Fernley and Evans [36], and Evans et al. [37]. Gibson and Subramanian [38] and Cerniglia and Heitkamp [39] present more recent reviews of the microbial metabolism of PAHs. PAHs with more than four rings do not provide a sole carbon source, but have been metabolized in combination with other organic compounds. This process employs the concurrent metabolism of two materials: a compound that a microorganism can only use as a supplementary source of energy and a carbon source capable of sustaining growth [4].

The phenols in creosote are generally more readily degraded than PAHs or PCP. The effect of phenols on soil microorganisms depends on the contaminant's concentration [40]. At low phenol concentrations (0.01 to 0.1 percent of soil weight), microbial numbers increase. Higher dose levels (additional 0.1 to 1.0 percent of soil weight) increasingly inhibit them. At these levels, a partial sterilization depresses microbial numbers, but does not destroy them. After a period of time, the microbes adapt (or phenol is lost through sorption or volatilization) and the population resurges.

Factors affecting degradation rates--Generally, degradation rates for PAH compounds decrease as the molecular weight increases. The process progresses faster in soil than water and, optimally, in an acclimated bacteria population [41]. This may reflect the higher microbial populations in soils rather than in water and increased metabolic activity towards specific contaminants within acclimated populations.

Readily mobilized compounds such as naphthalene, phenanthrene, and anthracene, are slightly water-soluble. Persistent PAH's, such as chrysene and benzo(a)pyrene, present even lower water solubilities. Pyrene and fluoranthene are exceptions because these compounds are more soluble than anthracene but are not appreciably metabolized by soil microorganisms [42]. Other factors affect PAH persistence: insufficient bacterial membrane permeability, lack of enzyme specificity, and insufficient aerobic conditions [40].

Biodegradation in soil--Sims and Overcash [43], Edwards [44], and Cerniglia [45] have studied the fate of PAH compounds in terrestrial systems, including degradation.

Bulman et al. [46] performed two sets of studies to assess PAH decline in soil. The first set found, during an initial period of 200 days or less, that naphthalene, phenanthrene, anthracene, pyrene, and fluoranthene disappeared rapidly from soil, with a loss of 94% to 98%. Within the initial 200 days, the remaining PAH (2% to 6%) declined at a much reduced rate. The second study indicated that some of the anthracene was mineralized, based on radio-labeled experiments. However, binding to soil solids and volatilization were the principal attenuation mechanisms. Adsorption to solids was sufficiently tight to prevent extraction with normal analytical procedures, and presumably to render the anthracene unavailable to microbial populations.

Sims et al. [47] further evaluated the degradation of PAHs in soils. Sims measured volatilization from soils and corrected degradation rates for volatilization. He measured significant volatilization for naphthalene and 1-methyl naphthalene, and observed extensive and rapid biodegradation for 2-ring and 3-ring PAHs. PAHs with 4, 5, and 6 rings were somewhat recalcitrant. The persistence of a PAH compound increased as molecular weight and ring number increased. In soil, the higher molecular weight compounds exhibited more resistance to biodegradation as pure compounds than when combined in complex wastes. This may be due to cometabolic processes, where other components of the waste mixture act either as inducers of necessary enzyme systems or as primary carbon substrates.

McGinnis et al. recently completed laboratory and field studies on the degradation of wood preserving wastes at several sites. They concluded that PAHs from creosote are readily degradable in soil systems and that lower molecular weight PAHs are transformed much more quickly than higher molecular weight PAHs, findings consistent with the bulk of the literature [48]. The less degradable, higher molecular weight compounds have been classified as carcinogenic PAHs (CPAHs). Therefore, the least degradable fraction of PAH contaminants in soils is generally subject to the lowest cleanup standards. This presents some difficulty in achieving cleanup goals with bioremediation systems.

Sorption/immobilization--Solubility and sorption to soil affect the mobility of creosote components. Phenols and lower molecular weight PAH components are more water soluble than higher molecular weight PAHs. Recent studies indicate that PAHs may undergo significant interactions with soil organic matter [49].

Toxicity reduction--Intermediate PAH degradation products (metabolites) in soil treatment systems may also display toxicity. Complete mineralization of PAHs is slow; intermediates may remain for substantial periods of time. For example, Mueller et al. [50,51,52] reported only slight decreases in toxicity and teratogenicity of groundwater that was contaminated with creosote and pentachlorophenol after it had received 14 days of biological treatment. PCP and high molecular weight PAHs were still present in the treated groundwater. The degradation kinetics of PCP and PAHs, may explain these findings.

Cerniglia and Gibson [53] reported that the metabolites formed during the degradation of BaP by a fungus were very similar to those formed during BaP metabolism in mammals. Such metabolites are probably responsible for the carcinogenicity of BaP. However, Shabad et al. [54] reported that extracts of a medium containing BaP were less carcinogenic to mice (Mus spp.) after microbial degradation than before

degradation. Aprill et al. [55] found no Ames test mutagenicity in soil that incorporated wood treating wastes after 1 year of treatment, but some Microtox toxicity was found in water soluble fractions and leachate samples. These reports indicate that toxicity reduction should be monitored during remediation.

Metals--

Water-soluble inorganic wood preservatives contain either chromated copper arsenate (CCA), fluor-chrome-arsenate phenol (FCAP), chromated zinc chloride, acid copper chromate, ammoniacal copper arsenate (ACA), or ammoniacal copper-zinc-arsenate (ACZA). CCA -- made from the oxides of chromium, copper, and arsenic -- is the most widely used inorganic wood preservative. Coal, the raw material for the manufacture of creosote, contains trace levels of various toxic metals including chromium, copper, lead, and zinc. Depending on its source, the petroleum used as a carrier for PCP can display a significant concentration of toxic metals. Uncontrolled waste sites may contain a combination of all wood preservative types.

Metals, unlike the hazardous organic constituents of wood preserving waste, cannot be degraded or readily detoxified. The presence of metals among wood preserving wastes can pose a long-term environmental hazard. Immobilization of metals by adsorption and precipitation can impede their migration to groundwater. The fate of the metal depends on its physical and chemical properties, the associated waste matrix, and the soil. Significant downward transportation of metals from the soil surface occurs only when the metal retention capacity of the soil is overloaded. As the concentration of metals exceeds the ability of the soil to retain them, the metals will travel downward with the leaching waters. The extent of vertical contamination intimately relates to the soil solution and surface chemistry. Unfortunately, little information is available on the specific interactions between metals, the matrix of wood preserving wastes, and soil.

Copper--Soil retains copper (Cu) through exchange and specific adsorption. Cu adsorbs to most soil constituents more strongly than any other toxic metal, except lead (Pb). Cu, however, has a high affinity for soluble organic ligands; the formation of these complexes may greatly increase its mobility in soil.

Zinc--Clay carbonates, or hydrous oxides readily adsorb zinc (Zn). Hickey and Kittrick [56], Kuo et al. [57], and Tessier et al. [58] found that the greatest percent of total Zn in polluted soil and sediment was associated with iron (Fe) and manganese (Mn) oxides. Precipitation removes Zn from soil because the Zn compounds are highly soluble. As with all cationic metals, Zn adsorption increases with pH. Zn hydrolyzes at a pH >7.7. These hydrolyzed species strongly adsorb to soil surfaces. Zn forms complexes with inorganic and organic ligands which will affect its adsorption reactions with the soil surface.

Arsenic--Arsenic (As) exists in the soil environment as arsenate, As(V), or as arsenite, As(III). Both are toxic. However, arsenite is the more toxic form; arsenate is the most common form. Arsenical wood preservatives use arsenate oxide, As(V).

The behavior of arsenate in soil seems analogous to that of phosphate, because of their chemical similarity. Like phosphate, arsenate is fixed to soil and thus is relatively immobile. Iron (Fe), aluminum (Al), and calcium (Ca) influence this fixation by forming insoluble precipitates with arsenate. Woolson et al. [59] stated that arsenate may be leached from soil if the levels of reactive Fe, Al, and Ca in soil are low. The presence of Fe in soil is most effective in controlling arsenate's mobility. Arsenite compounds are 4 to 10 times more soluble than arsenate compounds.

The adsorption of arsenite is also strongly pH dependent. Griffin and Shimp [60] found increased adsorption of As(III) by two clays over the pH range of 3 to 9. Pierce and Moore [61] found the maximum

adsorption of As(III) by iron oxide occurred at pH 7. Elkhatib et al. (1984b) found adsorption of As(III) to be rapid and irreversible on ten soils. They determined, in this study and another [63], that Fe oxide, redox, and pH were the most important properties in controlling arsenite adsorption by these soils.

Under anaerobic conditions, arsenate may be reduced to arsenite. Arsenite is more subject to leaching because of its higher solubility.

Chromium--Chromium (Cr) can exist in soil in three forms: two trivalent forms, the Cr^{+3} cation and the CrO^- anion, and the hexavalent forms, $(Cr_2O_7)^{-2}$ and $(CrO_4)^{-2}$. Hexavalent chromium is the major chromium species used in industry; wood preservatives commonly contain chromic acid, a Cr(VI) oxide. The two forms of hexavalent chromium are pH dependent; hexavalent chromium as a chromate ion (CrO_4^{-2}) predominates between pH 6 and higher; dichromate ions $(Cr_2O_7^{-2})$ predominate between pH 2 to 6. The dichromate ions present a greater health hazard than chromate ions, and both Cr(VI) ions are more toxic than Cr(III) ions.

Because of its anionic nature, Cr(VI) associates only with soil surfaces at positively charged exchange sites, the number of which decrease with increasing soil pH. Iron and aluminum oxide surfaces adsorb the chromate ion at an acidic or neutral pH [64,65,66]. Stollenwerk and Grove [67] concluded that groundwater alluvium adsorbed Cr(VI) due to the iron oxides and hydroxides that coat the alluvial particles. The adsorbed Cr(VI) was, however, easily desorbed with the input of uncontaminated groundwater, indicating nonspecific adsorption of Cr(VI). No precipitates of any hexavalent compounds of chromium were observed in a pH range of 1 to 9 [60]. Thus Cr(VI) is highly mobile in soils.

In a study of the relative mobilities of 11 different trace metals for a wide range of soils, Korte et al. [68] found that clay soil containing free iron and manganese oxides significantly retarded Cr(VI) migration. Hexavalent chromium was the only highly mobile metal in alkaline soils. The parameters that correlated with Cr(VI) immobilization in the soils were free iron oxides, total manganese, and soil pH. Neither soil properties, cation exchange capacity, surface area, nor percent clay influence Cr(VI) mobility.

Chromium (III) is the stable form of chromium in soil. Rai et al. [69] reported that Cr(III) is readily adsorbed by soil. In a study of the relative mobility of metals in soil at pH 5, Cr(III) was the least mobile [60]. Cr(III) hydroxy compounds precipitate at pH 4.5. and complete precipitation of the hydroxy species occurs at pH 5.5. In contrast to Cr(VI), Cr(III) is relatively immobile in soil. Chromium (III) does, however, form complexes with soluble organic ligands which may increase its mobility [70].

Regardless of pH and redox potential, most Cr(VI) in soil is reduced to Cr(III). Soil organic matter and Fe(II) minerals donate the electrons in this reaction [71,72]. The reduction reaction in the presence of organic matter proceeds at a slow rate under environmental pH and temperatures [71,73,74], but the rate of reaction increases with decreasing soil pH [72,75]. Bartlett and James [76], however, demonstrated that Cr(III) can be oxidized to Cr(VI) under conditions prevalent in many soils. The presence of oxidized Mn, which serves as an electron acceptor, is an important factor in this reaction.

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SECTION 3

REMEDIAL OPTIONS

CLEANUP GOALS AND SELECTION OF OPTIONS

Table 3-1 relates residential and commercial/industrial exposures to carcinogenic PAH (CPAH) action levels at several wood preserving sites. In such cases, the remedial manager must select remedial options that will meet the established cleanup levels. Only two general options exist: destruction or immobilization. Separation/concentration technologies prepare wood preserving matrices for either destruction or immobilization.

If the cleanup goals are based on CPAHs and residential exposures, the selected option, such as incineration or pyrolysis, will probably require high energy input. If less stringent CPAH levels are acceptable, a low energy technology such as in situ biodegradation may be more appropriate. Figure 3-1 shows the inverse relationship between action levels and energy use -- as well as the positioning of options. These qualitative relationships refer to PAH contamination. Figure 3-1 shows acceptable cleanup levels based on CPAHs but also can be used for cleanup levels of other contaminants. If dioxins are present, only thermal or dechlorination techniques are capable of remediation. CCA contamination requires stabilization/ solidification (S/S) treatment for metals, in addition to any treatment selected for organics. The various contaminant forms may mandate combinations of technologies.

The appendix tables align CERCLA wood preserving sites with their established ROD cleanup levels and the treatment combinations selected. Note that a technology chosen as the principal component of a treatment train in one case, (e.g., incineration followed by S/S), might act as a secondary component (posttreatment) in a different treatment train (such as solvent extraction followed by incineration). The remedial manager must consider each element of the system, from excavation to treatment of residual streams.

Each option description that follows will present a schematic diagram for an overall treatment process, from excavation to posttreatment. When evaluating total treatment costs, the remedial manager must compare all elements of each train, not just the principal components. The treatment costs for well-developed and field-tested components (such as incineration and bioremediation) can be quite reliable, but estimates for innovative and emerging components become increasingly less reliable.

The technology descriptions below deal primarily with soil treatment. The remedial manager can also expect to find sediment and sludge on site. Natural water bodies such as ponds and streams can become contaminated first (directly) as holding ponds/lagoons, or secondarily, by migration of wood preserving compounds. Sludge from lagoon bottoms and processing equipment will require treatment. Sediment contains a smaller particle size distribution and higher moisture content than soil. Usually, pretreatment dewatering will render sediment capable of processing as a wet soil. Sludge, in comparison to sediment, contains highly concentrated contaminants in a rheological matrix. The options for treating sludge are limited.
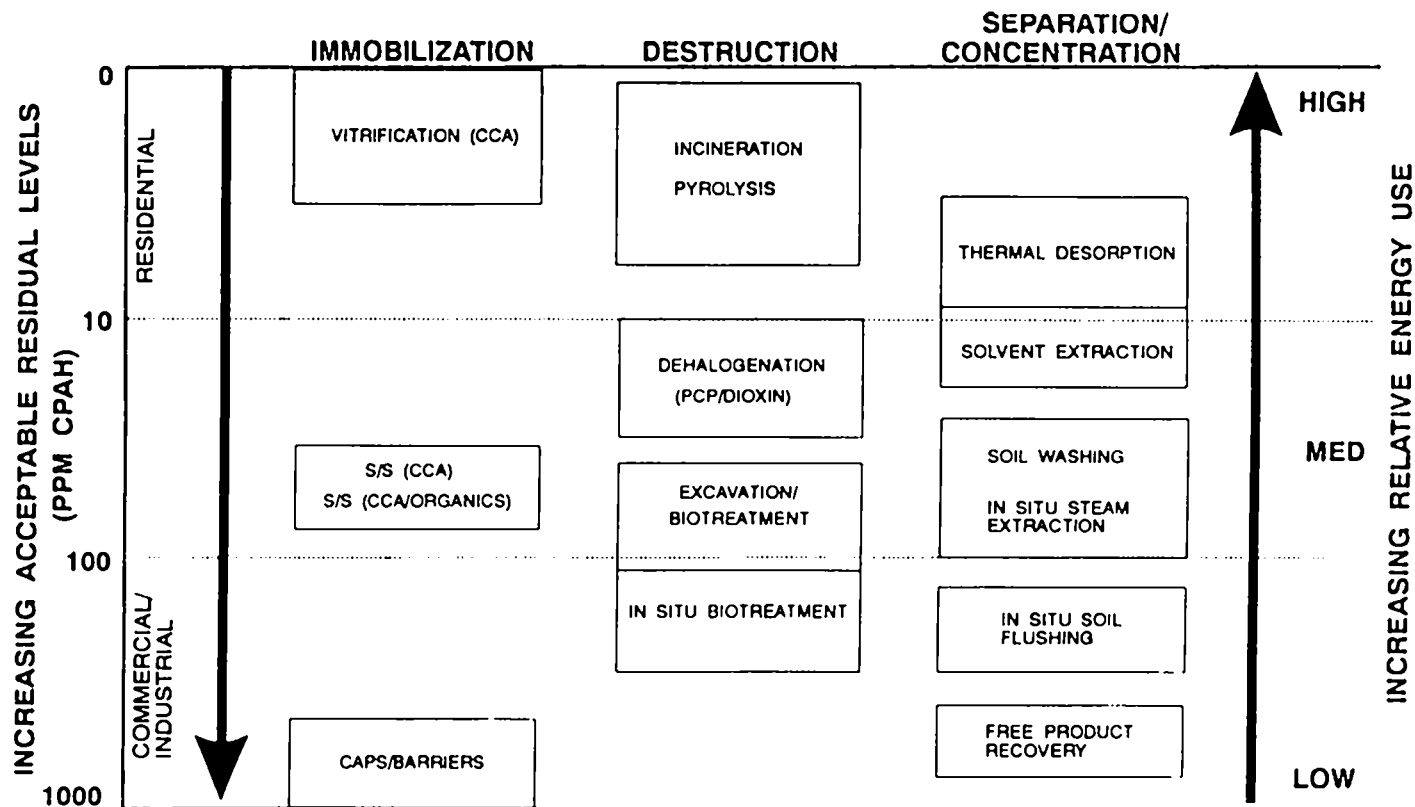
Figure 3-1. Conceptual presentation of remedial options for soil and sediment at wood preserving sites.

TABLE 3-1. SOIL ACTION LEVELS VERSUS RISK (CARCINOGENIC PAHs) AT SUPERFUND WOOD TREATING SITES

| Site | Residential exposures | | |
	Action level (ppm)	Risk	Notes
United Creosoting, Conroe, TX (9/89)	0.3	1×10^{-6}	A
Mid South Wood Prod., Mena, AR (11/86)	3.0	1×10^{-5}	
N. Cavalcade, Houston, TX (6/88)	1.0	1×10^{-5}	
Bayou Bonfouca, Slidell, LA (3/87)	2.0	3×10^{-5}	B
Midland Products, Ola, AR (3/88)	<0.2	$< 10^{-7}$	C
Koppers, Orville, CA (12/89)	0.19	1×10^{-6}	
Cape Fear Wood, NC (6/89)	2.5	1×10^{-5}	
Southern Maryland Wood, MD (6/88)	2.2	1×10^{-6}	
	Commercial/Industrial exposures		
United Creosoting, Conroe, TX (9/89)	40.0	3×10^{-5}	A
S. Cavalcade, Houston, TX (9/88)	<700	$< 1 \times 10^{-4}$	D
Koppers, Texarkana, TX (9/88)	100	1×10^{-5}	
Libby Groundwater, MT (12/88)	88	1×10^{-5}	

A. PAHs expressed as BaP equivalents.
B. Carcinogenic PAHs represent 2% of total PAHs. ROD action level is 100 ppm for total PAHs.
C. Action level driven by ARAR (not health risk) is 1.0 ppm PCP. Inputed PAH level is far below detection limits; health risk is far less than 10^{-6}.
D. Action level is 700 ppm plus no leachate from soils. (Risk and action levels will be less than stated.)

IMMOBILIZATION TECHNOLOGIES

Containment Technology

Containment of groundwater plumes is a common component in the overall remediation of a wood preserving site. One of the first on-site actions establishes containment provisions to accomplish the following:

- Minimize migration of contaminated groundwater from the site,
- Prevent the increase of groundwater contamination due to water run-on and precipitation,
- Control population exposure to contaminants,
- Contain contaminants while remediation proceeds, and
- Reduce air emissions.

Thus, containment control ranges from a surface cap that limit's infiltration of uncontaminated surface water to subsurface vertical or horizontal barriers that restrict lateral or vertical migration of contaminated groundwater.

Capping Systems--
Capping systems reduce surface-water infiltration; control gas and odor emissions; improve aesthetics; and provide a stable surface over the waste. Caps can range from a simple native soil cover to a full RCRA Subtitle C, composite cover.

Vertical Barriers--
Vertical barriers minimize the movement of contaminated groundwater off site or limit the flow of uncontaminated groundwater on site. Common vertical barriers include slurry walls in excavated trenches; grout curtains formed by injecting grout into soil borings; vertically-injected, cement-bentonite grout-filled borings or holes formed by withdrawing beams driven into the ground; and sheet-pile walls formed of driven steel.

Wood preserving compounds can affect caps and cement-bentonite barriers. The impermeability of bentonite may significantly decrease when it is exposed to high concentrations of creosote, water-soluble salts (copper, chromium, arsenic), or fire retardant salts (borates, phosphates, and ammonia). Specific gravity of salt solutions must be greater than 1.2 to impact bentonite [10,11]. In general, soil bentonite blends resist chemical attack best if they contain only 1% bentonite and 30 to 40% natural soil fines. Treatability tests should evaluate the chemical stability of the barrier if these conditions are suspected.

Carbon steel used in pile walls quickly corrodes in dilute acids, slowly corrodes in brines or salt water, and remains mostly unaffected by organic chemicals or water. The salts associated with wood preservatives and fire retardants will reduce the service life of a steel sheet pile; corrosion-resistant coatings can extend their anticipated life. Major steel suppliers will provide site-specific recommendations for cathodic protection of piling.

Horizontal Barriers--
Horizontal barriers can underlie a sector of contaminated materials on-site without removing the hazardous waste or soil. Established technologies use grouting techniques to reduce the permeability of underlying soil layers. Studies performed by the U.S. Army Corp of Engineers [1] indicate that conventional grout technology cannot produce an impermeable horizontal barrier because it cannot ensure uniform lateral growth of the grout. These same studies found greater success with jet grouting techniques in soils that contain fines sufficient to prevent collapse of the wash hole and that present no large stones or boulders that could deflect the cutting jet.

Implementation Costs--
Capping--Cap construction costs depend on the number of components in the final cap system, i.e., costs increase with the addition of barrier and drainage components. Additionally, cost escalates as a function of topographic relief. Side slopes steeper than 3 horizontal to 1 vertical can cause stability and equipment problems that dramatically increase the unit costs shown in Table 3-2.

Vertical barriers--Construction costs for vertical barriers are influenced by the soil profile of the barrier material used and by the method of placing it. The most economical shallow vertical barriers are soil-bentonite trenches (Table 3-3) excavated with conventional backhoes; the most economical deep vertical barriers consist of a cement-bentonite wall placed by a vibrating beam.

3-4

TABLE 3-2. CAPPING COSTS

Component	Installation	Cost ($)
Bedding layer	On-site excavation, hauling, spreading, compaction	1.00 to 2.50/yd³
Gas collecting layer	Off-site excavation, hauling, spreading, and collector pipes Geonet alternative	12.00 to 18.00/yd² 0.40/ft²
Composite barrier: clay	On-site excavation, hauling, spreading, compaction Bentonite board alternative Add for off-site clay (< 20 mile haul)	2.40 to 6.00/yd³ 0.85/ft² 8.00 to 14.00/yd³
Composite barrier: geomembrane	Installed HDPE - 60 mil PVC - 40 mil	 0.50/ft² 0.35/ft²
Drainage layer	Off-site excavation, hauling, spreading, and collector pipes Geonet alternative	12.00 to 18.00/yd² 0.40/ft²
Protective layer	On-site excavation, hauling, spreading, compaction	1.00 to 2.50/yd³
Vegetative layer	Topsoil hauling, spreading, and grading	10.00 to 16.00/yd³
Asphalt hardened cap option (4 to 6 in)	Delete protective and vegetative layers, hauling, spreading, rolling	4.00 to 6.00/yd²
Concrete hardened cap option (4 to 6 in)	Delete protective and vegetative layers, on-site mixing, hauling, spreading, finishing	6.00 to 11.00/yd²

TABLE 3-3. VERTICAL BARRIER COSTS

Component	Depth (ft)	Cost ($/ft²)
Soil-bentonite slurry wall	30 30-50 50-125	3 to 7 6 to 11 9 to 15

Cement-bentonite slurry wall
   Vibrating beam
 	
   Injection grout
		Comparable to above
		
		3 to 5 times above

Steel sheet pile wall		16 to 28

<u>Horizontal barriers</u>–Since few horizontal barriers have been constructed, accurate costs have not been established. Work performed by COE for USEPA has shown that it is very difficult to form effective horizontal barriers. The most efficient barrier installation used a jet wash to create a cavity in sandy soils into which cement-bentonite grouting was injected. The costs relate to the number of borings required. Each boring takes at least one day to drill.

Typical equipment costs range from $1,200 to $3,000 per day. The spacing of boreholes is a function of grout penetration; it is site-specific. Typical boring spaces range from 6 to 10 ft centers. Horizontal barrier costs for boring and injection alone may exceed $80.00/ft². The cost of the grout is relatively minor.

Stabilization/Solidification Technologies

Stabilization and solidification (S/S) processes reduce the mobility of a contaminant, either by physically restricting its contact with a mobile phase (solidification) or by chemically altering/binding the contaminant to reduce its mobility (stabilization). Solidification also refers to the use of binders for waste bulking to facilitate the handling of liquid wastes. While stabilization can be achieved without solidification, solidification is usually accompanied by some stabilization.

Binding agents for stabilization fall into several classes. The most common binders are cementitious materials, including Portland cement, fly ash/lime, fly ash/kiln dust. These agents form a solid, resistant, aluminosilicate matrix that can occlude waste particles, bind various contaminants, and reduce permeability of the waste/binder mass. Proprietary agents added to the binder may improve specific properties of S/S treatment, such as strength, curing rate, contaminant binding, pore size, or waste dispersion.

Treatment Combinations--
Immobilization treatment does not usually apply to sites contaminated by both organic and inorganic wood preservatives. S/S technology is not effective on sites contaminated with organic wood preservatives although new developments are making it increasingly more effective. However, S/S technology can be combined with other remediation processes in successful treatment trains (Table 3-4).

TABLE 3-4. S/S TREATMENT TRAINS FOR WOOD PRESERVING SITES[a]

Contaminants	Treatment operations	
Metals	Soil washing ------------------------------>	S/S
Metals and PCP or creosote	Incineration ------------------------------>	S/S
	Soil washing ----> biotreatment ---->	S/S
	Land biotreatment --------------------->	S/S

[a] U.S. EPA, 1990, Report no. EPA/625/7-90/011 [3]

Technology Applicability--

<u>Organic compounds</u>–There are two considerations in S/S treatment of organic compounds: the immobilization of the organic contaminant, and the potential effects of organic compounds on matrix solidification or on immobilization of other contaminants.

Organic compounds can retard or prevent setting of typical S/S matrices. *Connor [2] found that many* types of organics have adverse effects on set/cure times, cement hydration, and product properties (e.g., unconfined compressive strength). To date, no threshold concentrations have been established for organic interference with conventional binder systems.

Organic compounds, although present below cleanup action levels, may interact with a binder or inorganic contaminants. They can exert a negative influence on S/S treatment of metals by forming complexes that hinder those reactions that immobilize metals. Organic compounds that form anions at the particular pH level of the waste, such as alcohols and carboxylic acids, are most likely to bind with cationic metals. In addition, the organic compounds may be hydrophobic; thus, they can hinder the waste-binder contact necessary for immobilization of metals.

Organics may volatilize during the period between mixing and curing of waste in the S/S process. Even organics with low vapor pressures can disperse significant concentrations of organic compounds into the air. This effect is enhanced when the treatment involves heat, as with some cementitious binders. Volatilization must be addressed at sites containing benzene (a constituent of creosote) and low molecular-weight solvents, since they exert appreciable vapor pressures at 20°C.

S/S is not a conventional remedy for organic contaminants. Consequently, little data are available for guidance in designing S/S treatments for organic wood preservatives. Of 15 records of decision (RODs) on wood preserving sites stored in the Alternative Treatment Technology Information Center (ATTIC) data base prior to September 1991, only one included S/S of soil contaminated by both organic and inorganic chemicals. More common treatments included soil washing, soil flushing, biological treatment, and incineration. These techniques either destroy the organic compounds or remove them from the soil matrix for off-site disposal/destruction.

Several experimental technologies may be useful for S/S of organic wood preservers. Organophilic clays (e.g., modified smectite) and activated carbon treat organic contaminants, with or without other cementitious binders. Laboratory tests have demonstrated the sorption of PCPs [4]. Organic polymers and asphalts can also interact with organic waste constituents. At the least, they can form a matrix with an affinity for organic compounds and with internal spaces large enough to accommodate these molecules. Only additional experience can provide sufficient evidence to make these binders acceptable for immobilization. Treatability tests for binders must determine the fate of organic contaminants.

Solidification, or waste bulking, sometimes facilitates the handling of organic-dominated wastes in preparation for off-site disposal/treatment or for interim management prior to on-site remediation. Two entries in the ATTIC database describe using solidification followed by RCRA capping. This process usually produces containment of nonaqueous phase liquids, such as oil-based wood preservatives. The treatment agent is often a lime-containing waste, such as baghouse dust from limestone calcination or cement production (sometimes called kiln dust or fly ash), and fly ash from coal-fired power plants. As with S/S treatment, the possibility of organic volatilization must be considered in waste bulking processes. There is no clear evidence that organics will volatilize in bulking wood preserver wastes, but prudence suggests testing for volatilization until sufficient scientific data can be gathered to prove the practice safe.

Metals--S/S has often been applied to wastes and soils containing metals. Unlike organic compounds that can be destroyed, metals can only be changed in oxidation state, chemical species, and physical form. The goal of S/S is to convert the metal to a less mobile form and to physically restrict its contact with water and air. Cementitious materials are the most common binders. In addition to solidification, calcium hydroxide in these binders can cause precipitation of many metals as sparingly-soluble oxyhydroxides. Metals can also adsorb to the aluminosilicate matrix or replace cations normally present in the crystalline structures of cement.

The high alkalinity that favors precipitation of many metals can hinder immobilization if the metals form soluble anionic hydroxides at a high pH. Cadmium, for example, can precipitate at a moderately alkaline pH as $Cd(OH)_2$ but becomes increasingly soluble at a higher pH, owing to the formation of an anionic cadmium hydroxide. Because the pH for minimum solubility differs for each metal, one set of conditions may not cover all metal-insoluble hydroxides.

Sulfide agents can produce highly insoluble metal compounds with cationic metal species such as copper. However, the solubility depends on the permanent exclusion of oxygen and other oxidizers from contact with the metal sulfide.

Another complication in S/S treatment is the speciation of metals in the raw waste. Chromium, arsenic, selenium, and some other metals form both soluble cationic species and soluble oxide anions (e.g., chromate and arsenite). The latter form will not precipitate as hydroxides; their sorption differs from that of cationic species in a cement matrix. Although rarely performed, analyses of raw wastes and their leachates for metal oxidation state and chemical species are important in designing the most effective immobilization treatment. For some metals, the oxidation state also affects toxicity (e.g., trivalent vs. hexavalent chromium).

Technology Status/Performance--

Treatability test data compiled from numerous sources indicate that the metals in wood preservatives are amenable to solidification/stabilization. The particular S/S system that will perform well on a given contaminated material must be determined by site-specific screening and treatability tests. Some results are shown in Table 3-5. The chromium-containing wastes illustrate the importance of the contaminant oxidation state in stabilization. Ideally, the waste is tested for contaminant speciation so that prior experience with the same chemical form of contaminant can assist decision-makers in the selection of binders for treatability testing. Reduction of hexavalent chromium followed by precipitation as $Cr(OH)_3$ is a common water-treatment method that applies to S/S technology, since the hydroxide is compatible with cement matrices and any solubilized metal would exist in the less toxic form.

TABLE 3-5. S/S METAL TREATABILITY TEST RESULTS

Contaminant	Initial concentration	Reduction (%)	Binders
Arsenic	420 mg/L	22 to 91	Cement kiln dust; slag/lime/fly ash/ silica; sulfide/silicate
Chromium (III)	33 to 3,960 mg/L	34 to 99 76 to 88	Cement kiln dust; slag/lime/fly ash/ silica Sulfide silicate Sulfide silicate
Chromium (VI)		97 to 99	Sulfide silicate
Copper		51 to 99	Unspecified

Source: USEPA RREL, Cincinnati, OH.

The effect of binders on wastes containing only CCA metals is not completely clear. *Table 3-6 shows* treatability data for a CCA waste. The degree of stabilization is not constant for one metal across the S/S formulations, or for one formulation across the metals. Connor [2] reported results on another CCA wood preserving waste with EP Toxicity leachate levels of 1.8 mg/L of As, 90 mg/L of Cr, and 13 mg/L of Cu before treatment. After treatment with several S/S agents, leachable metals ranged from <0.01 to 3 mg/L of As, 0.5 to 150 mg/L of Cr, and <0.05 to 9.9 mg/L of Cu. In this case, the greatest reduction in leachability for all three metals was observed with a potassium silicate formulation.

TABLE 3-6. EP TOXICITY TEST RESULTS FOR RAW AND TREATED CCA WASTE LEACHATE[a]

Element	Raw (mg/L)	Treated waste (mg/L)		
As	1.8	2.3	1.4	2.5
Cr	98.4	116.0	12.4	106.0
Cu	13.6	0.2	4.7	0.1

[a] Data from Weston, 1988, Palmetto Woods Treatability Study, EPA Contract No. 68-03-3482 [3].

A single binder process does not usually produce optimal immobilization for multiple metals. All three metals may not need to be remediated at all sites; sometimes only one or two metals need to be remediated. However, a system can generally be developed to meet cleanup criteria for multiple metals. The appearance of increased leachable metals in residuals following treatability tests is not unusual; it can result from contaminant destabilization (soluble complex formation with treatment agents), sample heterogeneity, or analytical error. Representative sampling, sample homogenization, multiple treatment, and analytical replication may be necessary to ensure useful results.

Other binder systems may well apply to CCA wood preservative contamination, but there is less documented experience with noncementitious agents. The following factors may make an alternative binder suitable for treatability tests:

- Tolerance of organic contaminants with respect to chemical and physical characteristics,
- Planned posttreatment use such as subpavement,
- Volume increase that affects off-site disposal costs, and
- Data supporting cost effectiveness.

A detailed description of how to evaluate S/S technology as a remedial method for a particular waste is given in *Stabilization/Solidification of CERCLA and RCRA Wastes: Physical Tests, Chemical Testing Procedures, Technology Screening and Field Activities* [5].

No extant theoretical or empirical method can predict the degree of immobilization attained by applying a particular S/S technology to a particular waste. Site-specific screening tests and treatability tests (Table 3-7) determine whether S/S is a suitable and cost-effective remediation method; they can also optimize the waste/binder/additive/water mix. In addition to ensuring compliance with contaminant- or site-

TABLE 3-7. WOOD TREATING SITE S/S TREATABILITY TEST RESULTS

Site	Equipment	Feed	Results
J.H. Baxter Site, Wood, CA	HAZCON, Inc. lab/bench scale	Soil: As, Cu, Zn, PCP, creosote	Marked reduction in metallic contaminants. No reduction in PCP levels.
Coleman Evans Wood Preserving Site, Whitehouse, FL	Lab/bench scale by three different vendors	PCP	TCLP PCP concentration met goals.
No site yet selected	Hayward Baker in situ S/S	Soils/sludges: PCB, PCP	Technique accepted into SITE Program.
Selma Pressure Treating, Selma, CA	Silicate Technology Corp. process	PCP, As, Cr, Cu	PCP leachate concentrations reduced up to 97%; As, Cr, and Cu distilled water TCLP leachate concentrations reduced to 98, 54, and 90%, respectively[a].
Site not identified	Waste Technologies Group, Inc. (WTG)	Soils: PAHs 42-205 ppm Phenol 77 ppm	<3.3 to 4.4 ppm <3.3 ppm

[a] (EPA/540/5-91/008).

specific leachability limits, these tests can identify the S/S mix that will balance cost and volume increase in achieving immobilization. The increase in volume upon S/S treatment can significantly impact on- or off-site, disposal space transportation, and landfill costs.

Implementation Costs--

The cost of treatability screening (initial S/S applicability) for a specific site can range from $10,000 to $20,000. Treatability costs at the remedy selection stage are higher and more variable, depending on the matrix of binder types, binder ratios, and water contents to be investigated. Associated analytical costs increase dramatically as the number of organic compounds being analyzed increases. Costs of $50,000 or more are not unusual.

Connor [2] estimated the cost of treatment, transportation, and landfill disposal for some common S/S systems: prices ranged from $74 to $397 per ton for landfilling on site and from $119 to $517 for landfilling 200 miles from the contaminated site. The cost was quite dependent on binder cost and on the solids content of the waste, since much more binder is required to solidify low-solids wastes. Locally available waste products (fly ash and kiln dust) can be inexpensive S/S agents, while manufactured treatment agents (organic polymers) can and be quite expensive.

Data Requirements--

Some of the factors affecting S/S are shown in Table 3-8. Collecting and evaluating physical and chemical data about these factors can help determine the applicability of S/S treatment to the contaminant and matrix.

TABLE 3-8. FACTORS AFFECTING STABILIZATION/SOLIDIFICATION TREATMENT

Factor	Possible effect
Coal or lignite content	Causes defects in product.
Cyanides content	Affects bonding (>3,000 ppm).
Halide content	Retards setting; leaches easily.
Inorganic salts content	Reduces product strength and affects curing rates (soluble salts of manganese, tin, zinc, copper, and lead).
Leachable metals content	Affects immobilization.
Oil and grease content	Affects bonding (>10%).
Organic content	Inhibits bonding (>20 to 45 wt%).
Particle size	Affects bonding (<200 mesh or >1/4" dia.)
Phenol concentration	Affects product strength (>5%).
Semivolatile organics	Inhibits bonding (>10,000 ppm).
Sodium arsenate, borate, phosphate, iodate, sulfide, sulfate, carbohydrate concentrations	Retards setting and affect product strength.
Solids content	Requires large amounts of reagents (<15%).
Volatile organic concentrations	Affects immobilization.

Source: USEPA, 1988 [8].

From a remediation viewpoint, the most important consideration in binder selection is the chemical composition of the material to be treated. Numerous samples from various locations on site should be analyzed for the active wood preserving ingredients, the carrier oil components, and other characteristically hazardous compounds. Test samples should include full extracts or digestates of the raw waste as well as on TCLP extracts and extracts from any other regulation-mandated test, to facilitate an estimate of the leachability of each constituent. Areas known by site characterization data to be sources of migrating contaminants should be the targets of more extensive sampling.

In addition to chemically characterizing the waste, these data will locate typical and worst case samples for treatability tests. In multi-contaminant wastes, there may be several worst cases: high metals, moderate organics; moderate metals, high organics; metals and organics in hydrophobic carrier solvents; etc.

The remedial manager should study the chemical characterization of the waste, researching the available literature and vendor treatability data to determine whether the waste is comparable to another material that has been successfully treated. With organic contaminants, only treatability data that clearly show no volatilization during treatment are relevant.

Vitrification Technologies

Vitrification converts waste into a high-strength glass or glass-like substance. It can treat excavated waste or soil in situ. In situ vitrification (ISV) presents two advantages: materials need not be excavated and they remain buried on site. Vitrified excavated materials provide improved process control and capture/ treatment of volatilized organics and metals.

Vitrification of Excavated Waste--

Current industrial-size systems use plasma arc, microwave heating, kiln, and other mixed thermal methods to accomplish vitrification. For wood preserving wastes, this technology should be considered innovative and promising.

In Situ Vitrification--

This S/S process converts contaminants into glass-like materials and chemically inert and stable gases by using large electrodes inserted into the soil [6]. These electrodes, containing significant levels of silicate material, generate heat (up to 3,600°C) by passing electric current through them. Because dry soils do not conduct electricity, a layer of flaked graphite and glass frit transfers electrical energy between the electrodes. This layer acts as a starter to increase the soil temperature. Soil or rock components melt, organic compounds pyrolyze in the glass matrix, and many metallic materials fuse or vaporize. The fused waste material then resides in a chemically inert and stable crystalline form that has low leachability rates and almost the same chemical stability as granite. A hood above the treating area draws off process gases and vapors for further treatment [7].

Technology Applicability--

Vitrification can treat organics and/or immobilize inorganics in contaminated soil and sludge.

Technology Status/Performance--

Vitrification technology has not yet been used to remediate a Superfund site. However, Geosafe Corporation has demonstrated ISV on radioactive wastes at the DOE's Hanford Nuclear Reservation. A large-scale remediation project using this process was temporarily suspended because a fire caused the loss of off-gas confinement and control during a large-scale test (Geosafe Corporation, 1991). Retention tests on excavated, vitrified, metal-containing waste showed efficiencies ranging from 67 to 99% for volatile metals such as As, Cd, and Pb, and 90 to 99.9% for nonvolatile metals such as Cu, Cr, and Zn. This suggests a need for significant metals posttreatment. Organics results showed destruction of dioxins, furans, PCBs, and PCP as shown in Table 3-9.

TABLE 3-9. VITRIFICATION RESULTS

Initial concentration (ppb)		Destruction (%)
Dioxin	>47,000	99.9 to 99.99
Furan	>9,400	99.9 to 99.99
PCB	19,400,000	99.9 to 99.99
PCP	>4,000,000	99.995

Implementation Costs--
Costs for in situ vitrification approach $350 to $400 per cubic yard [9].

DESTRUCTION TECHNOLOGIES

Destruction technologies for remediation of contaminated soil, sludge, and sediment at wood preserving sites can be divided into three categories:

- Thermal,
- Chemical, and
- Biological.

Table 3-10 lists the typical treatment combinations for destruction options. Waste preparation includes excavation and conveying the soil, dredging and/or dewatering sediment/sludge, screening to remove debris, and reducing particle size.

Table 3-11 provides the applicability of destruction options to contaminant groups found at wood preserving sites.

Thermal Destruction Technologies

Two thermal technologies destroy contaminants in soil, sludge, and sediment: incineration and pyrolysis.

Incineration--
Incineration treats organic contaminants in solids and liquids by subjecting them to temperatures typically greater than 1,000°F in the presence of oxygen. Volatilization and combustion of the organic contaminants occurs, converting them to carbon dioxide (CO_2), water (H_2O), hydrogen chloride (HCl), and sulfur oxides (SO_x). Three common types of incineration systems can treat contaminated solids: the rotary kiln, the infrared incinerator, and the circulating fluidized bed units. The rotary kiln and the infrared units contain a primary chamber that usually operates in the temperature range of 1,000°F to 1,800°F. The rotary kiln is a refractory-lined, slightly-inclined, rotating cylinder that serves as a combustion chamber. The infrared unit uses electrical resistance heating elements or indirect fired radiant U-tubes to heat material passing through the chamber on a conveyor belt. As material passes through the primary chamber, the unit evaporates moisture, volatilizes organic contaminants, and partially combusts the volatilized contaminants. Since conversion of the organic contaminants is inadequate in the primary chamber, the system sends the partially combusted gases to a secondary combustion chamber that usually operates between 1,600°F to 2,200°F. The gases are held at temperature for a residence time of 2 seconds to ensure adequate destruction of the contaminants. The circulating fluidized bed (CFB) unit uses high velocity air to circulate and suspend the waste particles in a combustion loop. The CFB operates in the temperature range of 1,500°F to 1,800°F and does not need a secondary combustion chamber to achieve adequate destruction of organic contaminants. The incinerator off-gas requires treatment by an air pollution control (APC) system to remove particulates and to neutralize and remove acid gases (HCl, NO_x, and SO_x). Baghouses, venturi scrubbers, and wet electrostatic precipitators remove particulates; packed bed scrubbers and spray driers remove acid gases. The CFB removes acid gases by adding limestone to the combustor loop. Figure 3-2 illustrates an incineration treatment train.

Process Residuals--This technology may generate three residual streams: solids from the incinerator and APC system, water from the APC system, and emissions from the incinerator.

TABLE 3-10. TYPICAL TREATMENT COMBINATIONS FOR DESTRUCTION OPTIONS

Pretreatment/materials handling	Destruction technology	Posttreatment/residuals management
Excavation/conveying Dredging/dewatering Screening/size reduction	Incineration	Air pollution control Scrubber effluent treatment/disposal Ash treatment/disposal
Excavation/conveying Dredging/dewatering Screening/size reduction	Pyrolysis	Air pollution control Scrubber effluent treatment/disposal Ash treatment/disposal
Excavation/conveying Dredging/dewatering Screening/size reduction	Chemical dehalogenation	Air pollution control Washwater treatment/disposal Treated soil treatment/disposal
Excavation/conveying Dredging/dewatering Screening/size reduction Water addition, mixing	Chemical oxidation	Air pollution control Filtration, treated soil treatment/disposal
Excavation/conveying Dredging Screening/size reduction Soil washing Water addition, pH, and temperature adjustment	Slurry-phase bioremediation	Air pollution control Process water treatment/disposal Treated soil treatment/disposal
Excavation/conveying Dredging Screening/size reduction Mixing, pH adjustment	Solid-phase bioremediation	Air pollution control Incomplete degradation Products treatment/disposal Leachate treatment/disposal
Water recirculation system Conditioning of infiltration water with nutrients and oxygen In situ soil flushing	In situ bioremediation	Groundwater treatment/reinjection

Bottom ash (treated soils) from the primary chamber and fly ash from the APC system may contain heavy metals contaminants such as chromium, lead, copper, and arsenic. The fly ash may also contain high concentrations of volatile heavy metals such as lead, cadmium, and arsenic. If these residues fail the required TCLP leachate toxicity tests, they can be treated by another process, such as stabilization/solidification, and then be properly disposed on site or in an approved landfill.

Liquid wastes from the APC system may contain excess caustic or acid, high levels or chloride, dissolved and suspended heavy metals, trace organic compounds and fine inert particulates. These contaminants may require further treatment as follows: neutralization of the acids or bases; chemical precipitation and/or ion exchange to remove metals; settling, filtration, and reverse osmosis to remove particulates; and carbon adsorption to remove trace organic compounds.

Stack emissions are minimized by the APC system, the combustion control system, and stack emission monitors. Fugitive emissions are controlled by equipment design (enclosed feed and ash systems and dust control systems) and operating procedures.

TABLE 3-11. APPLICABILITY OF DESTRUCTION OPTIONS TO CONTAMINANT CLASSIFICATIONS

Group No.	Contaminant group	Destruction options				
		Thermal destruction	Chemical dehalogenation	Chemical oxidation	Bioremediation	In situ bioremediation
W02	Dioxins/furans/ PCBs and their precursors	●	●	O	O	O
W03	Halogenated phenols, creosols, ethers, and thiols	●	◕	◕	◕	◕
W07	Heterocyclics and simple non-halogenated aromatics	●	O	◕	●	●
W08	Polynuclear aromatics	●	O	◕	●	●
W09	Other polar organic compounds	●	O	◕	●	●
W10	Non-volatile metals	O	O	◕	O	O
W11	Volatile metals	O	O	◕	O	O

● - Demonstrated effectiveness
◕ - Potential effectiveness
O - No expected effectiveness

Source: USEPA Engineering Bulletins

Technology applicability--Incineration has effectively treated soil, sludge, sediment, and liquids containing all the organic contaminants found on wood preserving sites, such as dioxins/furans, PCP, PAHs, and other halogenated and nonhalogenated volatiles and semivolatiles. Incineration has treated wood preserver wastes to the most stringent cleanup levels. A substantial body of trial burn results and other quality-assured 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 [1,2]. Incineration does not destroy metals. However, metals will produce different residuals (bottom ash, cyclone ash, and liquid) depending on the volatility of their compounds and the incinerator operating conditions [3].

The moisture content and the heating value of the contaminated wastes are important parameters that affect the economics of the incineration process. High moisture content and high heating value reduce the incinerator's capacity. Several feasibility studies have screened out incineration due to either high moisture content or high heating value of the wastes. This is questionable, however, since engineering solutions can improve the economics. When a waste has both high heating value and high moisture content, the moisture content cools the products of combustion efficiently and permits higher throughputs [1]. In addition, mechanical or thermal dewatering techniques can reduce high moisture content and blending with wastes of low heating value can process high heating-value wastes.
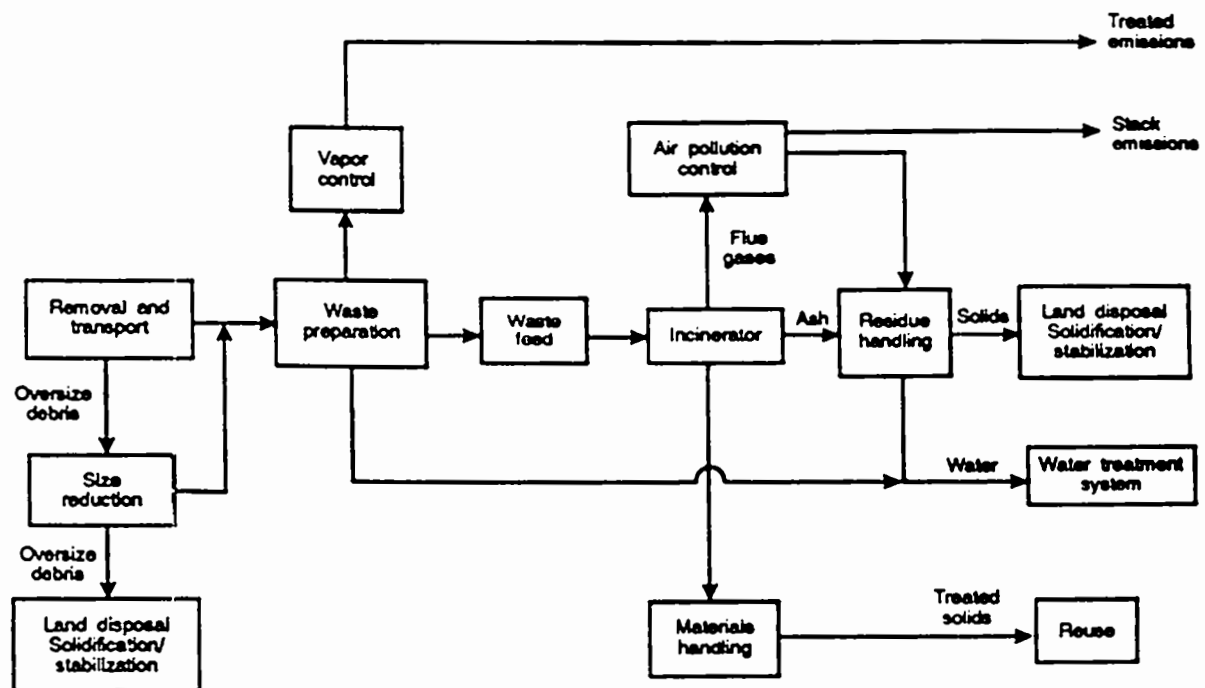
Figure 3-2. Schematic for an incineration treatment train [1].

Technology status/performance--Out of 29 RODs for wood preserving sites, 7 selected incineration as an integral part of a treatment train. Thermal destruction has been fully proven in commercial use. Table 3-12 lists the results of several selected incineration treatability studies. Newer techniques being studied will lower temperatures in primary incineration chambers and add agents (e.g., lime, iron oxide, fly ash, proprietary inorganics) to bind and treat volatile metals in the incinerated material.

TABLE 3-12. INCINERATION TREATABILITY TEST RESULTS

Site	Equipment	Feed	Results
Allied Chemicals, Birmingham, AL	John Zink Rotary Kiln	Sludge/sediment: naphthalene (4%), phenanthrene (3.5%), fluoranthene (2.5%), other active organics (30%)	No detectable priority pollutants in the ash/ scrubber water residues [5,6]
Allied Chemicals American Wood Division, Richton, MS	USEPA Combustion Research Facility	Sludge: PCPs 970 to 3,800 ppm, PNAs and volatile organics (benzene and toluene)	No detectable priority/ volatile/semivolatile compounds in residual ash/scrubber water [7]
American Crossarm, Chehalis, WA	Rotary kiln	Not listed	Treated dioxins to <0.001 mg/kg
Bell Lumber, New Brighton, MN	Rotary kiln	Not listed	Reduced PCP to <0.5 mg/kg
Los Alamos National Laboratory, NM	Model 500-T Air Incinerator	Boxes treated with PCP	DRES >99.99% [8]
Prentiss Creosote, Prentiss, MS	Rotary kiln	Not listed	Treated PAHs to <2 mg/kg
Stringfellow Acid Pit Superfund Site, CA	Pyretron Oxygen Burner (SITE Demonstration)	Sludge: 6 PAHS - naphthalene, acenaphthalene, fluorene, phenanthrene, anthracene, and fluoranthene	>99.99% DRE for PAHS [9]

Implementation costs--The cost of incineration includes fixed and operational costs. Site preparation, permitting, and mobilization/demobilization costs are relatively fixed; operational costs such as labor, utilities, and fuel, vary according to the type of waste treated and the size of the site. Figure 3-3 shows the effect of site size on incinerator costs [4]. Average costs for incineration range from $300 to $1,000/ton. These costs do not include excavation, materials handling, or disposal.

Data requirements--Table 3-13 summarizes factors affecting incineration performance. These factors determine the data requirements for incineration -- the type of information (site/waste characterization, treatability study, etc.) needed to implement this technology at a wood preserving site.

Pyrolysis--

Pyrolysis differs from incineration because it uses heat *in the absence of oxygen* to decompose organic materials. It transforms hazardous, long-chain, carbonaceous materials into less hazardous, gaseous components and a solid residue (coke) containing fixed carbon and ash. The gas product contains lower molecular weight hydrocarbons, CO, H_2, and methane.

TABLE 3-13. FACTORS AFFECTING INCINERATION PERFORMANCE

Factor	Potential effect
Ash fusion temperature	Melts and agglomerates inorganic salts.
Halogenated organic compound concentration	Forms acid gases.
Heating value	Requires additional energy use (<8,000 BTU); affect throughput.
Metals content	Vaporizes; becomes difficult to remove from emissions (volatile metals: As, Cd, Zn).
Moisture content	Increases feed handling and energy requirements.
Organic phosphorous content	Forms acid gas (high concentrations).
Particle size	Hinders processing (oversized debris); causes high particulate loading from fines carried through the process.
PCBs, dioxins	Require higher temperatures for destruction.

Pyrolysis operates at temperatures between 800° and 2,100°F. Cracking organic contaminants produces coke by-products that add to the heating value of the process, while desorption mechanisms concentrate the contaminants. Pyrolysis produces fewer air pollutants, allows more control, permits higher throughput, and operates at lower temperatures than incineration.

Typical treatment combinations--The pyrolytic process generates three streams: solids, liquids, and gases. The solids consist of the treated soil and the coke formed from hydrocarbon decomposition. Some compounds volatilize rather than decompose, requiring condensation for further treatment. Condensed volatiles and process water comprise the liquid streams. They may contain chlorides, volatile metals, trace organics, and particulates. Feedstock dewatering can lower treatment costs. Standard water treatment techniques for wastewater will suffice for treatment; air pollution control systems will control dusts and scrub acid gases. S/S can treat solids and fly ash generated from the process.

Technology applicability--Pyrolysis generally applies to a wide range of organic wastes in soil and sludge, but not to inorganics and metals. Treatment data for PCBs (analogous to wood-preserving PCP), dioxins, and PAHs are available. Small-scale tests suggest that pyrolysis can treat soil, sediment, and sludge contaminated with nonhalogenated semivolatiles and PCBs, as well as sediment/sludge contaminated with dioxins/furans. However, it will not treat or immobilize metals [10].

Technology status/performance--Pyrolysis is an emerging technology; performance data are limited. No ROD has yet chosen pyrolysis.

Five companies market pyrolytic systems: Southdown Thermal Dynamics (HT-V System), Deutsche Babcock Anlagen AG, Surface Combustion, Westinghouse, and SoilTech, Inc.
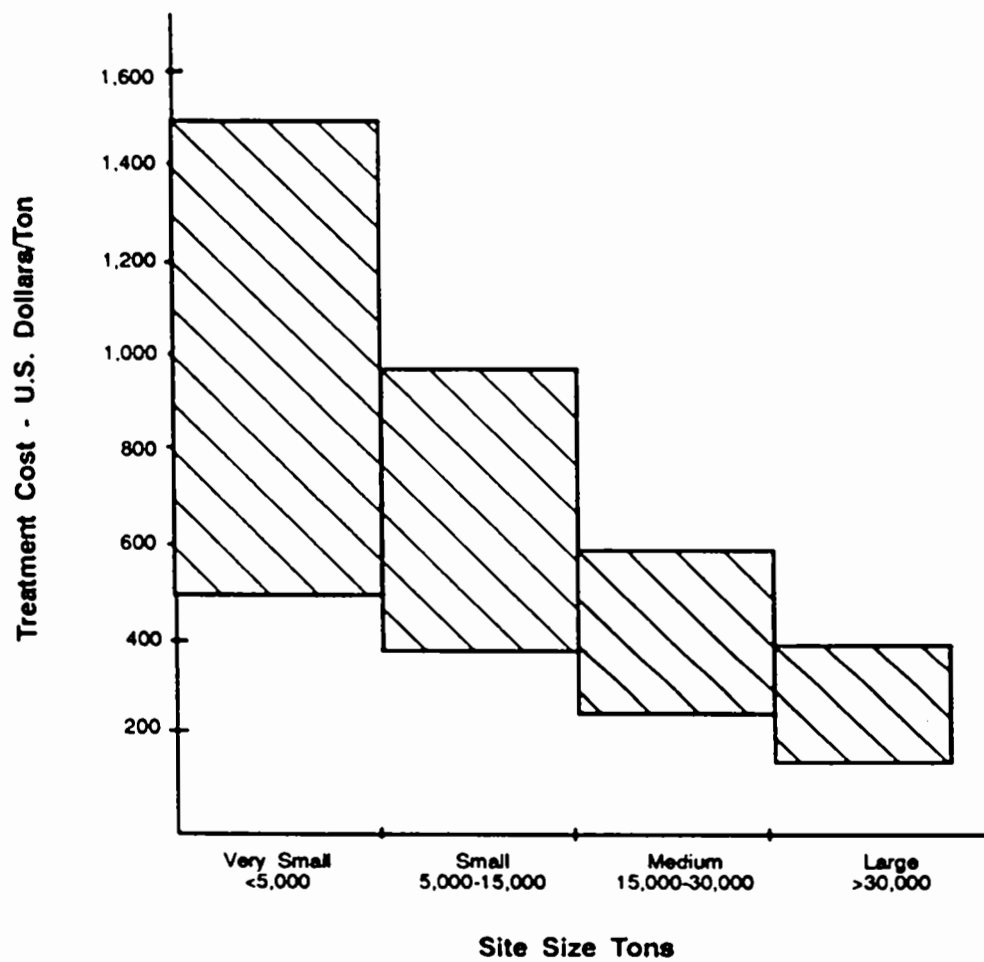
Figure 3-3. Effect of site size on incineration costs [1].

The **HT-V System** has treated oily sludges contaminated with dioxins and PCBs at the bench scale. Wastes contaminated with 2,3,7,8-TCDD were treated with an efficiency of over 99.99%. A mixture of PCB-contaminated oil, water, and soil showed a 99.99% reduction in PCBs.

The **Deutsche Babcock System**, tested at full-scale, treated 35,000 tons of soil. The destruction of 17 PAHs was measured; an efficiency of 99.77% was achieved (Table 3-15).

Implementation costs--Costs have not yet been determined.

Data requirements--The primary factors affecting pyrolytic performance are summarized in Table 3-14.

TABLE 3-14. FACTORS AFFECTING PYROLYSIS PERFORMANCE

Factor	Potential effect
Temperature	
Residence time	
Moisture content (<1%)	Affects number of treatment cycles
pH (5 to 11)	Affects component corrosion
Volatile concentration	Affects pretreatment options

Chemical Destruction Technologies

Two types of chemical destruction technologies apply to contaminated soil, sludge, and sediment at wood preserving sites:

- Dehalogenation, and
- Chemical oxidation.

Dehalogenation--
Chemical dehalogenation uses a chemical reaction to remove the chlorine atoms from chlorinated molecules. This converts the more toxic compounds into less toxic, sometimes more water-soluble products, leaving compounds that are more readily separated from the soil and treated [11]. Dehalogenation of halogenated aromatic compounds uses a nucleophilic substitution reaction to replace a chlorine atom with an ether or hydroxyl group. Dehalogenation or dechlorination of chlorinated aliphatic compounds occurs through an elimination reaction and the formation of a double or triple carbon-carbon bond [12].

Field and laboratory tests have identified several types of solutions that can dechlorinate PCBs, dioxins, and furans. These solutions include potassium polyethylene glycolate (KPEG), sodium polyethylene glycolate (NaPEG), and methoxypolyethylene glycolate (MPEG). These are generally classified as alkali polyethylene glycolate solutions (APEG). Figure 3-4 presents a schematic flow diagram for this technology. The base-catalyzed decomposition process (BCDP) uses sodium bicarbonate in a heated reactor to effectively treat halogenated compounds.

TABLE 3-15. DEUTSCHE BABCOCK PYROLYTIC ROTARY KILN CONTAMINATED SOIL RESULTS

Pollutant	March 8, 1989		January 27, 1989	
	Input mg/kg	Output mg/kg	Input mg/kg	Output mg/kg
Naphthalene	101.00	1.7	161.60	0.5
2-methyl-naphthalene	40.20	0.5	73.80	0.1
1-methyl-naphthalene	23.40	0.3	42.90	0.1
Dimethylnaphthalene	nd*	nd*	93.20	0.3
Acenaphthylene	nd*	nd*	68.20	0.1
Acenaphthene	nd*	nd*	42.30	0.1
Fluorene	136.00	0.1	238.00	0.1
Phenanthrene	686.00	0.6	1,055.30	1.4
Anthracene	281.00	0.1	226.00	0.3
Fluoranthene	nd*	nd*	688.60	1.3
Pyrene	236.00	0.1	398.20	0.6
Benzo(a)anthracene	155.00	0.2	2,259.20	0.3
Chrysene	214.00	0.3	134.60	0.9
Benzo(a)pyrene	66.60	0.4	111.50	1.1
Benzo(p)fluoranthene	112.00	0.1	168.50	5.2
Benzo(k)fluoranthene	43.70	0.1	81.90	0.3
Benzo(a)pyrene	86.60	0.2	138.10	0.4
Dibenzo(ah)anthracene	16.80	0.1	23.20	0.1
Benzo(ghi)perylene	14.00	0.1	60.20	0.1
Indeno(1,2,3-cd)pyrene	33.80	0.1	69.50	0.1
Totals	2,266.10	5.2	6,134.80	13.4
Decontamination efficiency	99.77%		99.78%	

*nd = not detected
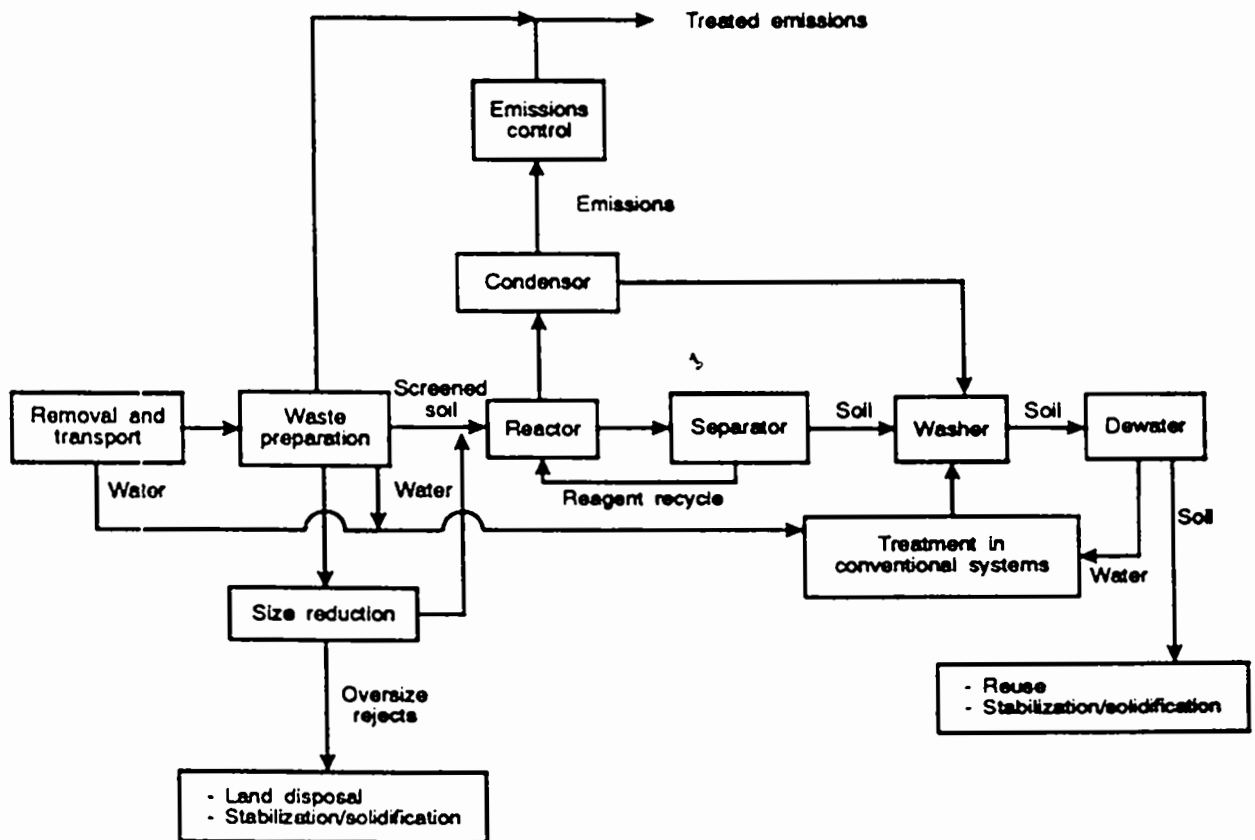
Figure 3-4. Schematic for chemical destruction process [15].

Typical treatment combinations--Dehalogenation generates three residuals: treated soil, wash water, and air emissions. Since this treatment is effective only for dioxin/furan/PCB and halogenated phenol/creosol groups, the presence of other contaminants may demand posttreatment, such as bioremediation or incineration. The wash water may require treatment prior to discharge. Volatile air emissions, captured by condensation and/or activated carbon adsorption, can be thermally regenerated.

Technology applicability--Chemical dehalogenation can treat halogenated aromatic contaminants in a waste matrix consisting of soil, sludge, or sediment. This technology has achieved removal efficiencies up to 95%, with an average of 83% in bench-scale studies for PCB contaminants (analogous to PCP). Bench-scale studies produced removal efficiencies of 96% for PCP [13]. The presence of other contaminants may require a treatment combination that would add bioremediation, incineration, or another option.

Technology status/performance--Chemical dehalogenation is an innovative alternative to conventional technologies, such as incineration. Table 3-16 presents several selected wood preserving site treatability tests.

TABLE 3-16. DECHLORINATION TREATABILITY TEST RESULTS

Site	Equipment	Feed	Results
KPEG Lab Test		Slurry: PCP 1,100 mg/kg, total PAHs 1,746 mg/kg	Treated soil: 31 ppm (97%) PCP; 721 ppm (59%) total PAHs [16]
RREL	Base catalyzed dechlorination process (BCDP)	Soil/sediment: PCB, PCP	Selected for SITE demo at Navy Site, Stockton, CA [17]
Montana Pole and Treating Site, Butte, MT		PCP/oil/dioxin: 3.5% PCP; dioxins 442 ppb tetra-isomers to 83,923 ppb octa-isomers	Non-detect levels (less than 1 ppb) [18,19]
Sea Marconia CDP Process (dehalogenation)		Solids/solvents: 2,3,7,8-tetrachlorodibenzo-p-dioxin	Destroyed [20]

Implementation costs--APEG treatment costs range from $200 to $500/ton [14].

Data requirements--Table 3-17 summarizes the factors that affect dechlorination efficiency and, thus, determine the data requirements for chemical destruction.

Chemical Oxidation--
Oxidation adds chemical compounds to oxidize organic contaminants and liberate free oxygen. The presence of heat and a catalyst may enhance its effectiveness. The most common oxidizing agents are hydrogen peroxide (H_2O_2) and ozone (O_3); the catalysts, metals such as Fe, Al, and Cu. Ultraviolet (UV) radiation can enhance the oxidation process. The presence of photosensitive material (e.g., TiO_3) can significantly enhance the oxidation of highly halogenated organic contaminants.

3-23

TABLE 3-17. FACTORS AFFECTING DECHLORINATION PERFORMANCE

Factor	Potential effect
Aliphatic organics, inorganics, metals	Achieves best results with aromatic halides (PCB, dioxins, chlorophenols, chlorobenzenes)
Aluminum and other alkaline reactive metals	Requires increased use of reagent; can produce H_2 gas.
Chlorinated organics (>5%)	Requires excessive reagent.
Clay and sandy soils	Increases reaction time.
Humic content	Increases reaction time.
Moisture content (>20%)	Requires excessive reagent.
pH	Must remain >2 for process to be effective.

Catalytic or photocatalytic oxidation converts organic contaminants to products like CO_2 and H_2O. The heteroatoms (Cl, P, N, S, etc.) in the organic molecule convert to acid gases like HCl, SO_x, NO_x, or P_2O_6. Chemical oxidation in a reactor can produce an aqueous or a slurry phase. These units generally do not require extensive air pollution control. The technology yields its best results when applied to excavated material in a reactor.

Typical treatment combinations--Residuals from chemical oxidation, such as partially oxidized products, may require further treatment. Depending on the oxidizing agent and the chlorine content of the feed, oxidation of organic compounds forms HCl and NO_x. Any salt precipitation must be filtered out and may require additional treatment.

Technology applicability--Oxidation effectively treats liquids that contain oxidizable contaminants, such as PCBs, halogenated phenols/creosols, PAHs, nonhalogenated semivolatiles, and metals. However, this technology can also be used on similarly contaminated slurried soil and sludge.

Technology status/performance--A well established technology, oxidation is used to disinfect drinking water and wastewater. It is also a common treatment for cyanide wastes [22]. However, its application in environmental remediation is limited. To date, no ROD has directed the use of oxidation as a remedy for soil, sludge, or sediment at a wood preserving site.

Biological Destruction Technologies

Bioremediation uses microorganisms to chemically degrade organic contaminants. Biodegradation can occur either in the presence (aerobic) or in the absence (anaerobic) of oxygen. In the presence of oxygen, microorganisms convert organics to carbon dioxide, water, and microbial cell matter. In the absence of oxygen, they degrade the contaminants to methane, carbon dioxide, and microbial cell matter. Biological activity accomplishes much of the natural transformation of organic contaminants in soil.

Both bacteria and fungi have figured in bioremediation processes. Most research has centered on bacteria, but some investigators have found that fungi can play an important role, especially with halogenated compounds (e.g., PCP). Almost all bioremediation relies on a variety of microorganisms, rather than one or a few species. It enhances the development of large populations that can transform contaminants and initiates intimate contact between microbes and contaminants. If biodegradable contamination of the soil has endured for more than a few months, and the microorganisms have grown and reproduced in the contaminated soil, then native microorganisms can generally transform the wastes. The remedial manager needs to determine what management techniques can optimize the transforming activity to degrade the wastes to required levels in an acceptable time frame. There is little or no evidence to indicate that augmentation with cultured microorganisms enhances the natural bioremediation process. Three bioremediation processes apply to wood preserving sites: slurry-phase, solid-phase, and in situ biodegradation.

Slurry-phase Bioremediation--

Slurry-phase bioremediation mixes excavated soil or sludge with water in a tank or lagoon to create a slurry, which is then mechanically agitated. The procedure adds appropriate nutrients and controls the levels of oxygen, pH, and temperature. This process is suitable for high concentrations of organic contaminants in soil and sludge. However, the presence of heavy metals can inhibit microbial metabolism.

Solid-phase Bioremediation--

Solid phase bioremediation places contaminated soil in a lined bed to which nutrients such as nitrogen and phosphorous are added. The bed is usually lined with clay and plastic liners; furnished with irrigation, drainage, and soil-water monitoring systems; and surrounded by a berm. Aeration, temperature control, and a leachate collection system may increase efficiency. This process is one of the older and more widely used technologies for hazardous-waste treatment. It has been particularly successful in the United States, especially at petroleum refinery sites treated under RCRA and at creosote-contaminated sites.

Composting is a variation of solid-phase bioremediation. Waste decomposition occurs at higher temperatures resulting from the increased biological activity within the bed. The composting process can treat highly contaminated material by mixing contaminated soil with a bulking agent (straw, bark, manure, wood chips), piling it, and aerating it (with natural convection or forced air) in a contained system -- or by mechanically turning the pile. Bulking agents, when added to compost, improve texture, workability, and aeration; carbon additives provide a source of metabolic heat. One significant disadvantage of composting is the increased volume of treated material due to the addition of bulking agents. Simple irrigation techniques can optimize moisture, pH, and nutrient control; an enclosed system can achieve volatile emissions control. Where temperature is critical to removal rates, other sources of organic matter can increase the biological activity and, therefore, the temperature of the system.

In Situ Biodegradation--

In situ biodegradation promotes and accelerates natural processes in undisturbed soil. It can use recirculation of extracted groundwater that is supplemented aboveground with nutrients and oxygen. Alternatively, vacuum or injection methods can supply oxygen to the subsurface soil. Under appropriate conditions, this technology can destroy organic contaminants in place without the high costs of excavation and materials handling. It can also minimize the release of volatile contaminants into the air. However, in situ bioremediation cannot be used to directly destroy concentrated masses of NAPLs.

Typical Treatment Combinations--

Figure 3-5 is a schematic diagram of slurry-phase biodegradation. If the treated and dewatered solids contain organic contaminants, they may need further treatment. When these solids are contaminated with
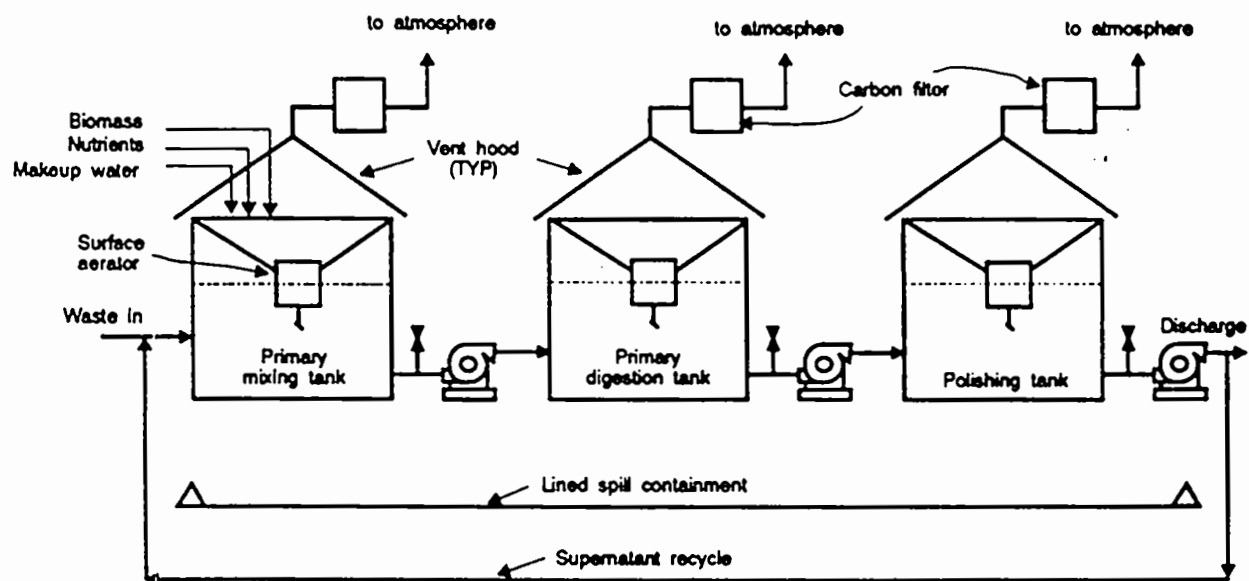
Figure 3-5.   Slurry phase bioremediation [22].

heavy metals, stabilization may be necessary. The process water may also require on-site treatment prior to discharge. Depending on the waste characteristics, air pollution control measures, such as adsorption by activated carbon, may be necessary.

Figure 3-6 shows a solid-phase system. Figure 3-7 presents a schematic diagram of an in situ biodegradation process. Surface treatment of recovered groundwater may accompany this process.

Technology Applicability--
Bioremediation can treat soil, sludge, and sediment contaminated with organic contaminants such as halogenated phenols and creosols, other polar organic compounds, nonhalogenated aromatics, and PAHs. Biotreatment of nonhalogenated aromatics and polar organic compounds has produced average removal efficiencies in excess of 99%. However, a 99% removal efficiency for nonhalogenated volatile contaminants may have resulted from volatilization tied to bioremediation. Biological treatment in pilot-scale studies on PAHs as well as on halogenated phenols and creosols has achieved average removal efficiencies of 87% and 74%, respectively. No data are available on the bioremediation of dioxins and furans [13]. Biotreatment may not be effective for wastes with high levels of toxic metals.

In situ biodegradation has shown potential for effective treatment of soil containing organic contaminants such as halogenated phenols, nonhalogenated aromatics, PAHs, and polar organic compounds.

Technology Status/Performance--
Out of 29 RODs for wood preserving sites, 10 sites selected bioremediation as an integral part of a treatment alternative: 6 solid-phase processes for excavated waste and 4 in situ remedies. Laboratory treatability studies and field scale demonstrations have shown that PCP and other organic contaminants in soil at wood preserving sites are amenable to biodegradation (Table 3-18).

Solid-phase treatment is one of the oldest and most widely used technologies for hazardous-waste treatment. It has been successfully demonstrated at wood preserving sites with creosote-contaminated soil and sludge (e.g., Burlington Northern).

In situ bioremediation holds promise for cost-effective treatment of contaminated soil and groundwater contaminated with creosote and other coal tar products.

Implementation Costs--
One vendor estimates that the cost of a full-scale slurry biodegradation operation ranges from $80 to $150/yd^3 of soil or sludge, depending on the initial concentration and the treatment volume. The cost to use slurry biodegradation will vary, depending upon the need for additional pretreatment, posttreatment, and air emission control [24].

Costs for solid-phase land treatment range between $50 and $80/yd^3, according to the need for a liner and the extent of excavation required. Composting costs about $100/yd^3. Costs of in situ treatment range from $8 to $15/lb of contaminant [25].

Data Requirements--
Table 3-19 summarizes the factors affecting biological treatment. A remedial manager can derive data requirements for biological destruction from this list. The data requirements include site factors and waste characteristics.
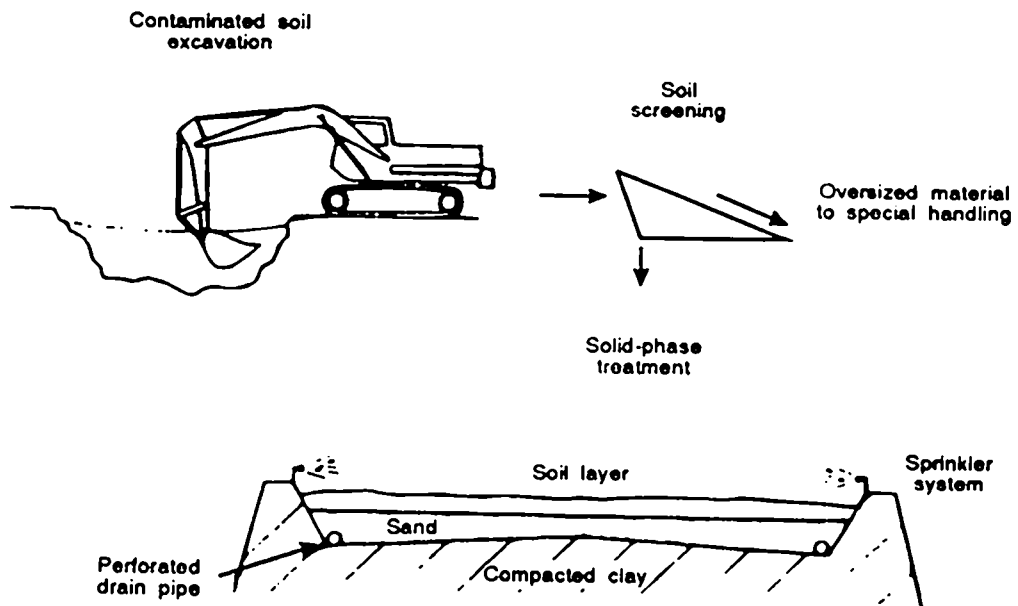
Figure 3-6. Solid phase bioremediation [22].
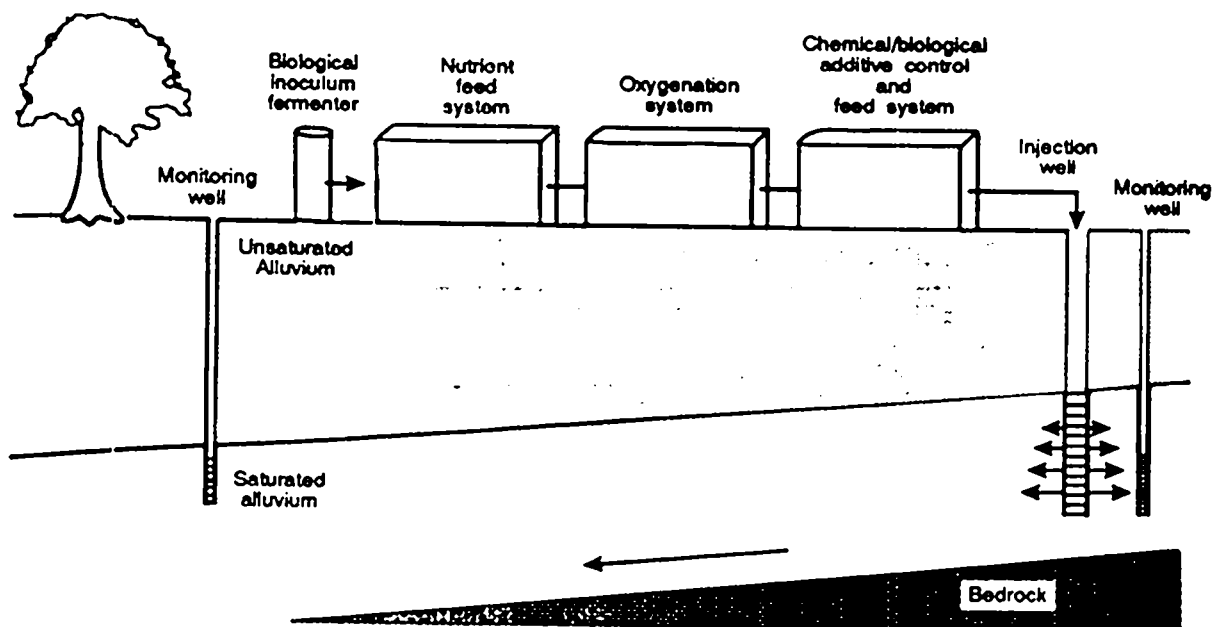
Figure 3-7. In situ bioremediation [23].

TABLE 3-18. BIOTREATABILITY TEST RESULTS

Site	Equipment	Feed	Results
Arkwood, Inc. Site, Omaha, AR	BioTrol, Inc. slurry biodegradation	PCP, PAHs	56-day reduced PCP and PAH concentrations 85% and 80%, respectively. After 98 days, levels not detectable in TCLP leachate.
Baxley Creosoting, Inc., Baxley, GA	Slurry biodegradation	Soil: Phenol 3.91 mg/kg TCP 11.07 mg/kg PCP 420 mg/kg PAHs 82 to 519 mg/kg	Phenol <0.01 mg/kg TCP <0.02 mg/kg PCP <13.1 mg/kg PAHs 0.5 to <0.03 mg/kg [24,14,27].
J.H. Baxter Superfund Site	Bench-scale slurry-phase and solid-phase bioremediation	Soil: PCP Soil: PCP	Significant biodegradation of PCP and other organics [28,29]. Poor degradation during 90-day studies -- a relatively short time frame [30,31].
Burlington Northern, Brainerd, MN	Bench-scale SITE test of ECOVA Corporation's bioslurry reactor Solid-phase land treatment by Remediation Technology, Inc.	Creosote contaminated soil (PAHs) Contaminated soil and lagoon sediment	Reduction of 4- and 6-ring PAHs; >89% in first two weeks, >93% after 12 weeks. Bioremediation considered a success [32].
Coleman Evans Site, FL	BioTrol, Inc. biodegradation treatability study. A combined soil washing/ soil slurry bioreactor system	PCP average concentration: 369 and 442 ppm PCP: 3,500 mg/L	Soil washing may be an effective pretreatment step, reducing volume of soil approximately 90% before bioremediation [33]. PCP degraded [34].
Gulf States Creosote, Hattiesburg, MS	Pilot-scale landfarming	Soil: creosote	Quick initial drop followed by slower rate of reduction. Volatilization was a major reduction pathway.
Joslyn Manufacturing and Supply Co., Redmond, VA	ECOVA Corp. solid-phase land treatment unit	Soil: PCP (360 ppm), CPAHs (100 ppm)	PCP reduced to 110 ppm; CPAHs to 43 ppm.
Lake States Wood Preserving, Munishing, MI	Pilot-scale bioremediation	PCP	PCP reduction of 95% achieved in a field vault in 148 days.

TABLE 3-18. (Continued)

Site	Equipment	Feed	Results
MacGills and Gibbs Site, New Brighton, MN	BioTrol Slurry Bioreactor (SBR) BioTrol, Inc. SITE Program pilot-scale treatment train consisting of soil washing, aqueous treatment, and slurry biodegradation. (See soil washing and biological treatment sections for other results.)	Slurry feed: 2,570 ± 506 mg/kg PCP Liquid feed: 59 ± 19 mg/L PCP	90% PCP removal [35].
Major study at 8 wood-preserving waste sites		PCP	Degradation demonstrated on laboratory and field scales [36,21].
North Cavalcade Street, Houston, TX	BioTrol, Inc. treatability study combining biotreatment and soil washing	Mean PAH concentration: 3,700 mg/kg	Acclimated seed without surfactant removed 91% of total PAHs and over 63% of the CPAHs in 28 days [37].
RREL	In situ bioventing		Technique was accepted into the SITE Program.
RREL	White rot fungus		Technique was accepted into the SITE Program.
Scott Lumber Alton, MO	Bench-scale aerobic biological treatment	PAHs	PAHs removed at rates exceeding 100 ppm/day.
	ReTEC Remediation Technologies, Inc. conventional landfarming of 16,000 tons of soil	1,000 ppm PAHs 24 pm BaP	Reduced to 160 ppm PAHs, 12 ppm BaP.
South Cavalcade Street, Houston, TX	Two slurry reactors (aerobic and anaerobic)	PAHs	Lower molecular weight PAHs degraded faster than those with higher molecular weight. Destruction removal efficiencies: 91% for anaerobic column and 75% in aerobic column [38].

SEPARATION/CONCENTRATION TECHNOLOGIES

Separation/concentration options can be used either for excavated or in situ soil. There are several such options:

Excavated soil	In situ options
Soil washing	Steam extraction
Solvent extraction	Soil flushing
Thermal desorption	Free product recovery
	SVE

Table 3-20 lists typical remedial combinations for separation/concentration options. Table 3-21 summarizes the applicability of these options on contaminant groups and media.

Separation/Concentration Technologies for Treatment of Excavated Soil

Soil Washing--
Soil washing is a water-based process for mechanically scrubbing excavated soil to remove contaminants in two ways: by dissolving or suspending them in the wash solution or by concentrating them into a smaller volume of soil through particle size separation techniques. Soil washing systems that incorporate both techniques indicate the greatest success for soils contaminated with a heavy metal and organic contaminants. Contaminants tend to bind chemically and physically to clay and silt particles. The silt and clay, in turn, tend to attach physically to sand and gravel. The particle size separation aspect of soil washing first scours and separates the silts and clays from the clean sand and gravel particles. The process then scrubs the soluble contaminants from the particle surfaces and dissolves them in the liquid phase. The soil washing process uses various additives (surfactants, acids, chelating agents) to increase separation efficiencies. The washed soil, after successful testing, can be returned to the site or reclaimed. The aqueous phase and the clay/silt/sludge fraction contain high concentrations of contaminants. These two streams become waste feed for other on- or off-site destruction technologies.

Typical treatment combinations--Waste feed preparation of excavated soil includes removal, transportation, and screening to remove debris and large objects. In some cases, the process may need pumpable feed (achieved by the addition of water or solvent). Soil washing generates four main waste streams: contaminated solids, washwater, washwater-treatment sludge, and air emissions. Contaminated clay fines and sludge may require further treatment by other technologies, such as incineration, thermal desorption, stabilization/solidification, or bioremediation. Discharge standards may mandate washwater treatment prior to discharge. Permits may require collection/treatment of air emissions from the preparation area or the washing unit. Figure 3-8 presents a schematic diagram of soil washing.

Technology applicability--Removal efficiencies for soil washing depend on the type of contaminant as well as the type of washing fluid. Water alone may easily remove volatile organics. Semivolatile organics and hydrophobic contaminants may require the addition of a surfactant or organic solvent; metals and pesticides require pH adjustment with acids or the addition of chelating agents. Complex contaminant matrix systems, which contain a mixture of metals, nonvolatile organics, and semivolatile organics, may require sequential washing steps with variations in the wash formulation and operating parameters. Site-specific, bench- or pilot-scale treatability tests will determine the best operating conditions and wash fluid compositions. Depending on the washing fluid, soil washing effectively treats waste containing halogenated phenols and creosols, nonhalogenated aromatics, as well as nonvolatile and volatile metals. The process is best suited for sandy and sandy-loam soils that are low in organic matter and clay content. Soil washing

3-31

TABLE 3-19. FACTORS AFFECTING BIOLOGICAL TREATMENT

Factor	Potential effect
Contaminant solubility	Make low solubility components more difficult to remove from soils.
Heavy metals, highly chlorinated organics, some pesticides, inorganic salts	Inhibit microbial activity (high concentrations). Some inorganic salts necessary for biological activity.
Moisture content	May inhibit solid-phase aerobic remediation of soils if >80%; soil remediation inhibited if <40%. Soil slurry reactors may have 80 to 90% moisture content. Liquid phase reactors may have >99% moisture content.
Nutrients	Affect activity if lacking (C, N, P).
Oil and grease concentrations	Inhibit soil remediation at concentrations >5% by weight.
Oxygen	Sustains aerobic microbial population, inhibits anaerobic activity.
Particle size	Interferes with microorganism contact if nonuniform.
pH	Works effectively in a range of 4.5 to 8.5.
Soil permeability	Affects movement of water and nutrients for in situ treatment.
Suspended solids concentration	Should be less than 1% (can vary greatly in different types of bioremediation).
Temperature	Usually inhibits microbial activity (high or low temperatures). However, in some cases, can tolerate at temperatures down to freezing and over 100°F.
Variable waste composition	Large variations affect biological activity, especially where continuous flow liquid bioreactors are used.

has attained a removal efficiency greater than 99% for nonhalogenated aromatics. Bench-scale studies for nonvolatile and volatile metals achieved 99% [2]. In a pilot scale test the BioTrol soil washer achieved removals of up to 89% PCP and 88% TPAHs [4]. In the most recent pilot scale test with EPA's Volume Reduction Unit (VRU) removals of 98% PCP and about 96% PAHs were achieved [30].

Technology status/performance--Out of 29 RODs for wood preserving sites, 5 have selected soil washing; 1, solvent extraction; and 1, thermal desorption. Soil washing is widely accepted in Europe but has had limited use in the United States. A number of vendors provide soil washing processes. Information from treatability studies at wood preserving sites indicates possible applications (Table 3-22).

Implementation costs--Vendor-supplied treatment costs for soil washing processes range from $50 to $205 per ton of feed soil.

TABLE 3-20. TYPICAL TREATMENT COMBINATIONS FOR SEPARATION/CONCENTRATION OPTIONS

Pretreatment/materials handling	Separation/concentration technology	Posttreatment residuals management
Excavation/conveying Dredging Screening, water addition	Soil washing	Washwater treatment Air pollution control Contaminated solids treatment/disposal Wastewater treatment Sludges treatment/disposal
Excavation/conveying Dredging Screening, water addition	Solvent extraction	Concentrated contaminants treatment/disposal Soil residual treatment/disposal Separated water disposal
Excavation/conveying Screening	Thermal desorption	Air pollution control Treated soil treatment/disposal Concentrated contaminants treatment/disposal
Injection/recovery well installation	In situ steam extraction using steam, hot air, infrared, micro waves	Recovered contaminants treatment/disposal Separated water treatment/disposal Carbon regeneration/disposal
Flushing fluid delivery system Groundwater extraction well installation	In situ soil flushing	Flushing liquid/groundwater treatment/disposal Air pollution control In situ soil treatment
Extraction well/air injection well Installation	In situ soil vapor extraction	Air pollution control Contaminated groundwater treatment/disposal Soil tailings treatment/disposal

Data requirements--Data requirements for soil washing can be derived from the performance factors in Table 3-23.

Solvent Extraction--

Solvent extraction is a physical separation process that removes contaminants from soil, sludge, or sediment. It uses organic solvents to isolate contaminants, unlike soil washing which uses water or water-based solutions. Solvent extraction is more appropriate for organic contaminants than inorganics and metals; it reduces contaminant volume by concentrating them in the extract phase. There are three broad categories of the solvent extraction process: conventional solvent extraction, critical fluid extraction, and supercritical fluid extraction.

Conventional solvent extraction uses organic solvents to selectively extract the contaminants of concern. The process may require several passes to reduce contamination to the desired level. The extracted solvent can be stripped of the contaminants, condensed, recycled, and reused -- reducing contaminant volume and providing optimum extraction efficiency.
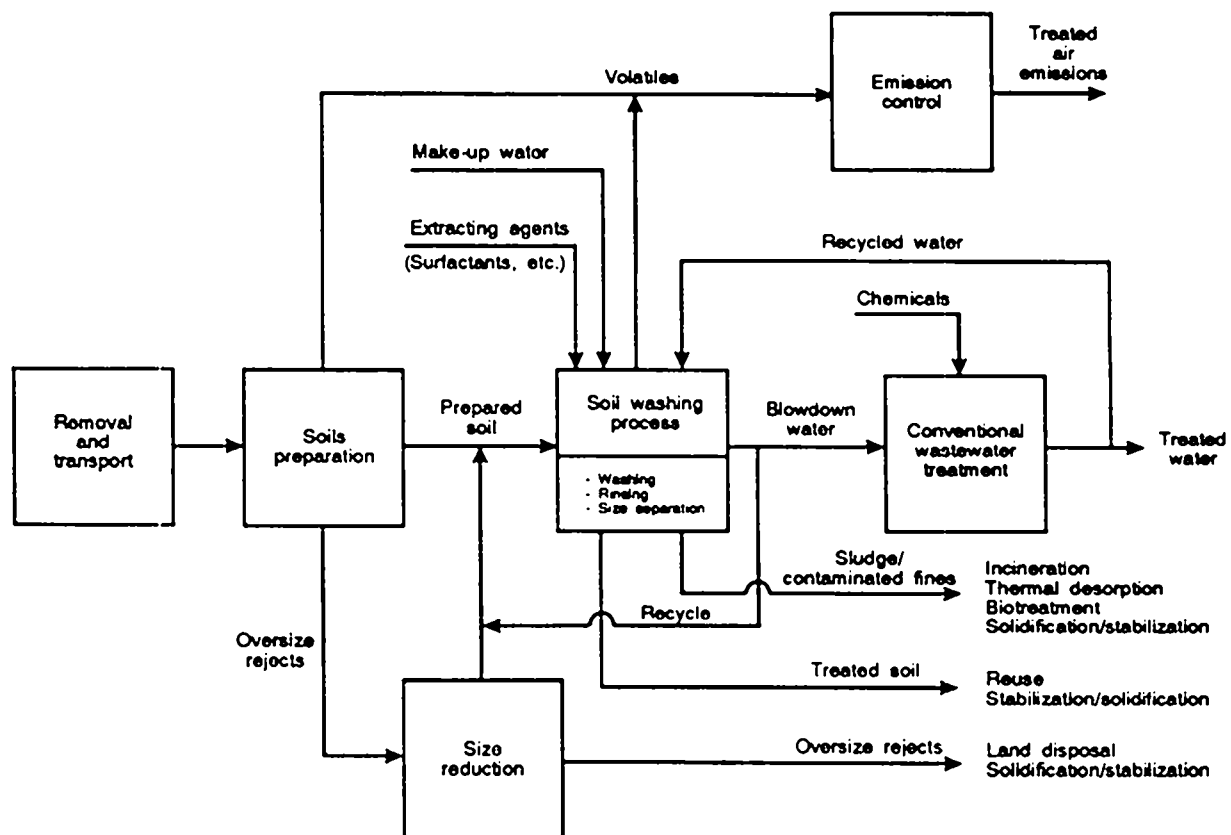
Figure 3-8. Aqueous soil washing [1].

TABLE 3-21. APPLICABILITY OF SEPARATION/CONCENTRATION OPTIONS

Group No.	Contaminant group	Separation/concentration options					
		In situ			Excavated soil		
		Soil vapor extraction	Steam extraction	Soil flushing	Soil washing	Solvent extraction	Thermal desorption
W02	Dioxins, furans, PCBs, and their precursors	O	O	◒	◒	◒	●
W03	Halogenated phenols, creosols, ethers, and thiols	◒	◒	◒	◒	◒	●
W07	Heterocyclics and simple non-halogenated aromatics	●	●	◒	●	●	●
W08	Polynuclear aromatics	●	◒	◒	◒	●	●
W09	Other polar organic compounds	●	◒	◒	◒	●	●
W10	Non-volatile metals	O	O	●	●	O	O
W11	Volatile metals	O	O	◒	●	O	●

● - Demonstrated effectiveness
◒ - Potential effectiveness
O - No expected effectiveness

Source: USEPA Engineering Bulletins

Critical fluid extraction uses solvents which are miscible with water at one temperature and insoluble with water at another temperature. Triethylamine is an example of a critical solution temperature solvent.

Supercritical fluid extraction uses highly compressed gases (CO_2, etc.), raised above their critical temperatures, to extract contaminants that generally resist extraction by conventional solvent. The highly compressed, gaseous fluid provides the additional diffusive/solvating power that is required to extract contaminants from hard-to-reach places in an environmental medium. Supercritical fluid extraction uses higher pressure and temperature than conventional solvent extraction. The process can also recycle and reuse the fluid.

Typical treatment combinations--Figure 3-9 provides a schematic diagram of the solvent extraction process. Solvent extraction generates three streams: concentrated contaminants, treated soil or sludge, and separated solvent. Concentrated contaminants may receive further treatment or proper disposal; the treated soil or sludge may require further drying. Depending on the metal content or other inorganic contaminants remaining, the cleaned solids may need treatment by some other technique such as stabilization/solidification. Analysis of the liquid component will determine whether further treatment is necessary before disposal.

TABLE 3-22. SOIL WASHING TREATABILITY TESTS

Site	Equipment	Feed	Results
Cape Fear Wood Preserving Site, Fayetteville, NC	BioTrol, Inc. soil washing treatability tests	Arsenic (289 ppm) Chromium (195 ppm) CPAHs (11.1 mg/kg)	90% of the original soil became clean sand; 10% (fines) required further treatment. Soil washing met cleanup goals [3].
Coleman-Evans Wood Preserving Co., Whitehouse, FL		PCP: 320 to 430 mg/kg, Chromium: 3.97 to 15.46 mg/kg Copper: 1.0 to 12.55 mg/kg	After washing, 96% of soil was recovered as clean, coarse fraction with PCP content below 4 mg/kg. The remaining 4% (fines) required further treatment.
The Coleman-Evans Site	Excalibur Enterprises, Inc. soil washing/catalytic ozone oxidation		Future SITE demonstration
MacGillis and Gibbs Site, New Brighton, MN	BioTrol Soil Washer (BSW) BioTrol, Inc. SITE Program pilot-scale treatment train consisting of soil washing, aqueous treatment, and slurry biodegradation (see bioremediation and aqueous biological treatment sections for other results)	130 and 680 ppm PCP 247 and 404 ppm TPAHs	14 and 87 ppm (89 and 87%) PCP respectively. 42 and 48 ppm (83 and 88%) TPAH respectively [4].
North Cavalcade Street, Houston, TX	BioTrol, Inc. treatability study of biotreatment and soil washing	PAHs	Showed excellent removal of both total and CPAHs from sand fraction [5].
South Cavalcade Street, Houston, TX		PAHs 3,747 mg/kg	Soil washing removed 77.7% PAHs from surface soil and over 99% PAHs from subsurface soil. Final concentration of total PAHs: surface – 836.6 mg/kg, subsurface – 23.6 mg/kg. Treated soil remained toxic [6].
Escambia Site, N. Palafox St., Pensacola, FL	USEPA Volume Reduction Unit (VRU) pilot-scale evaluation test program	PAHs: 1,200 to 2,500 mg/kg PCP: 150 mg/kg	PAHs reduced in the +100 mesh soil to less then 100 mg/kg; maximum removal of 96%. About 98% PCP removal [30].

TABLE 3-23. FACTORS AFFECTING SOIL WASHING PERFORMANCE

Factor	Potential effect
Clay content	Difficult contaminant removal.
Complex waste mixtures	Affect formulations of wash fluids, may require multiple process steps.
Humic content	Inhibits contaminant removal if high.
Metals concentration	Resists solubilization (insoluble metals). However, some metals can be solubilized and removed.
Particle size distribution	Affects removal from wash fluid (particles outside <0.063 mm or >2 mm difficult to treat; oversize debris requires removal).
Separation coefficient	Requires excessive leaching (highly-bound contaminant).
Wash solution	Difficult to recover or dispose.

Source: USEPA, 1988 [7].

Technology applicability--Solvent extraction is effective in treating sediment, sludge, and soil containing contaminants similar to wood preserving sites, e.g., halogenated phenols and creosols, simple nonhalogenated aromatics, PAHs, and other polar organic compounds. This technology generally does not resolve contamination by nonvolatile and volatile metals.

Technology status/performance--Three commercial vendors offer solvent extraction systems that have been tested at Superfund sites: the CF Systems Extraction System, the Basic Extractive Sludge Treatment (B.E.S.T.) System (Resource Conservation Company), and the Terra-Kleen Corp. System. The CF Systems process treated soil from a wood preserving site. Results of several treatability tests are shown in Table 3-24. The SITE Program demonstrated the Carver Greenfield Process (Dehydro-Tech Corp.) on Superfund waste in Edison, NJ.

Implementation costs--Cost estimates for solvent extraction range from $100 to $700/ton. The most significant factors influencing costs are the waste volume, the number of extraction stages, and the operating parameters such as labor, maintenance, setup, decontamination, demobilization, and time lost in equipment operating delays.

Data requirements--Table 3-25 helps identify the data needed to evaluate the system's performance.

Thermal Desorption--
Thermal desorption physically separates volatile and some semivolatile contaminants from excavated soil, sediment, and sludge. Thermal desorption uses ambient air, heat, and/or mechanical agitation to volatilize contaminants from soil into a gas stream for further treatment. Depending on the process selected,
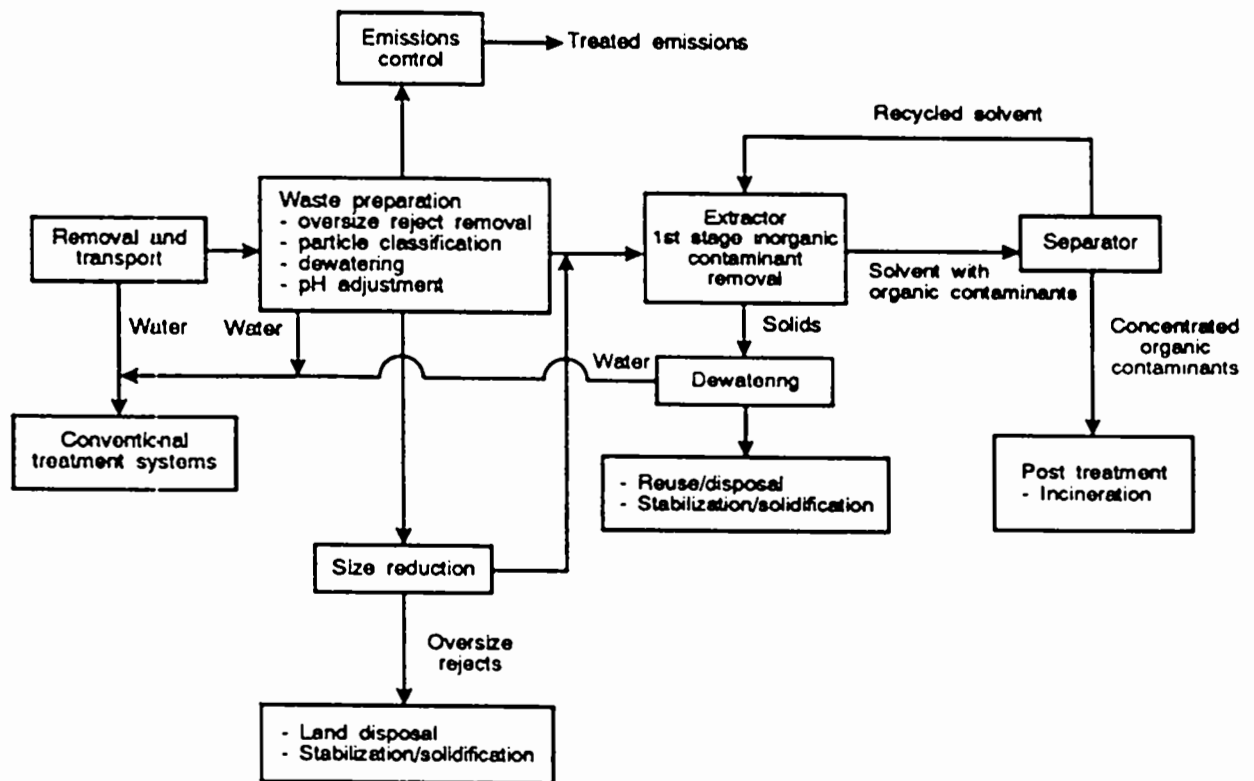
Figure 3-9. Solvent extraction process [8].

TABLE 3-24. SOLVENT EXTRACTION TREATABILITY TESTS

Site	Equipment	Feed	Results
Bayou Bonfouca Site, Slidell, LA	B.E.S.T. (pilot-scale) solvent extraction	SVOCs	Silty soil, >99% removal with 146 mg/kg residual TEA; clayey soil, >98% removal with 243 mg/kg residual TEA
	Sanivan Group Extraksol	PCBs, PCP, PAHs	SITE demonstration scheduled in 1992
Jennlson-Wright Corp., Granite City, IL	B.E.S.T. (pilot-scale)	Creosote, PCP	Achieved 97% removal of total SVOCs
Treban Site, Tulsa, OK	Terra-Kleen	PCB, PCP, creosote, naphthalene	PCB removal up to 99%
United Creosoting Co., Conroe, TX	CF Systems critical fluid extraction with propane	PCP, PAHs, dioxin/furan	Removal of 91% PCP, 98% PAHs, 72% dioxin/furan [9].
Pine Street Canal Site, Burlington, VT	B.E.S.T. (bench-scale)	CPAHs	TEA solvent: >99% removal, <1.5 ppm residual CPAH Propane solvent: 67.6 to 75.8% removal, 4.6 to 61 ppm residual

TABLE 3-25. FACTORS AFFECTING SOLVENT EXTRACTION PERFORMANCE

Factor	Potential effect
Complex waste mixtures	Affects solvent selected.
Metals	Resist removal.
Particle size	Affects solubilization. Particle size requirements vary with system from >1/8" to 2" diameter.
pH	Incompatible with extracting solvent.
Separation coefficient	Requires additional extraction steps (highly bound) contaminants.
Volatiles	Require additional extraction steps (high concentrations).

Source: USEPA (1988) [7]

this technology heats contaminated media to temperatures between 200° and 1,000°F, driving off water, volatile, and some semivolatile contaminants. Off-gases may be burned in an afterburner, condensed for disposal, or captured by carbon adsorption beds.

Typical treatment combinations--Thermal desorption systems create up to seven residual streams: treated media, oversized contaminated rejects, condensed contaminants, water, particulates, clean off-gas, and/or spent carbon. Debris and oversized rejects may be suitable for disposal on site. Depending on the residual content of nonvolatile heavy metals in the treated medium, solidification may be necessary. Condensed contaminants receive further treatment. Figure 3-10 is a schematic diagram of a thermal desorption process.

Technology applicability--Thermal desorption can successfully treat halogenated phenols and creosols as well as volatile nonhalogenated organic compounds at wood preserving sites. It cannot effectively separate from the contaminated media the nonvolatile metals (As, Cd, Pb, Zn) nor PAHs with boiling points above 1,000°F Mercury, a volatile metal, can be treated with some thermal desorption units. Bench-, pilot-, and full-scale studies have demonstrated that thermal desorption achieves treatment efficiencies of 99% or greater for VOCs, SVOCs, and PAHs. Some vendors can treat PCBs, pesticides, and dioxins/furans in contaminated solids [11,12].

Lime addition may tend to make contaminants bind more strongly, thus hindering thermal desorption. Alternatively, lime treatment may induce thermal desorption in wet wastes since the hydration of quicklime is highly exothermic and can elevate the waste temperature to the vicinity of 100°C. Lime addition for easier handling should be considered a bulking process; bulking is solidification without stabilization [13].

Technology status/performance--Commercial-scale, thermal desorption units are already in operation. The following treatability results (Table 3-26) suggest applications at wood preserving sites.

TABLE 3-26. THERMAL DESORPTION TREATABILITY TESTS

Site	Equipment	Feed	Results
Burlington Northern Superfund Site, Brainerd, MD	Pilot-scale thermal desorption	Creosote	>99.97% removal of SVOCs.
	Hazardous Waste Research and Information Center Thermal Desorption Study using IT Corp. desorber	Manufactured gas plant. PAHs: 400 to 2,000 ppm	TPAH concentrations ranged from 0.5 to 85 ppm.
Jennison-Wright Corp., Granite City, IL	ReTeC bench-scale thermal desorption	Creosote, PCP	Removals from 85 to 98%.
	Recycling Sciences International Thermal Desorption/Vapor Extraction Technique	Soil, sediment, sludge with PCB, PAH, PCP	Selected for SITE demonstration.
	Remediation Technologies, Inc. (ReTec)	PAHs: 1,321 to <0.1 ppm	2.5 to <0.1 ppm (82 to 99% removal). See Table 4-26 [14,15].
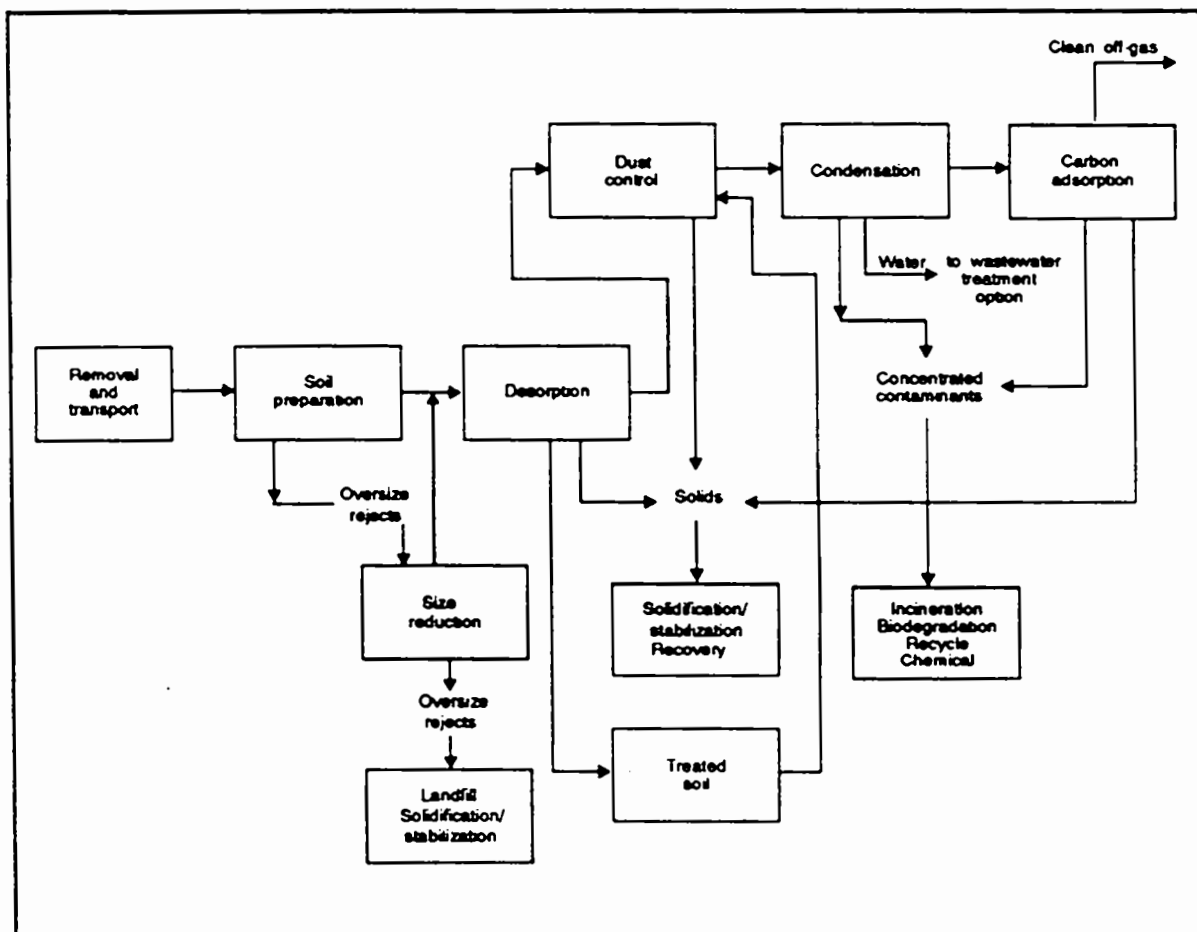
Figure 3-10.   Thermal desorption treatment [10].

TABLE 3-27. RETEC TREATMENT RESULTS ON CREOSOTE-CONTAMINATED CLAY

Compound	Original sample (ppm)	Treated sample (ppm)	Removal efficiency (%)
Naphthalene	1,321	<0.1	>99.9
Acenaphthylene	<0.1	<0.1	---
Acenaphthene	293	<0.1	>99.96
Fluorene	297	<0.1	>99.96
Phenanthrene	409	1.6	99.6
Anthracene	113	<0.1	>99.7
Fluoranthene	553	1.5	99.7
Pyrene	495	2.0	99.6
Benzo(b)anthracene	59	<0.1	>99.99
Chrysene	46	<0.1	>99.8
Benzo(b)fluoranthene	14	2.5	82.3
Benzo(k)fluoranthene	14	<0.1	>99.8
Benzo(a)pyrene	15	<0.1	>99.9
Dibenzo(ab)anthracene	<0.1	<0.1	---
Benzo(ghi)perylene	7	<0.1	>99.4
Indeno(123-cd)pyrene	3	<0.1	>99.3

Source: Ramin, 1990 [15].

Implementation costs--Several vendors have documented processing costs that range from $80 to $350 per ton of feed processed [15,16,17]. Costs must be considered in context because the base year of the estimates varies. Costs also differ due to the quantity of waste to be processed, the term of the remediation contract, the moisture content, the organic constituency of the contaminated medium, and the cleanup standards to be achieved.

Data requirements--Table 3-28 describes the factors affecting thermal desorption performance. Data requirements can be derived from these factors.

TABLE 3-28. FACTORS AFFECTING THERMAL DESORPTION

Factor	Potential effect
Clay content or tightly aggregated particles	Inadequately removes volatile contaminants.
Mercury content	Volatilizes.
Metals, inorganics, low volatile organics	Succeed with highly volatile organics (Henry's Law Constant $>3\times10^{-3}$ atm-m^3/mole).
Moisture content	Requires additional energy (high moisture content).
pH	Causes corrosion (outside 5 to 11 range).
Silt content	Causes high particulate loading.
Volatile organic content	Resists destruction (concentrations > 10%).

Source: USEPA, 1988 [7].

Description of In Situ Technologies

Steam Extraction--

Steam extraction physically separates volatile and semivolatile organics from soil, sediment, and sludge. The process uses a combination of thermal and mechanical energies generated by steam, hot air, infrared elements, and electrical systems to volatilize and transport the contaminants to the desorbed phase.

The extracted contaminants in the vapor phase can either be condensed and sent off site for further treatment, or destroyed in the vapor phase using a suitable technology. After passing through a carbon adsorber that removes trace quantities of organic contaminants, the noncondensibles in the vapor phase can vent to the atmosphere.

Typical treatment combinations--Steam extraction systems may be mobile or stationary. A mobile system injects steam through rotating cutter blades that disperse it through the contaminated medium. In a stationary system, steam flows through individual valves from the manifold to the injection wells. Recovery wells remove gases and liquids from the soil. The system then recovers the contaminants as condensed organics in the product water and on spent carbon. The water product is treated to remove any residual contaminants before disposal or reuse; the carbon can be regenerated or sent for proper disposal.

Technology applicability--Steam extraction is effective in removing the VOCs, such as nonhalogenated volatiles, often found at wood preserving sites. It may be effective for halogenated phenols and creosols, PAHs, and other polar organic compounds. A study of a mobile steam extraction system showed an 85% average removal efficiency for volatile contaminants [18].

Technology status/performance--Steam extraction is an emerging technology that appears promising, particularly if used in conjunction with SVE. However, only a limited number of commercial-scale systems are in operation.

SITE Demonstration Test - Western Research Institute

The CROW process developed by Western Research Institute involves an adaptation of a technology currently used for primary production of heavy oil and tar sand bitumen and for secondary petroleum recovery. Steam and hot water displacement move the accumulated oily wastes and water aboveground for treatment. This technology was tested at both the laboratory and pilot scales; it could apply to wood preserving sites contaminated with PCP and tar-like creosote [19]. The developer of the process has been invited to participate in the SITE Program to demonstrate the process at a Minnesota wood preserving site.

SITE Demonstration Test - Texarome, Inc.

Texarome, Inc. steam extraction system may remove PCBs, PCP, and creosote from soil, sludge, and sediment. The process has been accepted into the SITE Program.

Implementation costs--Estimates place costs for a stationary steam extraction system at about $50 to $300/yd^3, according to site characteristics [18]. For a mobile technology, a SITE demonstration reported costs of $111 to $317/yd^3 for 10-yd^3 and 3-yd^3 treatment rates, respectively (70% on-line efficiency). Cost estimates for this technology strongly depend on the treatment rate, which is a function of the soil type, the waste type, and the on-line process efficiency [20].

Data requirements--Table 3-29 illustrates important performance factors for steam extraction. Data for these factors should be collected.

TABLE 3-29. FACTORS AFFECTING STEAM EXTRACTION

Factor	Effect
Constituent vapor pressure	Affects removal efficiencies; requires vapor pressure curve for each pollutant.
Variable soil composition/consistency	Causes inconsistent removal rates.
Contaminant depth	Determines treatability volume.
Infiltration rate	Excessive rate hinders removal of organics.
Soil moisture content	Adds energy requirements for steam extraction.
Temperature	Inhibits volatilization (low temperature).

Soil Flushing--

Soil flushing extracts contaminants from soil with water or other suitable aqueous solutions. Soil flushing introduces extraction fluids into soil using an in situ injection or infiltration process (Figure 3-11). This method may apply to all types of soil contaminants. Soil flushing accomplishes permanent removal of contaminants from the soil; it proves most effective in permeable soils. The process must use an effective

collection system to prevent migration of contaminants and potentially toxic extraction fluids to uncontaminated areas of the aquifer. With bioremediation, soil flushing may make a cost-effective combination at certain sites. Typically, it is used in series with destruction treatments.

Typical treatment combinations--Depending on the contaminants, soil flushing can be a stand-alone treatment or part of a treatment system. Additional technologies treat the contaminated flushing fluid and groundwater to remove heavy metals, organics, and total suspended solids. Lime precipitation can remove metals; activated carbon, air stripping, or other appropriate technologies can remove organics. Wherever possible, treated water should recycle to the front end of the soil flushing process. The wastewater sludge and solids (such as spent carbon) require appropriate treatment before disposal.

Technology applicability--Depending on the type of flushing additive, in situ soil flushing can treat wood preserving site contaminants, such as halogenated phenols and creosols, simple non-halogenated aromatics, PAHs, other polar organic compounds, and nonvolatile and volatile metals [2].

Technology status/performance--Out of 29 RODs for wood preserving sites, 2 have selected in situ soil flushing. Soil flushing is an innovative technology with limited experience in the United States. Laboratory and site-specific treatability studies must precede selection as a treatment alternative. Some research/treatability test results are listed in Table 3-30.

TABLE 3-30. IN SITU SOIL FLUSHING TREATABILITY TESTS

Site	Equipment	Feed	Results
Laramie Tie Treating, WY	Waste-Tech Services, Inc.	93,000 mg/kg total extractable organics (TEO)	First test: 74% reduction of TEO to 24,000 mg/kg. Second test: 96% reduction to 40,000 mg/kg [21].
L.A. Clarke & Sons, Inc., Fredericksburg, VA	Waste-Tech Services, Inc. Alkali-polymer-surfactant (APS) formulation	Creosote	Pilot-scale test 80 to 85% removal of creosote [22].

Dworkin et al. [23] indicate that in situ soil flushing, in combination with a biodegradation process, can be a cost-effective means of remediating soil contaminated with creosote. Specifically, soil flushing may remove high concentrations of the PAHs associated with creosote contamination; the process train may then apply in situ biodegradation. This system of flushing/biodegradation could significantly reduce, or possibly eliminate, the health risks and environmental impacts associated with the migration of PAHs into groundwater and surface water.

Kuhn and Piontek [24] proposed using in situ soil flushing combined with biodegradation to remediate a contaminated wood preserving site. Screening tests determined that several combinations of alkaline agents, polymers, and surfactants might be effective for the specific site. They successfully predicted the degree of contaminant removal achievable with the combination. Laboratory testing removed 98 percent of the contaminants in core samples representing ideal field conditions. This program showed that in situ soil flushing followed by in situ biodegradation can be a cost-effective method of site remediation.

Implementation costs--Soil flushing costs are in the range of $50 to $120/yd^3 [25].
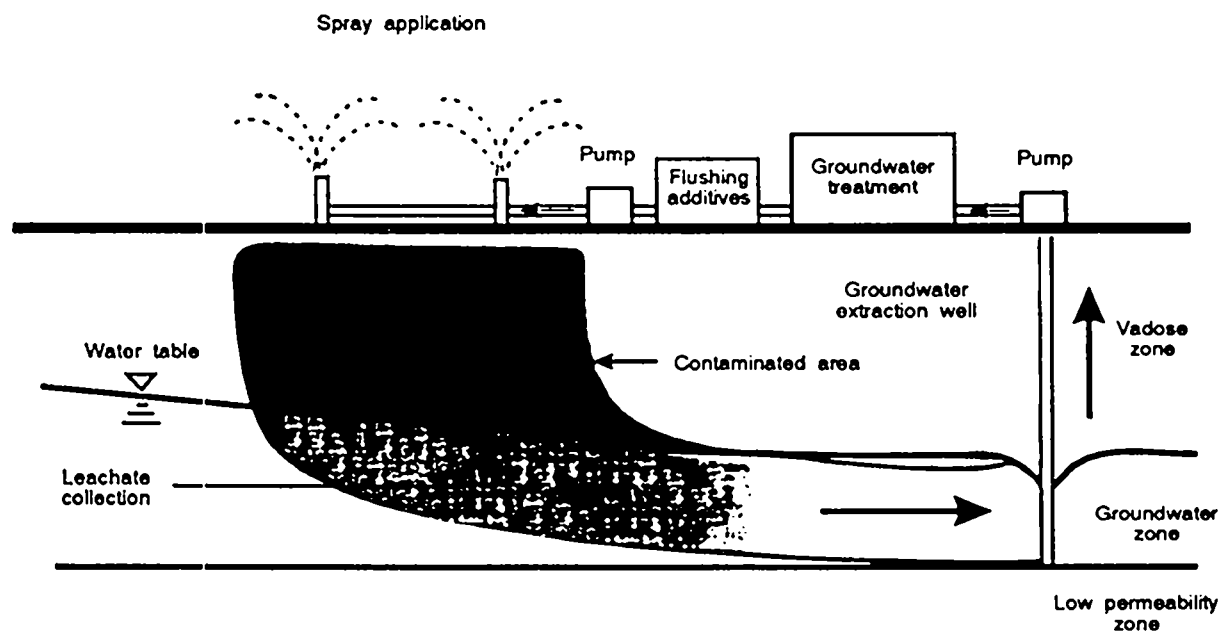
Figure 3-11.   Soil flushing [21].

Data requirements--Table 3-31 illustrates some important parameters affecting in situ soil flushing performance. These factors can provide a basis for determining data needs.

TABLE 3-31. FACTORS AFFECTING IN SITU SOIL FLUSHING

Factor	Effect
pH	Affects reagent requirements.
Heavy metals	May require pH adjustment (leaching) for removal.
Humic content	Inhibits desorption of contaminants.
Solubility data	Determines formula of suitable washing fluid.
Cation exchange capacity (CEC)	Measures clay fraction's ability to adsorb cations.
Site hydrogeology	Affects flow patterns that permit recapture of flushed contaminants.

Free Product Recovery--

A nonaqueous phase liquid (NAPL) is an immiscible liquid; it creates a physical interface with water. NAPLs are divided into two general categories: dense (DNAPLs), having a specific gravity greater than water; and light (LNAPLs), having a specific gravity less than water. Because of the behavior of wood preservative components, both DNAPLs and LNAPLs are likely to be found at sites contaminated with these compounds. The most common compounds associated with DNAPLs at wood preserving sites are creosote and PCP. DNAPL transport in the subsurface can be difficult to detect. Therefore, they are often overlooked during site characterization, but can have a significant effect on site remediation and technology selection.

DNAPLs may be present in the subsurface in various physical states or phases: gaseous, solid, water, and immiscible. In the unsaturated zone, the pore space may be filled with one or all three phases (gaseous, aqueous, immiscible). DNAPLs migrate downward by the force of gravity, and vertically as well as horizontally by soil capillarity [26]. Migration takes place until the DNAPL no longer is a continuous phase but has been dispersed into isolated globules. These globules slowly leach into groundwater over long periods of time and contaminate it. The fraction of the hydrocarbon that is retained in the porous media by capillary forces is called residual saturation.

Selection of site-specific remediation approaches requires site characterization of the subsurface. Characterization may include groundwater analysis to determine contamination from DNAPL, and physical and chemical analyses of the soil and aquifer material by exploratory borings to determine the type, phase, and location of the DNAPL. Cone penetrometer tests and soil-gas surveys can provide additional data.

NAPL compounds such as creosote may be recoverable if concentrations exceed their residual saturation. Normal recovery mechanisms consist of extraction wells and interceptor trenches/drains.

Extraction Wells--At wood preserving sites, extraction wells can capture contaminated groundwater or mobile NAPLs, which can be pumped to the surface for treatment. Proper well placement requires locating the contaminated groundwater plume or NAPLs in three-dimensional space, determining aquifer and chemical properties, designing a capture system, and installing the extraction, and in some cases, injection wells. Immobile NAPLs trapped in pore spaces by capillary forces may not readily flow to extraction wells. This residual saturation can become a significant source of miscible contamination. Unfortunately, a monitoring well water sample may not indicate residual NAPL because only the dissolved fraction travels in the water withdrawn from the well. The rate of NAPL dissolution limits its removal rate. Pump-and-treat removal may need the support of another remedial alternative that better addresses residual saturation (e.g., vacuum extraction) and/or hydraulic containment, such as interceptor trenches and drains [27].

Interceptor Trenches and Subsurface Drains--These buried conduits collect and convey liquids by gravity. Drains and trenches function like an infinite line of extraction wells. They create a continuous zone of influence in which groundwater flows by gravity toward the drain or trench. Trenches and drains contain or recover a plume, or lower the groundwater table to prevent contamination of groundwater/surface water. They usually drain to a collection sump where the NAPL is pumped to the surface.

For shallow contamination, drains may be more cost effective than extraction wells, particularly in strata with low or variable hydraulic conductivity. Under these conditions, it may be difficult to design wells, and cost-prohibitive to use a well-pumping system. However, subsurface drains can have higher operation and maintenance costs than pumping if sections of the trench system need excavation and replacement.

Soil Vapor Extraction--

SVE physically separates and concentrates VOCs dispersed in contaminated soil. It is an in situ technology that either injects hot air or fluid to force vapors out of the soil, or applies a vacuum to withdraw vapors from the soil. It then either condenses them for disposal off site or destroys them by a suitable technology.

Typical treatment combinations--SVE generates the following waste streams: vapor and liquid residuals, contaminated groundwater, and soil tailings from drilling the wells. The usual vapor treatments are carbon adsorption and thermal destruction. Other, less common, treatments include condensation, biological degradation, and ultraviolet oxidation. Contaminated groundwater can be treated and discharged. Highly contaminated soil tailings must be collected for treatment by another technology, such as incineration. Figure 3-12 shows a schematic diagram of SVE treatment.

Technology applicability--SVE has been effective in removing volatile organic compounds found at wood preserving sites, such as nonhalogenated volatiles. It may be effective for other wood preserving contaminants: semivolatile halogenated phenol and creosols, PAHs, and other polar organic compounds. Site-specific treatability studies are the only means of determining the applicability and performance of an SVE system. The process works best in well drained soil with low organic carbon content.

Technology status/performance--SVE is an accepted technology that has operated commercially for several years, although not yet at wood preserving sites where it may prove successful in conjunction with steam extraction.

Implementation costs--Typical costs for SVE treatment range from $10 to $150/ton [28]. Capital costs cover well construction, vacuum blowers, vapor and liquid treatment systems, pipes, fittings, and instrumentation. Operations and maintenance costs include labor, power, maintenance, and monitoring activities. Costs also vary according to site, soil, and contaminant characteristics.
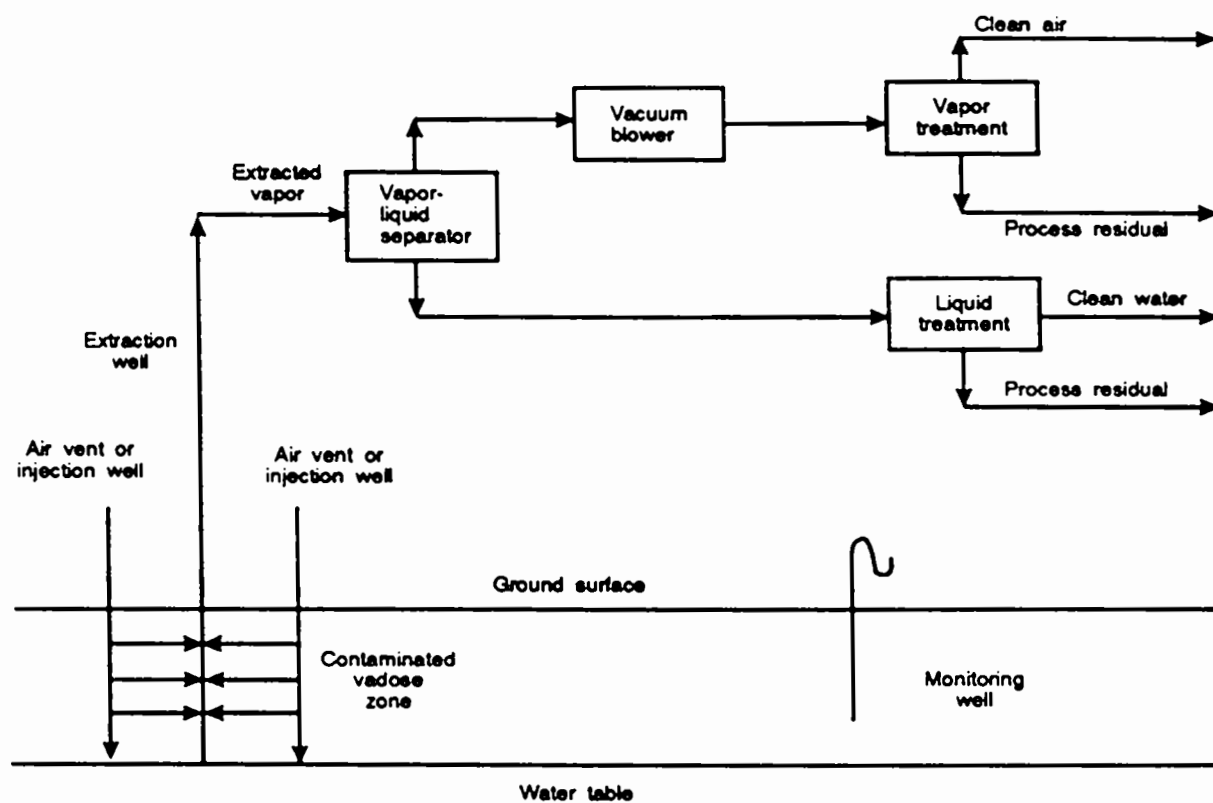
Figure 3-12. In situ soil vapor extraction [29].

WATER TREATMENT TECHNOLOGIES

Water treatment options address process wastewater, surface water, and groundwater at wood preserving sites.

Based on the site-specific contaminants and the selected remedies, process wastewater can require a range of treatment. The treatment of any surface water and remediation of groundwater may occur at the beginning, throughout or after the other remedial actions. Site-specific data will drive the selection of treatment options.

The future use of the site will also dictate the remedial methods to be selected for water treatment. There are basically two categories of treatment: Destruction technologies for organic contaminants and separation/concentration technologies that treat both organic and inorganic contaminants.

The technologies that treat wastewater, surface water, and groundwater at wood preserving sites are also appropriate to other types of sites. A brief overview is provided below. More detailed information is available in other USEPA documents listed in the bibliography.

Destruction Options	Separation/Concentration Options	
Chemical oxidation	Adsorption	Membrane separation
Dehalogenation	Filtration	Precipitation
Biological treatment	Ion exchange	Oil/water separation
	Air stripping	

Table 3-32 summarizes the water treatment options applicable to various contaminant groups found at wood preserving sites.

Destruction Technologies for Water Treatment

Chemical Oxidation--

This process oxidizes ions or compounds to render them nonhazardous or to make them more amenable to subsequent removal or destruction processes. It is most useful as a polishing step for dilute, relatively clean, aqueous wastes. The cost of chemicals, particularly for nonselective oxidation, limits the application of this technology to heavily contaminated wastes.

Chemical oxidants are relatively nonselective; they may oxidize other compounds in the waste prior to destroying the contaminants of concern. As a result, this process has limited application to waters with large amounts of oxidizable components.

Chemical oxidation primarily treats and/or destroys PCP, nonhalogenated aromatics, PAHs, other polar organic compounds, and nonvolatile and volatile metals found at wood preserving sites. Chemical/UV oxidation is a well-established disinfection technology for drinking water and wastewater. Enhanced systems now frequently treat hazardous streams [1]. Chemical/UV treatment technology at a wood preserving site is outlined below.

South Cavalcade Street, Houston, TX

Keystone Environmental Resources, Inc. carried out UV/ozone oxidation of oil- and grease-free site groundwater.

TABLE 3-32. APPLICABILITY OF WATER TREATMENT OPTIONS TO CONTAMINANT GROUPS

Group No.	Contaminant group	Water treatment options							
		Chemical oxidation	Dehalogenation	Biological treatment	In situ bioremediation	Adsorption	Ion exchange	Membrane filtration	Precipitation
W02	Dioxins/furans/PCBs and their precursors	◒	●	O	O	●	O	O	O
W03	Halogenated phenols, cresols, ethers, and thiols	●	●	◒	◒	●	O	●	O
W07	Heterocyclics and simple non-halogenated aromatics	●	O	●	●	●	O	◒	O
W08	Polynuclear aromatics	●	O	●	●	●	O	●	O
W09	Other polar organic compounds	●	O	●	●	●	O	●	O
W10	Non-volatile metals	●	O	O	O	◒	●	●	●
W11	Volatile metals	●	O	O	O	◒	●	●	●

● - Demonstrated effectiveness
◒ - Potential effectiveness
O - No expected effectiveness

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Contaminants in feed	Results
Phenol, PAHs	Levels declined by 98.4% and 52.5%, respectively. Lower molecular weight 2- and 3-ring PAHs showed greatest reduction [2].

Dehalogenation--

Dehalogenation uses chemical reagents to remove halogens from halogenated molecules, to break apart chlorinated molecules, or to change the molecular structure of the molecule. The process generally uses metallic sodium to strip the halogen away from constituents and form a sodium salt. Most dehalogenation research has centered on the detoxification of PCBs (analogous to PCP). This process applies to many other halogenated organic molecules, such as chlorinated pesticides and dioxins [3].

Biological Treatment--

Biological treatment of water, like soil biotreatment, detoxifies wastestream organic matter through microbial degradation. The most prevalent type is aerobic. A number of biological processes can treat water from wood preserving sites. These include conventional activated sludge techniques; various modifications of activated sludge techniques (e.g., those using pure-oxygen activated sludge, extended aeration, and contact stabilization); fixed-film systems (e.g., rotating biological discs and trickling filters); and in situ biological treatment.

- The activated sludge process introduces aqueous waste into a reactor containing a suspension of aerobic bacterial culture. The bacterial culture transforms organics into cell constituents, other organics, CO_2 and water. It also produces new bacterial cells.

- In the pure-oxygen activated sludge process, oxygen or oxygen-enriched air replaces ambient air and increases the transfer of oxygen.

- Extended aeration requires longer residence times and a higher population of microorganisms.

- Contact stabilization requires only short contact of the aqueous wastes and suspended microbial solids, with subsequent settling and further treatment to remove sorbed organics.

- Fixed-film systems require contact of the aqueous wastestream with microorganisms attached to some inert medium, such as rock or specially designed plastic material [4].

- Rotating biological contactors consist of a series of rotating discs connected by a shaft set in a basin or trough. The contaminated water passes through the basin where the microorganisms, attached to the discs, metabolize the organics in the water.

- In situ bioremediation of groundwater is becoming a frequently selected treatment for low-to-intermediate concentrations of organic contaminants. The addition of nutrients into an impacted aquifer, enhances the natural degradation of chemical compounds by indigenous microorganisms.

Technology status/performance--Several in situ bioremediation technologies have been demonstrated on a semi-commercial scale. However, they should be considered emerging technologies. Several fixed-film biological treatment processes have commercially treated wastewater. An example of bioremediation at a wood treating site is cited below:

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MacGillis and Gibbs Site, New Brighton, MN

BioTrol aqueous treatment system (BATS)
BioTrol, Inc. SITE Program pilot-scale treatment train consisting of soil washing, aqueous treatment, and slurry biodegradation.

Contaminants in feed	Results
14 mg/L PCP	1.3 mg/L PCP (91% removal)
44 mg/L PCP	3 mg/L PCP (94% removal) [5]

(See bioremediation and aqueous soil washing treatment sections of this document for additional detail.)

Separation/Concentration Technologies for Water Treatment

Adsorption--

In adsorption, one substance binds to the surface of another by physical and/or chemical means. In the adsorption process, contaminants transfer to the adsorbent, the most common of which are activated carbon and resins. The imbalance of forces in the pore walls of the adsorbent allow the contaminants to attach and concentrate. Once adsorption has occurred, the molecular forces in the pore walls stabilize. For further adsorption, regeneration of the adsorbent is necessary. Adsorption can effectively separate various contaminants from aqueous streams.

Adsorption, especially granular activated carbon (GAC) treatment, has removed PAHs, other polar organic compounds, PCP, non-halogenated aromatics, dioxins, furans, and some nonvolatile and volatile metals from water at wood preserving sites.

Koppers Co., Inc., Texarkana, TX

South Cavalcade Street, Houston, TX

Contaminants in feed	Results
PAHs	GAC successfully removed PAHs from groundwater.

Old Midland Products, Ala, AR

Contaminants in feed	Results
PCP	After processing groundwater through a 0.45 micron membrane filter, GAC removed 95% of the PCP. (Up to 19 mg of PCP were removed per gram of carbon.)

Filtration--

Filtration isolates solid particles by running a fluid stream through a porous medium. The driving force in filtration is either gravity or a pressure differential across the filtration medium. Filtration techniques

include separation by centrifugal force, vacuum, or high pressure. Therefore, filtration can separate various contaminant particulates from an aqueous stream.

Ion Exchange--

Ion exchange removes ions from the aqueous phase by the exchange of electrical charges between the contaminants and the exchange medium. Ion exchange materials may consist of resins made from synthetic organic materials that contain ionic functional groups to which exchangeable ions are attached. They may also be inorganic and natural polymeric materials. After the toxic materials have been removed, the resins can be regenerated for reuse.

Membrane Filtration--

Membrane filtration technologies, such as reverse osmosis and ultrafiltration, separate chemical constituents from water. Reverse osmosis (RO) is a pressure-driven, membrane-separation process. It does not destroy the chemicals; it merely concentrates them, making reclamation possible. RO is a low-energy process. It requires no phase change for separation of the dissolved materials, nor latent heat of vaporization, fusion, or sublimation. However, RO and ultrafiltration are very sensitive to the presence of fines that can clog the membranes. The membranes are also fragile; they often rupture from overpressure.

Reverse osmosis and ultrafiltration can treat groundwater contaminated with PCP, heterocyclics, simple nonhalogenated aromatics, PAHs, other polar organic compounds, some nonvolatile metals, and some volatile metals [6].

Precipitation--

This physical/chemical process transforms dissolved contaminant into an insoluble solid, facilitating the contaminant's subsequent removal from the liquid phase by sedimentation or filtration. The process usually employs adjustment of pH, addition of a chemical precipitant, and flocculation. Usually, metals precipitate from the solution as hydroxides, sulfides, or carbonates. The solubilities of the specific metal contaminants and the required cleanup standards will dictate the process to be employed.

Oil/Water Separation--

Oil/water separation removes oil from water by providing surface contact that de-emulsifies oil particles from the water phase. Oil/water separation is a frequent pretreatment for other processes.

Typical Treatment Combinations--

Table 3-33 presents typical treatment combinations for the remediation of water contaminated with wood preserving contaminants. The table includes pretreatment requirements and posttreatment/residuals management. It also relates the applicable media and wood preserving contaminant groups to a treatment train process.

Depending on the wastestream characteristics and the primary technology selected, the remedial combination may include pretreatment to remove free oils, using an oil/water separator, pH adjustment, addition of a chemical agent to enhance coagulation, flocculation, sedimentation, and removal of suspended solids by filtration. In case of biological treatment, the water may require heating to reach an optimum temperature, and the addition of inorganic nutrients.

The main process residual of an adsorption system is the spent sorbent holding the hazardous contaminants, which requires treatment or regeneration. As shown in Table 3-33, other water-treatment technologies such as filtration, ion exchange, chemical oxidation, precipitation, etc., produce contaminated

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TABLE 3-33. TYPICAL TREATMENT COMBINATIONS FOR WATER

Pretreatment/materials handling	Water treatment technology	Posttreatment/residuals management
Pumping Oil/water separator pH adjustment Flocculation/sedimentation Filtration	Chemical oxidation	Sludge treatment/disposal Oxidized products treatment/disposal
Pumping Oil/water separator pH adjustment Flocculation/sedimentation Filtration	Dehalogenation	Sludge treatment/disposal
Pumping, flow equalization Oil/water separator pH adjustment Flocculation/sedimentation	Biological treatment	Sludge treatment/disposal Polishing
Injection well/extraction Well installation Soil flushing Oil/water separator Nutrient addition pH adjustment	In situ bioremediation	
Pumping Oil/water separator pH adjustment Filtration	GAC treatment	Spent carbon disposal/regeneration Polishing treatment
Pumping Oil/water separator Filtration	Ion exchange	Regeneration of ion exchange resin Disposal of regeneration solution Sludge treatment/disposal
Pumping Oil/water separator pH adjustment Flocculation/sedimentation	Membrane filtration	Sludge treatment/disposal
Pumping Oil/water separator pH adjustment	Precipitation	Sludge treatment/disposal Polishing treatment

sludge, which also requires treatment prior to disposal. Depending on the contaminant, the treated water may need polishing by activated carbon or biological treatment.

Technology Status/Performance--

To date, 11 out of 29 RODs for wood preserving sites have selected granular activated carbon (GAC) treatment as an integral part of a remedial action. One wood preserving site selected ion exchange to treat groundwater contaminated with chromium. Two wood preserving sites contaminated with creosote wastes have selected chemical/UV oxidation. Three sites have chosen precipitation, fixed-film biological treatment, and in situ bioremediation, respectively.

Implementation Costs--

Table 3-34 summarizes the estimated treatment costs for water treatment technologies. Costs must be considered in project-specific context because the base years of the estimates vary. Wastestream flow rates, types of contaminant, toxic concentrations, and the desired cleanup standards make costs highly variable.

TABLE 3-34. WATER TREATMENT COSTS

Water treatment	Cost ($/1,000 gals treated)	Reference
Granular activated carbon	$0.48 to 2.52 $0.22 to 0.55	[7] [8]
Membrane filtration	$1.38 to $4.56	[9]
Ion exchange	$0.30 to 0.80[a]	[9]
Chemical/ultraviolet oxidation	$70 to 150	[1]
Precipitation	$0.07 to 0.28[b]	[9]
Fixed-film biological treatment	$50 to 90	

[a] 1987 dollars
[b] 1982 dollars

Data Requirements--

Table 3-35 summarizes data requirements for water-treatment technology options. The data requirements provide a basic guideline for the types of information required to remediate wood preserving sites.

TABLE 3-35. DATA REQUIREMENTS FOR WATER-TREATMENT TECHNOLOGY OPTIONS

Technology	Data needs		Possible effects
Granular activated carbon		Molecular weight	Loses efficiency with low molecular weight compounds.
		Polarity	High polarity compounds not recommended.
		Suspended solids	Can foul carbon (high suspended solids ≥ 50 mg/L).
		Oil and grease	May cause fouling of the carbon.
		Organic matter	Rapidly exhaust (high levels of organic matter, e.g., 1,000 mg/L).
Membrane filtration		Size of particles	May interfere with operation.
		Oil and grease	May interfere with the system.
		Contaminants	Succeed only with contaminant-specific membranes.
Ion exchange		Oil and grease	May clog resin.
		Suspended solids	May cause resin blinding (preferable limits ≤ 50 mg/L).
Dehalogenation		Oil and grease	May interfere with efficiency of the system.
		pH	May interfere with process operation.
		Suspended solids	May interfere with process operation.
Chemical oxidation		Oil and grease	Optimize the system efficiency (low levels).
		Concentration of contaminants	Proves too expensive for highly concentrated wastes.
Precipitation		pH	Can interfere with operation.
		Oil and grease	Can interfere with process.
In situ biological treatment	Physical	Moisture content	Inhibits bacterial activity (contents outside 40 to 80%)
		pH	Loses effectiveness beyond 4.5 to 8.5.
		Particle size	May interfere with process (nonuniform particle size).
		Water solubility	Hinder biodegradation (low).
		Oxygen availability	Limits oxygen rate.
		Temperature	Loses effectiveness outside temperature range 15 to 70°C.
	Chemical	Variable waste composition	Vary biological activity and cause inconsistent biodegradation

TABLE 3-35. (Continued)

Technology	Data needs		Possible effects
		Heavy metals, highly chlorinated organics, some pesticides, inorganic salts	Can be highly toxic to microorganisms.
		Nutrients (C, N, P)	Affects activity.
	Physical	Moisture content	Inhibits bacterial activity (content outside 40-80%).
	Biological	Biodegradability	Inhibits process.
	Soil characteristics	Permeability	Promotes movement of water and nutrients through contaminated area.
		Soil conditions	Vary biological activity and cause inconsistent biodegradation.
		Soil pH	Inhibits biological activity (pH <5.5).
		Organic content	Limits biological growth.
		Moisture content	Limits biological growth (content <10%).
		Site hydrology	Determines flow patterns that permit pumping for extraction and reinjection.
	Groundwater characteristics	Dissolved oxygen	Limits biological growth.
		pH, alkalinity	Inhibit biological activity.

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SECTION 4

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APPENDIX

TABLE A-1. CLEANUP GOALS AND TREATMENT TRAIN COMPARISONS AT NPL WOOD PRESERVING FACILITIES

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Region I Hocomonco Pond, Westborough, MA	RD	Soil	Creosote Phenol		Excavate/on-site landfill disposal
		Sediment	Creosote Phenol		Dewater/excavate/on-site landfill disposal
Pine Street Canal, Burlington, VT			Residual oil Wood chips saturated with organic compounds		
Region III Mid-Atlantic Wood Preservers, Harmans, MD	RA80	Soil	Cu Cr As	10 mg/kg	Excavate/off-site disposal in approved facility
		Soil	Cu Cr As		Off-site disposal
		Soil - As conc. > 10 mg/kg and < 100 mg/kg			Capping
		Groundwater	Cu Cr As		
Southern Maryland Wood Treating Corp., Hollywood, MD	RA82	Lagoon liquid	VOCs CPAHs BNAs		Spray irrigation.
		Lagoon sludge and freshwater pond sludge	VOCs CPAHs BNAs		Composit sludge and topsoil/spread on waste treatment area
	RD	Soil and sediment	VOCs CPAHs BNAs	2.2 ppm surface (1 ppm subsurface)	Excavate/on-site incineration/dispose ash on site

TABLE A-1. (Continued)

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Southern Maryland Wood Treating Corp., Hollywood, MD (cont.)	RD (cont.)	Surface water and groundwater	VOCs CPAHs BNAs		Slurry wall/pump and treat/ discharge on site
Havertown PCP Site, Havertown, PA	RA82 & 88	Storm water	PCP Cu Benzene Toluene	17 μg/L 5 μg/L	Containment
	RD	Soil			No action
		Surface water			Oil/water separator
		Drums	VOCs Phenols Dioxins PCP PAHs As Cr		Off-site land disposal
		Tank wastewater	VOCs PCP		Off-site treatment/disposal
L.A. Clarke & Sons, Inc. Fredericksburg, VA	RA82	Soil	Creosote CPAHs Benzene Heavy metals		Excavate/create RCRA-regulated soil waste pile
	RD	Subsurface soil	Creosote CPAHs Benzene Heavy metals	10.3 mg/kg (80 mg/kg TPAH) 94.03 μg/kg	In situ soil flushing/in situ biodegradation
		Lagoon sediment	Creosote CPAHs Benzene Heavy metals		Biological degradation
		Wetland sediment	Creosote CPAHs Benzene Heavy metals		Excavate/on-site landfarming

TABLE A-1. (Continued)

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
L.A. Clarke & Sons, Inc., Fredericksburg, VA (cont.)	RD (cont.)	Untreated soil/ sediment	Creosote CPAHs Benzene Heavy metals	0.08 mg/kg	Excavate/dredge/consolidate
Atlantic Wood Industries, Inc., Porstmouth, PA	RI/FS	Soil Sediment Tanks Groundwater	Creosote PCP		
Culpeper Wood Preservers, Inc., Culpeper, VA		Groundwater	As Cr		
Saunders Supply Co., Chuckatuck, VA	RA83	Soil	PCP CCA Pb		Excavate, off-site disposal in EPA-regulated landfill
	FS89	Groundwater	PCP Pb Cr As		
		Surface water	Cr		
	RA91	Sludge	Dioxins (TCDD equivalent)		Dechlorination
		Soil	PCP, As		Excavate, thermal desorption
Rentokil, Inc. (Virginia Wood Preserving Site), Richmond, VA	RI/FS	Surface soil	PAHs, As, dioxin, furans		
		Groundwater	PAHs, dioxins/furans, As, PCP		
		Surface water	As		
Sealand Ltd. and Oil Industry, Mount Pleasant, DE	RA83	Tanks - coal tar Drums Solid waste	PAHs Creosols Solvents Other toxic organic compounds		Removal to RCRA facility/cap (clay layer)

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Sealand Ltd. and Oil Industry, Mount Pleasant, DE (cont.)	RA83 (cont.)	Soil Tanks Drums	PAHs Creosols Solvents Other toxic organic compounds		
		Groundwater	Nickel Acenaphthalene		
Westline, PA	RD		VOCs Benzene	5 µg/L	No action, groundwater monitoring
Region IV American Creosote Works, Inc., Pensacola, FL	RA83	Waste ponds Pond sludge	Creosote Creosote		POTW Solidify/cap
	RD85	Solids, sludge, and sediment	Organics Dioxins CPAHs PCP		No action (on-site RCRA permitted landfill)
	RD89	Surface soil	Organics Dioxins CPAHs PCP	2.5 ppb for 2,3,7,8-TCDD toxicity (eq.) 50 ppm 30 ppm	Excavate/on-site bioremediation/on-site treated soil disposal
	RI/FS	Subsurface soil Sludge Groundwater		.	
Brown Wood Preserving, Live Oak, FL	RA88	Lagoon water, sludge and soil	Creosote PAHs		Remove/off-site disposal
		Lagoon water	PAHs Creosote	100 mg/kg of TPAHs	Pump/treat/discharge to POTW
		Severely contaminated soil and sludge	PAHs Creosote PCP	100 mg/kg 100 mg/kg	Excavate/off-site disposal

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Brown Wood Preserving, Live Oak, FL (cont.)	RA88 (cont.)	Less contaminated soil	PAHs Creosote		Excavate, on-site biodegradation/cover with clean fill
Coleman Evans Wood Preserving Co., Jacksonville, FL	RA80	Groundwater	PCP		Closed loop treatment
	RA85	Sludge	PCP		Excavate/soil washing/S/S
	RD	Soil and sediment (PCP conc. >10 mg/kg)	PCP	10 mg/kg	Excavate/on-site incineration/on-site disposal
		Groundwater with PCP concentration >1μg/L	PCP	1 μg/L	Pump/carbon adsorption/ discharge to on-site drainage ditch
Cape Fear Wood Preserving, Fayetteville, NC	RA77	Soil	Creosote		Remove/landfarming
	RA84	Soil and sludge			Excavate/off-site disposal
		Lagoon water			On-site storage
	RA86	Sludge			Excavate/solidification
		Wastewater	CCA		On-site storage
	RD	Drainage system solidified creosote	CCA salt crystals		Off-site disposal in RCRA landfill
		Soil	As Benzene Cr CPAHs TPAHs	94 mg/kg 0.005 mg/kg 88 mg/kg 2.5 mg/kg 100 mg/kg	Excavate/on-site soil flushing/on-site disposal; or thermal desorption/soil washing/on-site disposal; or S/S/on-site disposal
		Sediment	TPAHs As Cr	3.0 mg/kg 94 mg/kg 88 mg/kg	

TABLE A-1. (Continued)

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Cape Fear Wood Preserving, Fayetteville, NC	RD (cont.)	Groundwater	Benzene CPAHs PAHs	5 μg/L 10 μg/L 14,350 μg/L	Pump/on-site treatment/ POTW or surface stream
		Surface water	As Cr Cu	12 μg/L 11 μg/L 14 μg/L	Pump/on-site treatment/ POTW or surface stream
		CCA solution and wastewater			Sell CCA solution or on-site wastewater treatment
Koppers Co., Inc. (Morrisville Plant), Morrisville, NC	RA80 & 86	Lagoon soil	PCP		Remove, dispose in RCRA facility
		Soil Sediment Groundwater Surface water	PCP PCP PCP PCP		
Palmetto Wood Preserving, Cayce, SC	RA	Groundwater	As Cr Cu	50 mg/L 50 mg/L 1,000 mg/L	Pump and treat/discharge to off-site stream
		Soil	As Cr	200 mg/kg 627 mg/kg	Excavate/soil flushing/ backfill/acid ion exchange
Koppers Co., Inc. (Florence Plant), Florence, SC		Groundwater	Creosote PCP		
Gautier Oil Co., Inc.		Liquids and sludges	Phenol Naphthanlene Chloroform Anthracene Pb		
American Creosote Works, Inc. (Jackson Plant), Jackson, TN	RA83 RA86	Lagoon water Storage tanks	Creosote PCP		Pump and treat; storage oil/water on-site, stabilize soil/sludge; clay cap over lagoons

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
American Creosote Works, Inc., (Jackson Plant), Jackson, TN (cont.)	RD	Sludge Tank oil and sludge	VOCs PAHs Phenols		On- or off-site incineration
		Process liquid tanks	VOCs PAHs Phenols		On-site treatment/on-site stream discharge
		Diked water			Pump and treat/discharge pending
Newsom Brothers Old Reichold Site, Columbia, MS		Soil	PCP		Excavate/off-site disposal
		Wastewater	PCP		POTW
Koppers Co., Inc., Montgomery, AL					
Beazer Materials and Services, Florence, SC					
Region V Carter Lee Lumber Co., Indianapolis, IN		Soil	Phenanthrene Di-n-butylphthalate Fluoranthene Pyrene Benzo(a)anthracene Chrysene Benzo(b,k)fluoranthene Benzo(a)pyrene Indeno(1,2,3-cd) anthracene Benzo(g,h,i)perylene As Cr Cd		
Galesburg Koppers Co., Galesburg, IL	RD	Soil	Creosote PAHs PCP		Excavate/on-site bioremediation

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Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Galesburg Koppers Co., Galesburg, IL (cont.)	RD (cont.)	Groundwater	PAHs PCP		Pump and treat/POTW discharge
Reilly Tar & Chem., Corp. (Indianapolis Plant), Indianapolis, IN	RI/FS	Groundwater	Pyridine		
Boise Cascade/Onan Corp./ Medtronic, Inc., Fridley, MN		Groundwater	PAHs Phenolic compounds		Pump and treat
		Sediment	PAHs Phenolic compounds		
		Soil	PAHs Phenolic compounds		Excavate/off-site disposal
		Sludge	Creosote		
Burlington Northern (Brainerd/Baxter Plant), Brainerd/Baxter, MN	RA	Soil and sludge	PAHs Heterocycles Phenols	1,000 mg/kg	Excavate/landfarm/cap
		Groundwater	PAHs, CPAHs Heavy metals		No treatment - discharge to river
Joslyn Manufacturing and Supply Co., Brooklyn Center, MN	RA	Groundwater	PCP		Pump and treat/disposal
		Soil	CPAHs PCP	100 ppm 150 ppm	Excavate/on-site bioremediation/off-site disposal
MacGillis and Gibbs/Bell Lumber and Pole, New Brighton, MN	RI/FS	Groundwater	Creosote PCP CCA		Pump and treat
	RA	Soil	Creosote PCP CCA		Drummed/incineration

TABLE A-1. (Continued)

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Reilly Tar and Chem. Corp., St. Louis Park, MN	RA86	St. Louis Park Well (drinking water)	PAHs Phenol		Pump/well water/GAC treatment system
	RA	Groundwater	CPAHs PAHs Phenols	280 ng/L 280 ng/L	Monitor/pump & treat/POTW
		Exposed hazardous waste	PAHs Phenol		Cap and fill
Ritari Post and Pole, Sebeka, MN		Groundwater	PCP		
St. Regis Paper Co., Cass Lake, MN	RA86	Groundwater Surface water	Creosote PCP CCA PAHs		Pump and treat/surface discharge
		Soil	CCA PCP Creosote		Excavate/on-site storage
Reilly Tar and Chem. Corp. (Dover Plant), Dover, OH		Soil	Creosote		
		Groundwater	Creosote		Pump and treat
Moss-American Co., Inc., Kerr-McGee Oil Co., Milwaukee, WI	RA73	River sediment			Dredged
	RA77 & 78	Soil			Removed
	RD	Sediment and soil	Benzene Toluene Xylenes CPAHs Other organics	6.1 mg/kg	Reroute river channel, excavate/on-site soil washing/bioremediation/ on-site disposal/cap

TABLE A-1. (Continued)

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Moss-American Co., Inc.,· Kerr-McGee Oil Co., Milwaukee, WI (cont.)	RD (cont.)	Groundwater	Benzene Toluene Xylenes PAHs Other organics	0.067 μg/L 68.6 μg/L 124.0 μg/L	Membrane barrier/pump and treat/discharge to POTW or river
		Liquid waste			Off-site Incineration
Region VI Arkwood, Inc., Omaha, AR	RA	Soil	Dioxin PCP PAHs	0 μg/kg	Excavate/incinerate/ backfill/stabilization
		Groundwater	PCP		Natural attentuation
Mid-South Wood Products, Mena, AR	RA	Soils	PAHs PCP As Cr	3 mg/kg 5.6 mg/kg 19.4 mg/kg	Excavate/consolidate/cap
		Groundwater	PAHs PCP As Cr		Pump and treat/surface discharge
		Pond sludge or liquid	PAHs PCP As Cr		Stabilization/cap
Old Midland Products, Ola, AR	RA	Soil, sediment	CPAHs		Excavate/on-site incineration/ash disposal on-site/cap
		Sludge	PCP	1 ppm	Excavate/on-site incineration/ash disposal on-site/cap
		Groundwater, surface water	PCP PAHs	0.2 mg/L 28 ng/L	Collect/treat with carbon adsorption

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Bayou Bonfouca, Slidell, LA	RA85	Soil	Creosote PAHs		Excavate/off-site disposal
		Contaminated water			Off-site disposal
	RD	Soil, sediment	Total PAHs	100 mg/kg	Excavate/on-site incineration/on-site ash disposal/cap
		Groundwater	PAHs	100 μg/L	Pump and treat
Koppers Co., Inc., Texarkana, TX	RA	Soil, sediment	CPAHs PCP As Cr Cu Zn Benzene Toluene Xylene	100 mg/kg 83,000 mg/kg 2 mg/kg 1,500 mg/kg 111,000 mg/kg 633,000 mg/kg	Excavate/washing/disposal on-site; or excavate/washing/disposal off-site hazardous waste facility
		Groundwater	CPAHs PCP Benzene Toluene Xylene As Cr Cu	0.003 μg/L 2,000 μg/L 5 μg/L 220 μg/L 50 μg/L 50 μg/L 1,000 μg/L	Collection/treatment using oil/water separation/carbon adsorption/recycling NAPLs/ reinjection of treated groundwater; or collection/ treatment using oil/water separation/carbon adsorption/incineration of NAPLs off site, reinjection of treated groundwater
North Cavalcade Street Site, Houston, TX	RA	Soil, sediment	PAHs Benzene Toluene Xylene	1 mg/kg 0.04 mg/kg	In situ biological treatment

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
North Cavalcade Street Site, Houston, TX (cont.)	RA (cont.)	Groundwater	Benzene Toluene Xylene	5 μg/L 2,000 μg/L 440 μg/L	Pump and treat using oil/water separation/carbon adsorption/off-site incineration of NAPLs/reinjection/discharge into drainage ditch
South Cavalcade Street Site, Houston, TX	RA	Soil	PAHs Benzene Toluene Xylene As Cr Pb	700 mg/kg	In situ soil flushing. Excavate/soil washing/replace soil/cap
		Groundwater	Benzene Toluene Xylenes As Cr Pb PAHs	5 μg/L 28 μg/L 440 μg/L 50 μg/L 50 μg/L 50 μg/L 1 ng/L	Pump and treat using physical/chemical separation/pressure filtration/carbon adsorption/reinjection/off-site incineration or recycling of NAPLs
Texarkana Wood Preserving Co., Texarkana, TX	RA	Soil, sediment	TPAHs CPAHs PCP Dioxin	2,450 mg/kg 3 mg/kg 150 mg/kg 20 μg/kg	Excavate/on-site incineration/ash disposal on site/cap
		Sludge	PCP		
		Groundwater	CPAHs Dioxin PCP	0.001 μg/L 0.001 mg/L 10 μg/L	Pump and treat using carbon adsorption/reinjection into the aquifer
United Creosoting Co., Conroe, TX	RA83				Regrade contaminated soil, divert surface water/cap
	RA	Soil	PAHs PCP Dioxins Dibenzo furans	320 μg/kg 150 mg/kg 1 μg/kg 1 μg/kg	Excavate/critical fluid extraction/off-site incineration/disposal on site

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
United Creosoting Co., Conroe, TX (cont.)	RA (cont.)	Low organic concentrate			Off-site incineration/disposal on site
	RD	Soil			Excavate/consolidate/ temporary cap
Region VIII Broderick Wood Products Co., Denver CO	RD	Sludge and oil	PCP As Cd Pb Naphthalene Phenanthrene Pyrene Toluene Xylene	 7.98 mg/kg 7.98 mg/kg 7.28 mg/kg 0.143 mg/kg 0.162 mg/kg	Excavate/on-site incineration/off-site ash disposal
		Soil	PCP As Cd Pb Naphthalene Phenanthrene Pyrene Toluene Xylene	 7.98 mg/kg 7.98 mg/kg 7.28 mg/kg 0.143 mg/kg 0.162 mg/kg	Excavate/on-site incineration/off-site ash disposal; or if volume is large excavate/store on site
Burlington Northern Railroad (Somers Tie-Treating Plant), Somers, MT	RA85	Swamp pond sludge, soil and water	Creosote Metals		Remove/on-site landfarm

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Burlington Northern Railroad (Somers Tie-Treating Plant), Somers, MT (cont.)	RD	Soil	Creosote Metals CPAHs TPAHs Zn	3.6 mg/kg 1,875 mg/kg 15,750 mg/kg	Remove/off-site landfarm
		Sediment	TPAHs Zn	1,875 mg/kg 15,750 mg/kg	Remove/off-site landfarm
	.	Groundwater	Benzene CPAHs TPAHs Zn	5 μg/L 0.03 μg/L 0.3 μg/L 1,100 μg/L	In situ biological treatment/ flushing/UV oxidation/ reinjection
Idaho Pole Co., Bozeman, MT	RA84	Groundwater	PCP		Interceptor trench constructed
		Groundwater	PCP		
Libby Groundwater (Champion International Corp.), Libby, MT	RA86	Groundwater	VOCs Dioxin PAHs PCP As Oil		Upper aquifer - in situ bioremediation Lower aquifer - pump and treat (bioremediation)
		Soil - unsaturated	VOCs Dioxin PAHs		Excavate/consolidate/ bioremediation/landfarm/ cap
		Soil - saturated	PCP As Oil		In situ bioremediation/ recovered NAPL stored on site
Montana Pole and Treating, Butte, MT	RA86	Oil in groundwater	PCP Dioxin		Pump and treat
		Soil	PCP Dioxin		Excavate/containment
Baxter/Union Pacific Tie Treating, Laramie, WY	RD	Groundwater	Creosote PCP Oils		River realignment; slurry wall/pump and treat/ discharge to river

TABLE A-1. (Continued)

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Baxter/Union Pacific Tie Treating, Laramie, WY (cont.)	RD (cont.)	Soil	Creosote PCP Oils		Oil recovery/soil flushing/ bioreclamation
Region IX Coast Wood Preserving, Ukiah, CA	RA83	Soil, sediment	Cr Cu As		To be determined
		Groundwater	Cr Cu As		Pump and store on-site
J.H. Baxter Co., Weed, CA	RD	Soil	As Cr Cu Dioxin Furan CPAHs PCP Zn	8 ppm 500 ppm 2,500 ppm 0.001 ppm 0.001 ppm 0.51 ppm 17 ppm 5,000 ppm	Excavate/landfarm; or excavate/S/S
		Sediment	As Cr CPAHs PAHs PCP Zn	8 ppm 18 ppm 0.5 ppm 0.5 ppm 1 ppm 26 ppm	Excavate/treatment to be determined
		Groundwater	As Benzene Cr Cu Dioxin CPAHs PAHs PCP Zn	5 ppb 1 ppb 8 ppb 11 ppb 0.000025 ppb 5 ppb 5 ppb 2.2 ppb 90 ppb	Extraction/biological treatment/precipitation
		Surface water			Soil controls

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TABLE A-1. (Continued)

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Koppers Co., Inc., Oroville, CA	RA73				Groundwater pumping, discharge off site, off-site disposal of debris
	RA86				Alternate water supply to residents
	RA	Soil	TPAHs PCP As Cr Xylenes Cu PCDD/PCDF Metals	17 ppm 500 ppm 2,500 ppm 0.01 ppm	In situ biodegradation; excavate/soil washing/ redisposal on site/cap; Excavate/solidification/ on-site disposal
		Groundwater	TPAHs PCP As Cr Cu Xylene PCDD/PCDF	0.031 μg/L 220 μg/L 50 μg/L 50 μg/L 50 μg/L 1,750 μg/L 1.8 μg/L	Pump and treat using activated carbon/reinjection on site
Louisiana-Pacific Corp., Oroville, CA	RD	Soil	PCP PAHs Heavy metals		Controls
		Groundwater	PCP PAHs Heavy metals		Monitoring
Selma Pressure Treating Co., Selma, CA	RA	Soil	Dioxin As Phenols Cr	1 ng/g 50 mg/kg	Excavate/S/S/cap
		Groundwater	Dioxin Phenol As Cr	50 μg/L	Pump and treat/reinjection into aquifer

TABLE A-1. (Continued)

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Southern California Edison Co., (Visalia Poleyard), Visalia, CA	RA76	Soil	Dioxins/furans PCP Creosote		Excavate/landfill disposal
	RA77	Groundwater	PCP Creosote		Slurry wall/pump and treat using carbon filtration/discharge into sewer
	RA88	Groundwater	PCP Creosote		Pump and treat using filtration/discharge into nearby creek
Valley Wood Preserving, Inc., Turlock, CA	RA79	Soil	Cr Cu As		Excavate/off-site disposal
	RA80	Groundwater	Cr Cu As		Pump and treat/reinjection
Region X Joseph Forest Products, Joseph, OR		Soils	As Cr Cu		
American Crossarm and Conduit Co., Chehalis, WA	RA86	Soil, debris	Creosote PCP		Recovered and stored on site
	RA89	Soil, debris	Creosote PCP Dioxin		Incineration
		Sludge	PCP		S/S/landfill
		Groundwater	PCP		On-site water treatment
Wyckoff Co./Eagle Harbor, Bainbridge Island, WA	RI/FS	Soil, sediment, groundwater	Creosote		

RD   - Remedial Design   FS   - Feasibility Study
RI   - Remedial Investigation   RA   - Removal/Remedial Action

TABLE A-2. CLEANUP GOALS AND TREATMENT TRAIN COMPARISONS AT NON-NPL WOOD PRESERVING FACILITIES

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Region I Industrial Box and Lumber, Parson Field (Kezar Falls), ME		Soil	PCP		Drummed
Region II GCL Tie & Treating, NY			Creosote		Bioremediation (composting)
Region III Eager Beaver Lumber Co., Townville, PA		Soil Surface water	PCP Tetrachlorophenol Dioxin Xylene Lindane		Excavate/disposal
Belfield Avenue Site, Philadelphia, PA		Containers	PCP		Containment
National Wood Preserves, PA			PCP		
Region IV Brown Wood Preserving Co., Northport, AL			Not available		Water treatment
Escambia Wood, Pensacola, FL			Creosote		Water treatment
Lindsley Lumber, Dania, FL		Surface water Soil Groundwater	PCP Dioxin		On-site incineration
Augusta Wood Preserving Co., Augusta, GA			Cr Cu As		Soil removal/land disposal
Brunswick Wood Preserving, Brunswick, GA			PCP Creosote		Pump and treat, off-site disposal of chemicals
Dickerson Post Treating, Homeville, GA		Soil	Creosote PAHs		Excavate/landfill

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Dickerson Post Treating, Homeville, GA (cont.)		Liquid creosote	Creosote		Incinerated
Escambia Wood, Camilla, GA		Sludge	PCP		Stabilize/cap
		Wastewater	PCP		On-site wastewater treatment
American Creosote Works, Louisville, MS		Sludge	PCP Creosote		Solidification/cap
		Groundwater	PCP Creosote		Monitoring
Escambia Wood, Brookhaven, MS		Groundwater	Creosote PCP		Pump and treat/on-site discharge
		Chemicals	Creosote PCP		Off-site disposal
Hinds Wood Preserving Co., Learned, MS			Creosote		
Prentiss Creosote & Forest Products, Prentiss, MS	RA87	Lagoon water	Creosote PCP		Pump and treat on site
		Sludge	Creosote PCP		S/S
		Soil	Creosote PCP		Excavate
	RA88	Soil	Creosote PCP		On-site incineration
Southeastern Wood Preserving, Canton, MS	RA	Soil	PAHs Creosote PCP		Containment/soil washing/ bioremediation
Southern Lumber Company, Crosby, MS		Surface water	Creosote		On-site oil/water treatment

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Southern Lumber Company, Crosby, MS (cont.)		Sludge	Creosote PCPs Coal tar		Off-site incineration
Davenport Creosote, Pinetops, NC		Soil	Creosote Coal tar		Removal/disposal
Everhart Lumber Co., New Bern, NC		Soil	PCP		Excavate/disposal
		Surface water	PCP		Water treatment
Kellwood Timber Products, Hardeeville, SC		Wastewater tanks	CCA		Remove/recycle
		Sludge and soil	Pb CCA		Containment
Creosote Tanks/Tallyrand Road, Jacksonville, FL		Sediment	Creosote PCBs		Removal/solidification
Florida Steel, FL			Creosote		Incineration
Gulf State Creosote, Hattiesburg, MS			Creosote PCP		Bioremediation (landfarm)
Region V					
Jennison-Wright Corp. site, Granite City, IL			Creosote PCP		
Lake States Wood Preserving, Munishing, MI			PCP		
Region VI Mountain Pressure Pine Treating, Plainview, AR		Surface water	PCP CCA		Carbon bed treatment
		Surface soil	PCP CCA		Excavate/containment
		Sludge	PCP CCA		S/S/backfill/cap

TABLE A-2. (Continued)

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Mountain Pressure Pine Treating, Plainview, AR (cont.)		Liquid containers	PCP CCA		Off-site disposal
American Creosote, Winnfield, LA		Barrels	PAHs Dioxins/furans PCPs		Carbon filter/mixed bed gravity filtration
Springer Wood Treater, Springer, NM			PCP Creosote		Excavate/landfill
Scott Lumber, AR			Creosote		Bioremediation (landfarm)
Region VII Scott Lumber Co., Alton, MO	RA	Soil	CPAHs Creosote TPAHs Benzo(a)pyrene Coal tar	14 mg/kg 500 mg/kg	Excavate/bioremediation
Region VIII Beaver Wood Products, Columbia Falls, MT		Soil	PCP		Cap
Blackfeet Post & Pole, Browning, MT		Soil	PCP Dioxins/furans		On-site incineration
		Liquid	PCP Dioxins/furans		
Creston Post & Pole Yard, Kalispell, MT		Soil	PCP Dioxin		Cap
		Groundwater	PCP Dioxin		
Evans Post & Pole, Browning, MT		Soil	PCP		On-site incineration
Kalispell Pole & Timber Co., Kalispell, MT		Soil Groundwater	PCP Dioxin Heavy metals		Covered a seep

Site name	Status	Matrix	Contaminants	Cleanup goals	Technology
Larry's Post & Treating Co., Columbia Falls, MT		Soil	"Likely" PCP		Cap
Rocky Boy Post & Pole, Box Elder, MT		Soil	PCP Dioxin/furan Creosote TPAHs Chrysene	1 ppm surface < 10 ppm subsurface 1 ppb as 2,3,7,8-TCDD < 5 ppm < 50 ppm	On-site incineration
Whitewood Custom Treaters, Inc., Whitewood, SD		Soil	As Cr		Excavate/off-site disposal
Chippewa Pole, MT			Creosote PCP	.	Incineration
Region IX Marley Cooling Tower, Co., Stockton, CA		Soil Groundwater	Cr Cu As		
Region X Puget Sound Plywood, Eugene, OR					
Rangerfund II/Westfir, Westfir, OR			PCP		Solidification/drummed

RD   - Remedial Design   FS   - Feasibility Study
RI   - Remedial Investigation   RA   - Removal/Remedial Action

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