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Guide to Treatment Technologies for Hazardous Wastes at Superfund Sites

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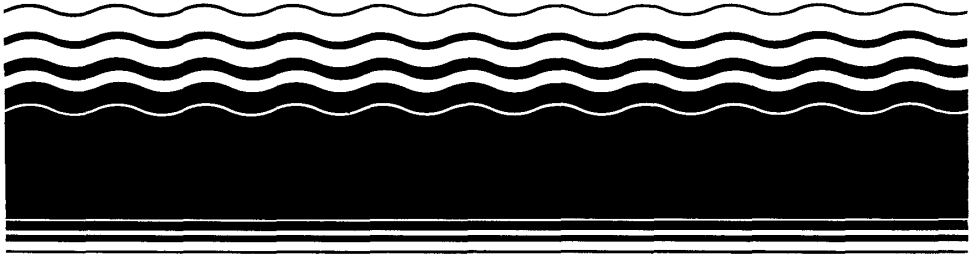

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Guide to Treatment Technologies for Hazardous Wastes at Superfund Sites

Office of Environmental Engineering and Technology Demonstration
U.S. Environmental Protection Agency
Washington, DC 20460

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Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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Introduction

Over the past few years, it has become increasingly evident that land disposal of hazardous wastes is at least only a temporary solution for much of the wastes present at Superfund sites. The need for more long-term, permanent treatment solutions as alternatives to land disposal has been stressed by recent legislation such as the Hazardous and Solid Waste Amendments of the Resource Conservation and Recovery Act (RCRA) as well as the Superfund Amendments and Reauthorization Act (SARA) of 1986. SARA directs the U.S. Environmental Protection Agency to establish an "Alternative or Innovative Treatment Technology Research and Demonstration Program," to identify promising technologies, assist with their evaluation, and promote the use of these technologies at Superfund sites.

This *Guide to Treatment Technologies for Hazardous Wastes at Superfund Sites* addresses alternative technologies that can be used to treat wastes at Superfund sites. This guide is designed for use by EPA Regional Offices, States, remedial contractors, and others to aid in the identification of alternative technologies that have been or are currently being developed. The alternative technologies presented in this guidebook are organized according to the method of treatment. These treatment methods comprise the following five sections of the alternative technologies table:

Section I: Biological Treatment. A treatment process in which bacteria, fungi, and/or microorganisms are used to alter or destroy hazardous waste. Liquid and soil wastes that can be treated by this method may include toxic chlorinated and aromatic organic compounds. The process is highly sensitive to environmental conditions, including fluctuations in pH and temperature, and to changes in the concentrations of heavy metals and salts in the waste stream.

Section II: Chemical Treatment. A treatment process in which the hazardous waste is altered by a chemical reaction in order to destroy the hazardous component. Wastes that can be treated by this method include both organic and inorganic compounds without heavy metals. Drawbacks to this method include the inhibition of the treatment process reaction by impurities in the waste and the potential generation of hazardous byproducts.

Section III: Physical Treatment. A treatment process in which the hazardous waste is separated from its carrier by various physical methods such as adsorption, distillation, filtration, etc. Physical treatment is applicable to a wide variety of wastes but further treatment is usually required.

Section IV: Stabilization, Solidification, and Encapsulation Treatment. A treatment process which isolates hazardous wastes from the surrounding environment without destroying the hazardous constituents. The treatment objective is normally achieved by mixing the waste with an inorganic compound such as fly ash, lime, clay, etc., to form a chemically and mechanically stable solid. The treated waste generally has higher strength, lower permeability, and lower leachability than the untreated waste. Stabilization/solidification/encapsulation treatment is applicable primarily to inorganic wastes containing heavy metals. Organic compounds often interfere with the setting action of the solidifying agent. There is no guarantee of the effectiveness of this method over time due to a lack of data on long-term leachability studies. This type of treatment may be feasible for use at sites with limited space or in emergency actions to alter the form of the waste to a more easily transportable form.

Section V: Thermal Treatment. A treatment process involving the decomposition of hazardous waste by thermal means into less hazardous or nonhazardous components. When subjected to high temperatures (2500-3000°F), organic wastes decompose to similar, less toxic forms. Complete combustion yields carbon dioxide and water plus small amounts of carbon monoxide, nitrous oxides, and chlorine and bromine acid gases. Some thermal processes produce off-gases and ash that require further treatment or landfill disposal. Thermal treatment is most suitable for organic wastes and is less effective when attempting to detoxify heavy metals and inorganic compounds. One drawback of thermal treatment is the high cost involved.

The alternative technologies are listed alphabetically under the five treatment methods. Each technology entry provides information concerning the type(s) of wastes to which the technology can be applied. The table also presents limitations and special use considerations for the particular alternative treatment technology (i.e., particle size restrictions, water-content limitations, heavy-metals-content limitations, etc.). The phase of development of the technology is also included in the table. The three phases of development for the alternative treatment technologies included in this guidebook are defined as follows:

1) *Available Alternative Technology*: a technology that is fully proven and in routine commercial or private use.

2) *Innovative Alternative Technology*: a technology for which cost or performance information is incomplete, thus hindering routine use at hazardous waste sites. An innovative alternative technology requires full-scale field testing before it is considered proven and available for routine use.

3) *Emerging Alternative Technology*: a technology that has not yet successfully passed laboratory or pilot-scale testing.

The table indicates whether or not the technology is transportable for use on site, and references are listed in the last column of the table to direct the reader to more detailed sources of information on the technology.

This guidebook is designed for use in the field as a guide to alternative technologies; it is not intended to serve as a reference source to identify the **best** available technology for treating a particular hazardous waste at a specific site. The mention of trade names or commercial products does not constitute their endorsement or recommendation for use by the U.S. Environmental Protection Agency.

Requests for copies of this document should be directed to the ORD Publications Office, Center for Environmental Research Information, Cincinnati, OH 45268, (513) 569-7562.

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I. BIOLOGICAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Activated Sludge	Soluble organics in dilute aqueous waste streams (< 1% suspended solids)	• BOD < 11,000 ppm • Requires low concentrations of heavy metals, PCBs, pesticides, oil, and grease • Output sludge contains heavy metals and refractory organics which require further treatment	A	X	1, 35, 58
Aerobic Treatment (sequential batch reactor, fluidized bed, fixed film fluidized bed with/without activated carbon, aerated biofilm reactor, membrane reactor)	Aqueous waste with low levels of nonhalogenated organics and certain halogenated organics (i e , phenols, formaldehyde, PCP)	• BOD < 10,000 ppm • Requires consistent, stable operating conditions	A	X	1, 2, 3, 5, 59
Anaerobic Treatment (fluidized bed, fixed film fluidized bed with/without activated carbon)	Aqueous slurry with low to moderate levels of non-chlorinated organic compounds containing < 7% solids	• Requires consistent, stable operating conditions • Unsuitable for oil and grease, aromatics, and long chain hydrocarbons • Output sludge requires incineration	A	X	1, 2, 3, 5, 62, 66
Bacteria	PCBs and various other organic compounds in soils (i e , 2,4,5-T and 2,4-D)	• May involve genetic engineering • Natural adaptation	A	X	6, 42, 54, 61, 62, 64, 65, 66

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I. BIOLOGICAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Composting	Aqueous sludge with < 50% solids, nonchlorinated hydrocarbons, high organic wastes including oils, tars, and industrial processing sludges	• Requires nutrient supplementations • Output sludge contains heavy metals	A	X	81, 82, 83, 84
Enzyme Treatment	Soluble organics in dilute aqueous waste streams	• Requires stable influent concentration	E	X	5, 41, 60, 61, 62, 65
Lagoons and Ponds	Industrial wastewater, organics with slow biodegradation potential, soluble organics in dilute aqueous waste streams	• Requires large area. • Unsuitable for solids • Requires a temperate climate • Output sludge contains heavy metals and refractory organics which require further treatment.	A		63, 66
Mycorrhizas	Soil-entrained hazardous waste constituents		E	X	77
Rotating Biological Contactor	Biodegradable dilute aqueous organic waste including solvents and halogenated organics	• Limited to low concentrations of heavy metals and concentrated refractory organics. • Unsuitable for sludges or solids.	A	X	1, 23, 24, 25, 40
Trickling Filter	Soluble organics in dilute aqueous waste streams with < 1% suspended solids including solvents and halogenated organics	• BOD < 5,000 ppm • Output sludge contains heavy metals and refractory organics which require further treatment	A	X	85

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I. BIOLOGICAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
White Rot Fungus *(Phanerochaete chrysosporium)*	Toxic or refractory halogenated organics in soil (i e , 2,3,7,8-TCDD, DDT, mirex, lindane, hexachlorobenzene)		E	X	1, 43, 56, 57, 60, 61, 62, 66, 68
Yeast Strains	Halogenated organics	• Involves genetic engineering	E	X	60, 61, 66

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II. CHEMICAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Chlorinolysis	Concentrated liquid chlorinated organic waste streams with low concentrations of sulfur and oxygen	• Unsuitable for solids and tars • Unsuitable for benzene and aromatics • Output carbon tetrachloride can be recovered	I		3, 50
Dehalogenation (including use of the Alkali Metal Polyethylene Glycol Reagent - APEG)	Halogenated organics in soils and sludges that are partially dehydrated (i.e., PCBs, dioxins)	• Requires heat and excess reagent	I	X	1, 2, 47
Electrochemical Dehalogenation	Halogenated organics (i.e., PCBs)	• Not known	E		22, 78
Electrolytic Oxidation	High concentration cyanide (10%) and metals wastes	• Suitable for low solid content waste	A		1, 2
Hydrolysis	Solids, soils, sludges, slurries, or liquids contaminated with organic compounds	• Requires careful handling of strong acids and alkalines • Reaction is performed at high temperatures and pressure requiring close monitoring	A	X	1, 2, 3
Ion Exchange	Aqueous organic or inorganic waste streams, principally metals	• Suitable for liquid waste only	A	X	1, 2, 5, 35
Lignin Adsorption	Aqueous organic or inorganic waste streams	• Not known	E	X	67

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TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Neutralization	Corrosive liquid wastes, both acids and bases	• Unsuitable for sludges and solids • Requires corrosion resistant equipment.	A	X	1, 2, 3, 35
Oxidation (chlorination, ozonation, hydrogen peroxide, potassium permanganate, chlorine dioxide, hypochlorites)	Dilute aqueous waste (< 1% waste) containing organic/inorganic compounds.	• Requires controlled reaction conditions. • Suitable for liquids and sludges only.	A	X	1, 2, 3, 5, 35, 50
Polymerization	Organic compounds such as aromatics, aliphatics, and oxygenated monomers.	• Application is limited to spills.	I	X	1, 2, 5
Precipitation	Aqueous organic and inorganic waste containing metals	• Requires optimization of the reaction pH for the specific mix of metals present • Output sludge requires further treatment. • Cross-reactivity may occur for mixed-metals content waste • Unsuitable for sludges, tars, and slurries	A	X	1, 2, 5, 35, 69, 70, 71

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II. CHEMICAL TREATMENT TECHNOLOGIES

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Reduction (Sulfur dioxide, sodium boro-hydride sulfite salts, ruthenium tetraoxide)	Dilute aqueous waste stream containing inorganic compounds, especially metals (< 1% heavy metal concentration)	• Applicable to inorganic waste only • Suitable for liquid waste only	I	X	1, 2, 3, 5, 35, 50
UV/Photolysis	Liquid waste containing dioxins	• Suitable for liquids only	E	X	1, 2, 5, 50

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III. PHYSICAL TREATMENT TECHNOLOGIES (COMPONENT SEPARATION)

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Air Flotation (dissolved or induced)	Liquid waste containing oils or light suspended solids	• Liquid effluent may require further treatment.	A	X	1
Centrifugation (bowl, basket, disk)	Organic/inorganic liquids, slurries, and sludges containing suspended or dissolved solids or liquids where one component is nonvolatile. For example, wastewater sludge, wastes containing immiscible liquids, or wastes containing three distinct phases	• Unsuitable for tars, solids, dry powders, or gases • Not applicable for small size or low density particles	A	X	1, 2, 7, 8, 9
FILTRATION:					
Belt Filter Press	Biological and industrial sludges	• Filter cake may require further treatment	A	X	1, 2, 8, 9, 11
Chamber Pressure Filtration (pressure leaf, tube element, plate and frame, horizontal plate)	Wastewater sludges, or sludges with a flocculated or adhesive nature.	• Dewatering technology • Unsuitable for sticky or gelatinous sludges	A	X	1, 8, 9, 11
Granular Media Filtration	Liquid waste containing suspended solids and/or oils	• Requires pretreatment for suspended solids with concentration < 100 mg/l • Requires frequent backwashing	A	X	1, 2, 3, 9, 11, 35
Vacuum Filtration (fixed media, rotary drum)	Organic or inorganic chemical sludges, metals, and cyanides bound up in hydroxide sludges	• Dewatering technology • Unsuitable for sticky or gelatinous sludges	A	X	2

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III. PHYSICAL TREATMENT TECHNOLOGIES (COMPONENT SEPARATION)

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Gravity Separation (coagulation, flocculation, sedimentation)	Liquid waste containing settleable suspended solids, oils, and/or grease	• Liquid effluent may require further treatment • Unsuitable for heavy slurries, sludges, or tars	A	X	1, 35
***In Situ* Soil Extraction**	Soils with low levels of organics or inorganics/metals contamination	• Unsuitable for dry or organic-rich soils	E	X	1, 2, 5

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III. PHYSICAL TREATMENT TECHNOLOGIES (PHASE SEPARATION)

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Air Stripping	Aqueous and adsorbed organic and inorganic wastes with relatively high volatility and low water solubility such as chlorinated organics, aromatics, and ammonia	• Limited to VOC concentration < 100 ppm • Suspended solids may clog tower	A	X	1, 2, 35, 50
Carbon Adsorption	Aqueous organic wastes (containing < 1% total organics and < 50 ppm solids) with high molecular weight and boiling point, and low water solubility, polarity, and ionization	• Unsuitable for metals • Unsuitable for oil and grease	A	X	1, 2, 5, 28, 29, 30, 31, 32, 35, 50
Colloidal Gas Aphrons (CGAs) (enhances air stripping and biodegradation)	Soils contaminated with phenols, phthalate esters, aromatic hydrocarbons, aliphatic hydrocarbons, chlorinated hydrocarbons, amines, and alcohols	• Hydraulic conductivity of the soil must be > 10^{-4} cm/sec	E	X	79, 80
Distillation	Liquid organic mixtures with low viscosity that can be separated due to molecular weight/volatility differences	• Unsuitable for thick polymeric materials, slurries, sludges, or tars	A	X	1, 2
Electrokinetics	Soils contaminated with organic or inorganic waste	• Soil matrix must be relatively permeable and saturated	I		1, 38, 49
Evaporation	Organic/inorganic liquid solvents contaminated with nonvolatile impurities (i.e., oils, grease, paint solvents, polymeric resins)	• Liquids must be volatile • Unsuitable for tars, solids, dry powders, or gases • Energy-intensive process	A	X	1, 2

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III. PHYSICAL TREATMENT TECHNOLOGIES (PHASE SEPARATION)

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Freeze Crystallization	Dilute aqueous organic/inorganic waste solutions containing < 10% total dissolved solids	• Unsuitable for foamy, viscous, or high solid content waste streams	E	X	86, 87, 88
Mechnical Soil Aeration	Volatile organics in sludge and soil	• Effluent may require further treatment	A	X	3
Metal Binding	Metal-contaminated aqueous waste streams, leachate, or groundwater.	• Limited to metal concentrations between 500-1000 ppm	E		1, 5, 10, 12, 21
Resin Adsorption	Aqueous waste streams containing soluble organics, particularly phenols and explosive materials	• Limited to low concentrations of organics (< 8%) and suspended solids (< 50 ppm)	A		35
Reverse Osmosis	Aqueous waste streams containing < 400 ppm heavy metals, high molecular weight organics, and dissolved gases	• Unsuitable for oxidants • Requires controlled pH, low concentration of suspended solids	I	X	1, 35, 73
Solvent Extraction	Aqueous stream contaminated with single- or multi-component dissolved organic wastes Sludge contaminated with oils, toxic organics, and heavy metals	• Extracting solvent must be immiscible in the liquid and differ in density so gravity separation is possible • Suitable for sludges containing < 20 wt % oil/organics and < 20 wt % solids	A, I	X	3, 17, 18, 20, 26, 50

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III. PHYSICAL TREATMENT TECHNOLOGIES (PHASE SEPARATION)

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Steam Stripping	Aqueous solutions of volatile organics	• Effluent may require further treatment • Suitable for waste streams with low metal concentration	A	X	1, 2, 19, 33, 34
Supercritical Extraction	Sludge, solids, or liquids contaminated with organics	• Effluent may require further treatment	E	X	1, 46, 51, 52
Ultrafiltration	Removes oils, metals, and proteins from aqueous solutions with dissolved organics, emulsions, and colloidal particles	• Limited to low concentrations of suspended solids	A	X	74, 75, 76

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IV. STABILIZATION/SOLIDIFICATION/ENCAPSULATION TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Cement-based Fixation	Treated sludges and soils containing metal cations, radioactive wastes, and solid organics (i.e., plastics, resins, tars)	• Long term stability/leachability is unknown • Lignite, silt, and clay increase setting time. • Dissolved sulfate salts, borates, and arsenates must be limited	A	X	1, 2, 3, 4, 27, 35, 48
Macro-Encapsulation, Overpacking, Thermoplastic and Thermosetting Techniques	Chemically or mechanically stabilized organic, inorganic, and radioactive wastes	• Encapsulating matrix must be compatible with waste • Long term leachability unknown, therefore, waste storage must be considered • Requires specialized equipment	A	X	2, 3, 4, 27, 35
Pozzolanic-based Fixation (fly ash, lime based)	Treated sludges and soils containing heavy metals, waste oils, solvents, and low level radioactive waste	• Borates, sulfates, and carbohydrates interfere with the process • Long term stability/leachability is unknown	A	X	1, 2, 3, 4, 27, 48
Sorptive Clays (treated, chemically modified)	Halogenated organic compounds and heavy metals	• Long term leaching is a problem, therefore, waste storage must be considered	I	X	1, 3, 4, 27, 35, 72
Vitrification	Soils contaminated with organic, inorganic, and radioactive wastes	• Limited to soils with high silica content	A, I	X	1, 2, 3, 27, 35, 44, 50

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V. THERMAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Electric Reactor	Soil contaminated with solid and liquid organics and inorganics	• Contaminated soil must be finely divided and dry	I	X	1, 2, 13, 16
Fixed Hearth	Bulky solids, liquids, and sludges	• Particle size must be large enough not to fall through grate	A		14, 15
Fluidized Bed	Organic solids, liquids, and sludges	• Requires low water and inert solid content	A	X	1, 2, 3, 14, 15, 35
Industrial Boiler	Granulated solids, liquids, and sludges	• Requires low chlorine and sulfur content • Ash content clogs system. • Small particle size	A		1, 2, 13, 14, 36
Industrial Kiln	Spent pot lining, nonhalogenated oils, and PCB-contaminated liquids and sludge	• Requires low chlorine and sulfur content	A		1, 2, 14
Infrared Incineration	Soils, solids, and sludges contaminated with chlorinated organic compounds (i e , PCBs, dioxins, explosives)	• Primarily for solid organic waste • Heavy metals are not fixed in ash	A	X	1, 2

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V. THERMAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Liquid Injection	Pumpable liquid organic waste	• Unsuitable for inorganic content and heavy metal content wastes • Chlorinated solvents cause accelerated corrosion rates	A	X	1, 2, 3, 14, 35
Molten Glass	Organic solids, liquids, gases, sludges (i.e., plastics, PCBs, asphalt, pesticides)	• Sodium sulfates must be limited to < 1% content • Inappropriate for soils and high ash content waste	I		1, 2, 16
Molten Salt	Low ash content waste, low water content liquid, or solid waste	• Corrosion problems • Requires frequent bed replacement	I	X	1, 2, 16
Multiple Hearth	Granulated solids, sludges, tars, liquids, and gaseous combustible waste	• Water, salt, and metal content must be limited • Particle size must be small enough to pass through injector nozzles • Not recommended for hazardous wastes	A		2, 3, 35
Plasma Systems	Liquid organic wastes (i.e., pesticides, dioxins, PCBs, halogenated organics)	• Liquids only		X	1, 2, 13, 16, 37
Pure Oxygen Burner	Liquid wastes which require high temperatures for destruction or have low heating values	• Requires specially engineered nozzles to atomize the liquid waste		X	16
Pyrolysis	Viscous liquids, sludges, solids, high ash content materials, salts and metals, and halogenated waste	• Requires homogeneous waste input • Metals and salts in the residue can be leachable		X	1, 2, 16, 50

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V. THERMAL TREATMENT TECHNOLOGIES

TECHNOLOGY	APPLICABLE CONTAMINANTS	QUALIFYING FACTORS	PHASE[1]	MOBILE[2]	REFERENCE
Radio Frequency Thermal Heating	Volatile, low boiling point, or easily decomposed organic compounds in soil	• Not known	I	X	2, 16, 50
Rotary Kiln	Solid, liquid, or gaseous organic waste	• Containerized wastes are difficult to handle • High inorganic salt or heavy metal content wastes require special consideration • Fine particulate matter must be limited	A	X	1, 2, 13, 14, 15, 35, 45
Supercritical Water Oxidation	Aqueous organic solution/slurry or mixed organic/inorganic waste	• Now known	I	X	1, 16, 39, 50
Wet Air Oxidation	Aqueous waste streams (< 5%) with dissolved or suspended volatile organic substances	• Unsuitable for solids, viscous liquids, or highly halogenated organic compounds • Not economical for dilute or concentrated waste	A	X	1, 16, 50

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