

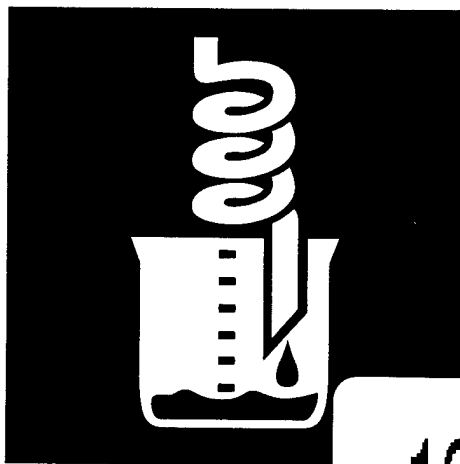


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Guidelines for Disposal of Lead-Based Paint Abatement Waste

by
Deborah Curtin



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The U.S. Army maintains more than 101 million sq ft of buildings that contain lead-based paint on their surfaces. Over 300 of the Army's elevated water storage tanks and hundreds of other concrete or steel structures are painted with red oxide primers. These lead-containing substances are often removed and disposed of during routine maintenance, or when the structures must be decommissioned or demolished. If the waste is not properly disposed of, the Army can be held liable for additional expenses under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), and human health may be compromised.

The U.S. Army Construction Engineering Research Laboratories (USACERL) continues to research the issue of lead disposal, to develop strategies for LBP management and disposal, and to determine the long-term fate of lead after disposal. A sound understanding of lead's fate in the environment will help Army managers make informed, environmentally sound decisions regarding the disposal of the potentially large quantity of lead-contaminated waste that the Army generates. This study gathered information on LBP abatement waste management options for demolition debris from structures contaminated with LBP and waste generated from specific abatement technologies, and authored guidelines for disposal of those wastes.

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The U.S. Army maintains more than 101 million sq ft of buildings that contain lead-based paint on their surfaces. Over 300 of the Army's elevated water storage tanks and hundreds of other concrete or steel structures are painted with red oxide primers. These lead-containing substances are often removed and disposed of during routine maintenance, or when the structures must be decommissioned or demolished. If the waste is not properly disposed of, the Army can be held liable for additional expenses under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), and human health may be compromised.

The U.S. Army Construction Engineering Research Laboratories (USACERL) continues to research the issue of lead disposal, to develop strategies for LBP management and disposal, and to determine the long-term fate of lead after disposal. A sound understanding of lead's fate in the environment will help Army managers make informed, environmentally sound decisions regarding the disposal of the potentially large quantity of lead-contaminated waste that the Army generates. This study gathered information on LBP abatement waste management options for demolition debris from structures contaminated with LBP and waste generated from specific abatement technologies, and authored guidelines for disposal of those wastes.

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Foreword

This study was conducted for the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE), under Project 4A162720A896, "Environmental Quality Technology"; Work Unit T06, "Lead-Based Paint Hazardous Waste Control Technology." The technical monitor was Malcolm McLeod, CECPW-ES.

The work was performed by the Troop Installation Operation Division (UL-T) of the Utilities and Industrial Operations Laboratory (UL), U.S. Army Construction Engineering Research Laboratories (USACERL). The USACERL principal investigator was Deborah R. Curtin. Part of this work was done by Science Applications International Corp., Reston, VA 20190 under contract No. DACA88-96-M-0127. Walter J. Mikucki is Chief, CECER-UL-T; John T. Bandy is Operations Chief, CECER-UL; and Gary W. Schanche is Chief, CECER-UL. The USACERL technical editor was William J. Wolfe, Technical Resources.

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1 Introduction

1.1 Background

The U.S. Army maintains more than 101 million sq ft of buildings that contain lead-based paint on their surfaces, and over 300 elevated water storage tanks and hundreds of other concrete or steel structures (bridges, equipment, and buildings) painted with red oxide primers. These lead-containing substances are often removed and disposed of in routine maintenance (e.g., repainting), or when the structures must be decommissioned or demolished. The U.S. Army is responsible for disposing of its LBP abatement waste in an environmentally responsible manner. If the waste is not properly disposed of, the Army can be held liable for additional expenses under the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), and human health may be compromised.

In response to federal regulations and guidelines, the Army published a Lead-Based Paint (LBP) Policy Guidance in 1993 mandating actions for the identification, management, and abatement of LBP and lead-contaminated dust. The U.S. Army Construction Engineering Research Laboratories (USACERL) continues to research the issue of lead disposal, to develop strategies for LBP management and disposal, and to determine the long-term fate of lead after disposal. A sound understanding of lead's fate in the environment will help Army managers make informed, environmentally sound decisions regarding the disposal of the potentially large quantity of lead-contaminated waste that the Army generates.

1.2 Objectives

The objectives of this study were to gather information on LBP abatement waste management options for demolition debris from structures contaminated with LBP and waste generated from specific abatement technologies, and to author guidelines for disposal of those wastes.

1.3 Approach

1. Science Applications International Corporation (SAIC) was contracted by USACERL to assist in developing guidelines for environmentally sound disposal methods for LBP abatement waste. The contract effort also involved conducting a comprehensive literature search to identify information on the migration of lead in the subsurface (Appendix A).

2. Regulations and requirements pertaining to LBP abatement and disposal were researched and reviewed (Chapter 2).
3. Current LBP abatement waste management strategies were reviewed (Chapter 3).
4. Guidelines were developed for disposal of LBP abatement wastes (Chapter 4).
5. State resources for LBP disposal and abatement regulations were researched and are summarized in Appendix B.
6. Information on commercial recyclers of LBP wastes was compiled, and is presented in Appendix C.

1.4 Definition of Terms

Hazardous Waste—solid waste which, if improperly managed, would pose a substantial present or future threat to human health or the environment. Hazardous waste is regulated by the U.S. Environmental Protection Agency (USEPA) under the Subtitle C of the Resource Conservation and Recovery Act (RCRA). A waste is characterized as hazardous if it meets the criteria of either:

1. A “characteristic” hazardous waste, based upon the fact that it is ignitable, corrosive, reactive, and/or toxic (as identified in 40 CFR 262, Subpart C); or
2. A “listed” hazardous waste such as those identified in 40 CFR 261, Subpart D.

Heterogeneous Waste Stream—Any total Waste Stream consisting of items, objects, components, materials, and/or areas that are dissimilar in composition, or that form a complex combination (e.g., an area designated as a Total Waste Stream that contains window frames, doors, bricks, cinder blocks, cement, steel or wood structural members, fiberglass insulation, etc.).

Homogenous Waste Stream—Any Total Waste Stream consisting of items, objects, components, materials, and/or areas that are alike or similar in composition (e.g., a drum containing LBP chips, paint sludge, and contaminated blasting grit), or that form a simple combination (e.g., windows and window frames or drywall and paint chips).

Lead-Based Paint (LBP)—Any paint containing lead levels in excess of regulatory limits, as follows:

1. Manufacture—When lead content is 0.06 percent by weight, per the Consumer Product Safety Commission.
2. Hazard Abatement—When lead content is 1.0 mg/cm² (milligrams per square centimeter) or 0.5 percent by weight, as measured by Atomic Absorption Spectrometry (A.A.S.) or by use of a spectrum x-ray fluorescence (XRF) analyzer.
3. Waste Disposal—When lead concentration exceeds regulatory limits for disposal, i.e., 35 mg/L (milligrams per liter) or 35 ppm (parts per million) as

measured by the Toxicity Characteristic Leaching Procedure (TCLP). Wastes exceeding such limits are designated as hazardous waste.

LBP-Contaminated Waste Stream—A total waste stream that includes any item, object, or structure containing concentrations of lead in paint 31.0 mg/cm² or 30.5 percent by weight as measured by laboratory test.

Nonhazardous Waste—A solid waste that neither exhibits the characteristics of a hazardous waste identified in 40 CFR 261 (Subpart C), nor is it identified as a "listed" hazard in 40 CFR 261 (Subpart D). The handling and disposal of nonhazardous wastes are regulated by the USEPA under Subtitle D of RCRA.

Representative Sample—A sample that will show the average value of the universe or whole (i.e., total waste stream that is being sampled).

Solid Debris—Any item such as old woodwork, plaster, windows, doors, and similar bulky components, or combination thereof.

Solid Waste—Any solid or liquid forms of household trash, discarded industrial materials, refuse from mining operations, etc. Handling and disposal of solid waste is regulated by the USEPA under Subtitle D of RCRA.

Special Waste—Solid waste that is not hazardous, but requires handling other than normally used for municipal solid waste. Regulations for the handling of special waste are set forth in 40 CFR 240.101.

Total Waste Stream—The entire object, series, or "universe" thereof slated for demolition and/or disposal (i.e., all of the solid waste plus all of the hazardous waste).

1.5 Mode of Technology Transfer

It is recommended that the results of this study be incorporated into a Public Works Technical Bulletin (PWTB) for distribution to Army installations through the U.S. Army Center for Public Works (USACPW), Alexandria, VA.

2 Regulations and Requirements

2.1 Residential Lead-Based Paint Hazard Reduction Act

The Residential Lead-Based Paint Hazard Reduction Act of 1992 (Title X of the Housing and Community Development Act of 1992), addresses the need to control exposure to LBP hazards. Title K makes the Federal government subject to the same stringent LBP laws and regulations as nongovernment entities, including requirements for certification, licensing, and recordkeeping, whether the law is Federal, State, or local. To permit effective enforcement of this statute, the United States has waived its immunity from lawsuits, subjecting the Federal government to all remedies provided for in the violated Federal, State, or local law. Title X also federally mandated the USEPA, the Occupational Safety and Health Administration (OSHA), and the Department of Housing and Urban Development (HUD) to issue lead regulations. These agencies issued a final rule establishing Requirements for Disclosure of Known Lead-Based Paint and/or Lead-Based Paint Hazards in Housing on 6 March 1996 (FR 61, No. 45, p 9063).

2.2 Resource Conservation and Recovery Act

RCRA establishes a comprehensive Federal program to regulate the handling of solid wastes. RCRA Subtitle C creates a cradle-to-grave regulatory structure for the treatment, storage, and disposal of hazardous waste. Subtitle D governs the disposal of nonhazardous waste.

Waste generated when removing lead-based paint may be subject to the RCRA, Subtitle C hazardous waste regulations. Under these regulations, waste generators are required to determine if the waste generated is hazardous by either testing a representative sample (in accordance with 40 CFR part 261 Subpart C, or an equivalent method), or by applying knowledge of the hazard characteristics of the waste in light of the materials or process used. LBP debris is subject to evaluation against the RCRA hazardous waste characteristics, primarily the toxicity characteristic. If the extract from a representative sample of the LBP debris contains lead at the concentration equal to or greater than 5.0 mg/L (ppm) when tested with the TCLP, the waste is hazardous for toxicity characteristics of lead.

The regulations conditionally exempt small quantity generators of 100 kg or less hazardous waste per month. However it is unlikely that waste generated during lead abatement work on large buildings would generate less than 100 kg, whether or not the waste is a hazardous waste. If the waste is classified as hazardous, it must be transported by a RCRA-permitted transporter to a RCRA-permitted treatment, storage, and disposal facility. If the waste is determined

not to be a hazardous waste, it is not as stringently regulated and is regulated under Subtitle D of RCRA.

2.3 Land Disposal Restrictions

The Land Disposal Restrictions of the Hazardous and Solid Waste Amendment (40 CFR 268.35) prohibit disposal of any hazardous waste in landfills, unless it has been treated to the levels specified in the standards.

2.4 Comprehensive Environmental Response, Compensation, and Liability Act

Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) regulations contain notification requirements when toxic hazardous waste is released into the environment. These requirements apply to releases of more than 1 lb of LBP debris (if considered hazardous waste) and to particles less than 4 mm in diameter.

2.5 Occupational Safety and Health

The Occupational Safety and Health Administration (OSHA), has established standards to regulate occupational exposures to lead. The standards (29 CFR 1926.62 and 29 CFR 1910.1025) specify measures to protect workers against hazardous exposure to lead in construction and general industry, respectively. The OSHA Lead Standards established an action level of 30 micrograms per cubic meter ($\mu\text{g}/\text{m}^3$) of air and a permissible exposure limit of 50 $\mu\text{g}/\text{m}^3$ of air. The standards also include requirements for exposure monitoring, engineering, work practice and administrative controls, respiratory protection, protective clothing, housekeeping and hygiene, medical surveillance, employee training, and hazard communication.

3 LBP Abatement Waste Management Strategies

3.1 Management and Disposal of LBP Waste

One key decision that an installation developing a LBP abatement strategy must make concerns the disposal of LBP abatement wastes. A basic step in the process is to determine what LBP-contaminated waste streams will be generated as a result of the work required and to characterize the potential waste streams as either hazardous or nonhazardous waste. Environmentally sound and cost effective disposal options for these wastes can then be selected and evaluated. Installation managers will also need to determine disposal requirements established by the appropriate State and local agencies. There are considerable variations in requirements for LBP abatement and disposal depending on the State, and these variations will impact the decision to select an abatement strategy and approach for waste management. Installations should contact the State and local government agencies for updated information on these requirements. Appendix B lists contacts for state agencies with responsibilities for LBP waste disposal.

An integrated LBP waste management strategy should involve an ordered hierarchy of waste management options including source reduction, recycling, treatment, and landfill disposal. The Army will be responsible for disposal of a potentially large quantity of lead-contaminated waste, including construction and demolition (CD) debris and LBP abatement wastes generated from managing and abating LBP hazards at Army installations. Because CD debris containing LBP already exists in the form of whole structures awaiting demolition, the method to achieve source reduction is generally limited to effective waste identification and segregation. Recycling CD debris containing LBP, and on- and off-site treatment of hazardous waste generated from LBP abatement should also be considered. The following sections describe disposal options for CD debris and abatement wastes from LBP abatement projects.

3.2 Construction Debris

Construction and Demolition Debris refers to materials generated as a result of construction, renovation, and/or demolition projects. Metals, wood, asphalt, concrete, rubble, soil, paper, plastics, and glass are among the many substances that can be considered CD debris. Construction activities that generate CD debris can generally be divided into five categories. Table 1 lists CD debris components most commonly associated with each category of construction and demolition activities.

Table 1. Typical components of CD debris.

Project Category	Typical Components
Construction	Mixed rubble, wood, roofing, wall board, insulation, carpet, pipe, plastic, paper, bricks
Demolition	Mixed rubble, concrete, steel beams, bricks, wood, pipes
Excavation	Earth, and, stones, wood
Roadwork	Asphalt, concrete, earth
Site clearance	Trees, brush, earth, concrete, mixed rubble, sand, steel, paper•

Recycling is a waste management strategy with significant potential for management of nonhazardous CD debris. The economic advantages of recycling whole structures have been demonstrated,* but the recycling option depends on the identification of markets for end-use products and the stability of these markets. USACERL is performing research to investigate concepts for the reutilization of construction materials and other post-consumer materials by means of recycling into new components that will be useful in construction, or by direct salvage and re-use without substantial alteration or reprocessing (USACERL 1995). To reduce the amounts of CD debris disposed of in landfills, installations should recycle CD debris when feasible. Appendix C provides a listing of recyclers of metal-bearing wastes that may be able to provide recycling services and technical assistance for recycling LBP wastes including CD debris.

The approach used to manage CD waste will depend on the quantities and characteristics of the waste, i.e., whether the waste is hazardous or nonhazardous. The general approach for management of nonhazardous CD debris includes the following:

- Identify nonhazardous debris through screening and quantification.
- Segregate debris into recyclable and nonrecyclable materials, including:
 - wood
 - metal
 - concrete, brick, cinder block, stone, glass, plaster, sheetrock, tile, asphalt roofing materials
 - other.
- Identify markets for recycling for each type of debris category based on feasibility and availability of cost-effective, reliable processing facilities.
- Dispose of CD debris in a Subtitle D facility if other options are not feasible.

*Personal communication from Christopher Sweet, SAIC, to Carl Alvers, Resource and Recycling Program Manager (31 July 1995).

The approach for management of CD debris contaminated with LBP and determined to be hazardous includes the following:

- Minimize the volume of hazardous debris through segregation and testing.
- If the volume of debris is small, select an extraction or destruction treatment, or another technology appropriate to the contaminated matrix. Test treated debris with TCLP. Dispose of treated debris that exceeds the TCLP standard for lead or other hazardous compounds in Subtitle C facility.
- Evaluate the feasibility of reuse management options such as cement kilns or metal recovery (secondary smelters) for large volumes of hazardous CD debris.
- Dispose of CD debris in a Subtitle C facility if other options are not feasible.

For some demolition projects, other approaches may be effective to reduce the volume of waste to be disposed. The Air Force has published findings of research conducted to evaluate an alternative to basic landfill disposal of construction debris. The 37th Civil Engineering Squadron of the U.S. Air Force at Lackland Air Force Base, in partnership with the Texas Natural Conservation Commission, conducted a pilot study to demonstrate the feasibility of demolishing and mechanically grinding building materials containing lead-based paint. The tub grinding of CD debris was proven to significantly reduce the volume of material to be landfilled. The grinding method evaluated indicated that the grinding process results in a substantial cost savings over the traditional "knock down, haul-off" demolition technologies used by the Air Force for demolition and disposal of similarly constructed facilities. A recommendation was made to continue to research recycling options for the resultant material to establish potential markets (U.S. Air Force 1995). Based on developments in the marketplace for CD recycling, recycling of some CD may also be feasible without segregating debris into categories (Woods 1996).

Secondary lead smelting of lead-containing waste may also be an option for appropriate projects. The process has been demonstrated to reclaim lead from a variety of solid materials, including rubber battery case material, lead dross, iron shot abrasive blasting material, and wood from demolition of houses coated with lead paint. The technology is applicable to solid wastes containing more than 2 percent lead, provided that they do not contain excessive amounts of calcium, silica, aluminum, or other similar constituents (USEPA 1994).

3.3 Wastes Generated From Abatement Technologies

The abatement technologies identified by USACERL for inclusion in this project have been proven to be effective in abating LBP, including:

- abrasive blasting (open and closed)
- wet abrasive blast cleaning
- high pressure water jetting
- high pressure water jetting with abrasive injection

- hand tool cleaning
- power tool cleaning
- chemical stripping
- combination of methods.

When abatement is selected to manage LBP hazards, significant amounts of waste and debris will be generated. This waste may include paint chips, abrasive media, wash waters, dust-containing lead, contaminated cleaning supplies, disposable cleaning equipment and clothing, plastic used for abatement containment, and filter products. The abatement technology for a specific project must be selected based on an assessment of the cost-effectiveness, efficiency, and amount of waste generated. Table 2 and the following sections present information on the performance characteristics and the wastes generated using the various abatement technologies.

Table 2. Comparison of characteristics of abatement technologies

Type of Lead Paint Removal System	Performance Characteristics		Substrate Viability	Effective Applications
	Advantages	Disadvantages		
Open Abrasive Blasting with containment	Removals all lead based paint and prepares surfaces for new coating simultaneously; fastest cleaning system available; can be used on a variety of projects ranging in size and structure; newer systems can recycle grit and contain some dust; used extensively in large scale industrial applications	Worker training is required; generates high levels of lead dust inside containment; expensive system to operate; all waste including spent grit may fail Toxic Characteristic Leachate Procedure and have to be disposed of as hazardous waste	Fastest system available for metal, concrete, cement and brick structures cleaning	Preferred system for steel bridges, water towers, marine vessels, planes, and on large scale concrete, cement or brick cleaning industrial projects.
Wet Abrasive Blasting with containment	Functions the same as abrasive blasting but utilizes liquid usually water mixed in with grit; controls dust emissions with water; can produce higher velocities with water	Flash rusting; may not be applicable to all the same projects as abrasive blasting because of the water supply; may increase hazardous waste disposal; may be difficult to contain water waste on large projects; worker training; expensive system	Fastest system available for metal, concrete, cement and brick structures cleaning	Steel bridges, water towers, marine vessels, planes, and on large scale concrete, cement or brick cleaning industrial projects

Type of Lead Paint Removal System	Performance Characteristics		Substrate Viability	Effective Applications
	Advantages	Disadvantages		
High Pressure Water jetting with containment	Utilizes streams of water under pressure to clean surface coatings; low dust emissions; can remove coatings from most surfaces; system can be used on materials that cannot tolerate abrasive grit	Massive amounts of water limit the systems use; may increase hazardous waste cost; water Containment problems; worker training required; slower than abrasive blasting	Metal, concrete, cement and brick structures cleaning	Steel bridges, water towers, marine vessels, planes, and on large scale concrete, cement or brick cleaning industrial projects
High pressure Water Jetting with cleaning abrasive with containment	Utilizes stream of water and cleaning abrasive under pressure to clean surface coatings; low dust emissions; can remove coatings from most surfaces; system can be used on materials that cannot tolerate abrasive grit	Need for large amounts of water limit the system use; may increase hazardous waste cost; water containment problems; worker training; slower than abrasive blasting	Metal, concrete, cement and brick structures cleaning	Steel bridges, water towers, marine vessels, planes, and on large scale concrete, cement or brick cleaning industrial projects
Hand tool cleaning with containment	Utilizes smaller hand tools to clean lead-based paint coatings; ideal for small operations and maintenance projects; necessary for cleaning hard to reach corners and edges; good system for preserving substrate integrity; good emission control	Labor intensive; could cause contamination problems if used improperly Not applicable to large projects	Slow deliberate system, good for use on small metal wood, plastic or special substrate projects or for projects where other systems are not available	Small scale residential or commercial applications
Power tool cleaning with containment	Faster than using hand tools slower than abrasive blasting; uses power tools to clean lead-based paint coatings; ideal for operations and maintenance projects and some large scale projects; necessary for cleaning hard to reach corners and edges; good emission control if used along with vacuum systems Hazardous waste amounts control	Not applicable in every application; new equipment may not be reliable Vacuum system captures most debris but not all; worker training; labor intensive	Metal, concrete, cement and brick structures cleaning	Steel bridges, water towers, marine vessels, planes, and on large scale concrete, cement or brick cleaning industrial projects Small scale residential or commercial applications

Type of Lead Paint Removal System	Performance Characteristics		Substrate Viability	Effective Applications
	Advantages	Disadvantages		
Chemical Stripping	Utilizes chemicals to loosen paint from substrate. Hand tools may be required to remove the paint after chemical treatment; no lead emissions; can be done on-site or off-site; most effective for historic structures. Containment may not be necessary.	Not applicable in every application; chemicals may damage substrates; wrong chemical could create mixed hazardous waste (toxic and ignitable); worker training; labor intensive; chemical exposure may be more hazardous than lead paint.	Removal chemicals exist for most substrates.	Can be used for most applications; chemical specific for substrate.
Combination of Methods	May be most cost effective means for removing LBP; may be necessary for surface preparation; can be used to lower amount of hazardous waste and dust emissions; may be required on complex projects with multiple substrates with varying levels of coating.	May involve more than one service contractor; may be slower than choosing one method; may cost more with multiple preparations.	All substrates.	Applicable to complex projects with multiple substrates and requirements.

Abrasive Blasting (Open and Closed)

Abrasive blasting is a widely used and very effective method for removing paint and other coatings from industrial structures like bridges, water towers, and communication towers. However, mineral abrasive blasting media can only be used once because, as soon as the abrasive strikes the surface being cleaned, the abrasive particles become rounded. The abrasive blasting process requires the collection and disposal of large quantities of spent abrasive that is intermingled and contaminated with a comparatively small quantity of removed LBP. For LBP, current USEPA regulations require not only that the blasting site be contained to avoid environmental contamination, but also that the spent, contaminated abrasive be disposed of as a hazardous waste.

Open abrasive blasting is very effective in removing old coatings, scale, and other particulate matter (oils, greases, environmental matter, etc.), preparing the surface for a new coating, and improving the substrate surface by smoothing out imperfections. Containment of the blasting material is necessary with this technology to prevent the removed material from being released into the environment. Closed abrasive blasting systems are designed to remove coatings

and other surface materials by abrasive blasting, and to collect and recover the spent abrasive and coating debris simultaneously (NRC 1992).

When considering an abrasive blasting system, several items should be evaluated. First, the type of coating and substrate material should be identified. Certain abrasive materials (grit) impact surfaces at different speeds and with different forces and some grit may bend and break. The desired surface will also influence the selection of abrasive. The Steel Structures and Painting Council (SSPC) has developed standards that refer to methods of performance of abrasive blasting. The standards describe grit size and relative surface profile provided by the abrasive grit (SSPC 1991). Table 3 lists several types of abrasive blast materials and different substrates on which the abrasive can be used (SSPC 1991). The amount of waste generated and the ability to treat or recycle the abrasive should also be considered.

An alternative treatment method for blast media that has been shown to be effective is the use of chemical stabilizer admixtures. The blast media is modified by the addition of the admixture before blasting. The additive chemically stabilizes the lead and permits conventional landfilling of the waste in a Subtitle D or permitted construction debris landfill (USACERL 1996).

Wet Abrasive Blast Cleaning

Wet abrasive blasting is similar to abrasive blasting with the exception that water is used along with abrasive grit. Wet blasting provides two benefits over dry blasting: (1) dust levels are reduced by the water, and (2) higher velocities can be achieved when using water. Wet systems add water to the abrasive blast material creating a mixture that is used as the blasting media. Water can be added directly to the abrasive material creating a slurry type of abrasive material, or water can be added to the system at the nozzle. In wet systems, waste debris is washed away by the wet abrasive mixture. Centrifugal systems use blades rotating at high speed to propel abrasive material against the surface to be cleaned. These systems also have the capability of recovering abrasive material and waste and are appropriate for use on flat, horizontal, or vertical surfaces. Cavitation systems use high pressure water in which bubbles are caused to form in the water jet. When the bubbles impact the coated surface, they collapse and create high pressure reversals that cause the coating to erode.

Table 3. Applications for types of abrasive blast media.

Types of Abrasive Media	Applications
Sand	Metals, concrete, brick, cement
Steel shot	Metals, concrete, brick, cement
Iron grit	Metals, concrete, brick, cement
Glass beads	Some metals, concrete, brick, cement
Crushed walnut shells	Some metals, concrete, brick, cement
Plastic beads	Some softer metals
Garnet	Metals, concrete, brick, cement
Ice	Some metals, concrete, brick, cement
Sodium bicarbonate	Some metals, concrete, cement

High Pressure Water Jetting

High Pressure Wet Jetting systems use the sheer force of water to remove surfacing material from the substrate. Typically water must be kept at or above 20,000 psi to be effective.

High Pressure Wet Jetting systems are effective at removing surfacing materials and coatings from a variety of hard substrates. These systems do not release as much dust as abrasive systems, but are much slower than abrasive blasting, and require that wastewater be contained for disposal. This system is also applicable to flat surfaces (NRC 1992).

High Pressure Water Jetting With Abrasive Injection

High Pressure Wet Jetting with abrasive systems use the sheer force of water to remove surfacing material from the substrate. Typically, water must be kept at or above 10,000 psi to be effective. High Pressure Wet Jetting with abrasive systems are effective at removing surfacing materials and coatings from a variety of hard substrates. These systems do not release as much dust as open abrasive systems, but are typically slower.

Hand Tool Cleaning

Hand tool cleaning refers to the use of hand tools like scrapers, wire brushes, and razor scrapers to remove lead-based paint. These tools are an important category of lead paint removal tools because they can be applied in all situations. Even on large projects, hand tools may be necessary to clean corners or edges that other tools cannot reach. Working with these tools is labor intensive, and is most effective on small projects in which the original components were going to be saved or have some historic value. Relatively small quantities of LBP wastes are produced using this abatement method. Often workers will combine wet methods with hand tools to prevent exposure to lead dust.

Power Tool Cleaning

Power tool cleaning refers to several types of categories including but not limited to: needle gun, grinders and roto-peen devices, wet sander and a number of tools that have assisted power. Use of these tools would allow workers to clean lead-based paint from surfaces much faster than using hand tools. Many power tools have been designed to accommodate vacuum recovery systems to control waste and dust generation.

Needle guns are devices that use single or multiple reciprocating needles powered to move at speeds high enough to fracture paint into fragments and free it from the underlying substrate. Most are specifically designed for surface preparation. One manufacturer created a "dustless" needle gun specifically for lead paint removal projects. The company states that this device can be used without building a containment enclosure because of its vacuum attachment. This device reduces that amount of hazardous waste generated because the

device can be adjusted to only remove paint and little or no substrate (SSPC 1991).

Grinders and roto-peen devices are also commonly used to remove lead-based paint. Grinders refer to any devices using grinding to remove the coating from a substrate. Roto-peen devices function like grinders and needle guns. Star like pins are spun in a manner that allows them to break and chip paint away from substrates. Both systems are made with vacuum attachments that can reduce dust emissions. Other power tools include wet sanders and saws, which would be used in cutting or preparation activities that may not require full removal of the existing coating.

Chemical Stripping

Chemical stripping involves the application of chemicals to the surface to soften the paint for scraping or water washing removal. The residue that must be disposed of consists of the chemical stripping agent along with the paint. Water is often required to rinse the surface of the stripping chemical. The waste material may be characterized as hazardous due to the LBP content or other characteristics based on the solvents used.

Combination of Methods

Because of the variability of the types of structures and substrates, combined with a need to optimize the management of hazards and costs associated with abatement, a combination of the above techniques may be used. Table 2 lists the advantages and disadvantages of this approach.

4 Guidelines for Disposal of LBP Abatement Wastes

4.1 Disposal Guidelines

A major component of LBP waste disposal is compliance with RCRA regulations. State agencies also have requirements for LBP abatement and disposal that installations must consider when planning for abatement. Beyond these requirements, installations should develop cost effective, environmentally sound approaches that minimize the amount of waste requiring disposal. This section outlines the elements of an approach an installation could take to dispose of LBP waste.

The basic steps to be completed for LBP disposal include:

- evaluate and characterize the wastes
- determine generator status
- obtain a USEPA generator identification number
- comply with storage and pretransportation requirements
- manifest waste shipments
- maintain records and submit reports.

4.2 Evaluate and Characterize Wastes

Different types of abatement approaches and methods will produce a variety of waste streams. To determine if the lead concentrations of the respective waste streams are within regulatory limits for disposal as established in 40 CFR 261.24, waste characterization must be conducted. Separating the wastes into a number of categories will facilitate the evaluation of waste as either hazardous or nonhazardous with a minimum amount of testing. Suggested categories may include:

- lead paint chips
- lead paint dust
- building demolition debris including old woodwork, plaster, windows, doors, and similar bulky components removed from the building
- plastic sheets and tape used to cover floors and other surfaces during lead paint removal

- solvents and caustics used during the stripping process
- sludge from paint stripping operations
- liquid waste, such as washwater from general cleanup or from decontaminating surfaces after solvents have been used, and liquid waste from exterior blasting
- rags, sponges, mops, HEPA filters, air monitoring cartridges, scrapers, and other materials used for testing, abatement, and cleanup
- disposable work clothes and respirator filters.

Once these waste streams have been categorized, the installation should determine whether the waste is hazardous or nonhazardous as defined by RCRA. Building demolition debris must be sampled to determine if these materials must be managed as hazardous waste. The installation must determine the percentage of all types of materials used in the building, i.e., glass, concrete, brick, wood, etc. A representative sample in the same proportions as found in the demolition debris must be collected and submitted for TCLP analysis. Other categories of waste, such as disposable clothing, rugs, and carpets, and containment plastic sheeting and tape can be disposed of as solid waste. Table 4 lists criteria for disposal of wastes generated from LBP abatement projects that can be used in the planning process.

Table 4. Disposal Criteria.

Disposal Criterion	Waste Management Procedure
RCRA <i>Hazardous Waste</i> Toxicity Characteristic (TC) Listed Waste Small Quantity Exemption <i>Non Hazardous Waste</i>	If > 5 ppm TCLP, dispose as Hazardous Waste Identified in 40 CFR 261 Exempt if < 100 kg Dispose of waste per 40 CFR 261 Subtitle D
Construction/Demolition Waste Structures and/or components with salvage potential C/D Debris - Recyclable C/D Debris - Not Recyclable	If property is classified as Class III or eligible to be downgraded to Class III, evaluate salvage feasibility, then develop salvage specifications, conduct salvage/recycling operations Evaluate feasibility of recycling C/D debris (i.e., light steel, heavy steel, copper, lumber, etc.) Dispose as Solid Waste in accordance with Installation Waste Disposal Plan Dispose as Hazardous Waste or perform TCLP testing in accordance with Installation Hazardous Waste Management Plan; Recycle LBP waste at a secondary smelter (see Appendix B)
LBP Waste Generated from Abatement Technologies Paint Chips, Dust, Sludge, Blast Media Abatement Area Wash waters, Disposable clothing, Rugs and Carpets Bulk Components abated using chemical removal or abrasive removal Containment Plastic Sheeting and Tape	Dispose as Hazardous Waste or perform TCLP testing in accordance with Installation Hazardous Waste Management Plan; Recycle LBP waste at a secondary smelter, Evaluate treatment options (blast media additive, stabilization/solidification, etc.) Dispose as Solid Waste in accordance with Installation Waste Disposal Plan Identify Recycle/Reuse Opportunities; Dispose as Solid Waste in accordance with Installation Waste Disposal Plan Dispose as Solid Waste in accordance with Installation Waste Disposal Plan

4.3 Determine Generator Status

The previous step will have determined the applicability of RCRA. The installation as required would then need to determine its generator status under RCRA by identifying how much waste will be generated per month, by applying the following:

- Conditionally Exempt Small Quantity Generator—100 kg or less per month
- Small Quantity Generator—100 to 1,000 kg per month
- Large Quantity Generator—1,000 kg or greater.

It is unlikely that most installations conducting abatement or lead removal projects would qualify as a Conditionally Exempt Small Quantity Generator. Conditionally Exempt generators are required only to dispose of their wastes in compliance with State regulations. In most States, this means that the waste must be labeled and taken to a licensed solid waste disposal facility. However, specific State agencies should be consulted for requirements. Appendix B lists State agency contacts.

4.4 Obtain an EPA Generator Identification Number

An installation determined to be a small or large quantity generator under RCRA is required to obtain a Generator Identification Number (GIN). The installation should contact state hazardous waste management agencies of the regional USEPA office for "Notification of Hazardous Waste Activity Form 8700-12." A form must be submitted for each abatement site at which hazardous waste is generated. Assignment of a GIN takes 3 to 6 weeks, so the application should be submitted well in advance of the start of abatement.

4.5 Storage and Pre-Transportation Requirements

Hazardous waste may be stored in 55-gal drums, tanks, or other containers suitable for the type of waste generated. Procedures and work practices must be followed to protect human health and the environment, and to reduce the likelihood of damages or injuries caused by leaks or spills of hazardous waste. Specific storage requirements pertain to each type of generator. If any of the following time or quantity limits are exceeded, the generator is considered a storage facility; a storage permit is required and other regulations must be met.

Conditionally Exempt Generators

If this limit is exceeded, the generator becomes subject to all the requirements for Small Quantity Generators.

Small Quantity Generators

Small Quantity Generators may accumulate up to 6,000 kg of waste on site for 180 days (or 270 days if the disposal site is more than 200 miles away).

Large Quantity Generators

Large Quantity Generators may accumulate up to 6,000 kg on a site for only 90 days.

Special care must be taken in removing the hazardous waste from the abatement site, to avoid environmental contamination or injury to workers or residents. The following procedures should be followed as appropriate:

- HEPA-vacuum and wet-wipe the exterior of the filled waste containers to remove residual contamination.
- If plastic bags are used, they should be double bagged as they are removed from the work area.
- Remove wastes from work areas at times when use of hallways and staircases is low.
- Select the path from the work area to the truck or dumpster to minimize contacts with tenants and to ensure access to freight elevators or loading docks.
- Move and pack the containers into the truck with care.
- Use hand trucks, dollies, or pull carts along with ramps or trucks with lift gates, if possible.

4.6 Manifest Waste Shipments

For Small and Large Quantity Generators, the hazardous waste shipments must be accompanied by a Uniform Hazardous Waste Manifest. The manifest is a shipping document completed by the generator, and signed by the generator, transporter, and waste disposal facility. The purpose of the manifest is to track hazardous waste from its point of generation to its ultimate disposal.

4.7 Maintain Records and Submit Reports

By signing the manifest, the generator certifies that the manifest is complete and accurately describes the shipment, that the shipment is ready for transport, and that reasonable efforts have been devoted to minimizing the amount and hazardous nature of wastes generated. Once the waste is received at the disposal facility, the operator of the facility must send a signed copy of the manifest back to the generator. If this copy is not received within 35 days (45 days for a small quantity generator) of the shipment of the waste, the generator must contact the operator of the disposal facility to ascertain the status of the shipment. If the copy is still not received with 45 days (60 days for small quantity generators) of the shipment, the generator must contact the Regional Administrator of USEPA, and send to the regional office a legible copy of the manifest signed by the generator, with a letter explaining the efforts taken to locate the shipment. This is called an "exception report."

Waste records must be maintained for 3 years. These records include, but are not limited to:

- copies of manifests and exemption reports
- results of testing the waste for hazardousness.

In addition, large quantity generators are required to file biennial reports of hazardous waste activity with the state hazardous waste agency or the USEPA regional office.

5 Summary

This study gathered information on LBP abatement waste management options for demolition debris from structures contaminated with LBP and waste generated from specific abatement technologies, and authored guidelines for disposal of those wastes.

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Appendix A: Lead Migration in the Subsurface, A Literature Review

Introduction

Heavy metals such as lead are often found in soils at U.S. Army installations at high concentrations as a result of past military and industrial activities and environmental disposal practices. Lead-contaminated wastes from these installations, including lead-based paint wastes generated during abatement, are frequently disposed of in landfills. Infiltrating surface water or migrating groundwater can pass through the waste materials in landfills, resulting in contaminated leachate, and surrounding soils may become contaminated due to leaching from the landfills. Water contaminated by trace metals generally presents a more serious problem than organics because trace metals have no taste or odor, are not biodegradable, and are not easily detected. Preventive measures are not required to protect aquifers from contamination because subsurface transport is slow, and as a result, the consequences of improperly designed landfills may not emerge for decades. For these reasons, information on the chemical fate of lead in the landfill environment is necessary to minimize future financial, legal, and human health liabilities.

To understand the mobility of lead in the subsurface, the USACERL has investigated lead transport from lead-based paint inside a landfill. USACERL is also conducting research to look at other parameters that may affect the lead movement including the presence of low molecular weight organic acids and the effects of pH on the kinetics of lead leaching from lead-based paint. Previous research conducted by USACERL indicates that the addition of fulvic acid, which is an organic acid likely to be found in high concentrations in leachate, enhances the sorption of lead to clay in the subsurface (Foy 1995). However, other parameters such as pH, oxidation-reduction potential, soil particle surface area, advection, organic materials, ionic strength, and biological reactions may also affect the mobility of lead.

This Appendix presents a review of information on the migration of lead in the subsurface obtained from a comprehensive literature search of research articles published over the last 3 calendar years. References to 19 publications and reports are cited.

Scope of Review

This review focused on recently published research on the parameters that affect the movement of lead through the subsurface environment. This information is needed by USACERL for continuing research on factors that influence the migration of lead in a disposal environment. Based on a review of the reports

available for this subtask, this discussion of the various factors on the transport and fate of lead in the subsurface was grouped into six areas:

1. Factors affecting lead association with soils
2. Lead mobility in sediments
3. Extent of migration at metal recycling sites
4. Transport of lead in clay liners
5. Facilitated transport
6. The effects of phosphorus on lead mobility.

Soil Factors Affecting Lead Mobilization

Heavy metals can be mobilized in one of two basic ways. First the soil particles with adsorbed metals can be mechanically carried by water, air, or human or animal activities. Second, changes in redox state, pH, or organic composition of the interstitial solution can convert species to a more soluble form or can cause adsorbing phases to release the metals to solution and subsequent transport by ground or surface water (Brika 1995).

Lead is strongly retained in soil and sediment in the form of divalent lead cation, lead carbonates, lead sulfate, and lead sulfide. Lead also forms complexes with soil organic matter. Soil consists of weathered mineral grains and organic materials in varying proportions. Soils typically are heterogeneous and may be stratified due to historical variations during the soil formation process. The organic content of soil can vary from <1 percent in dry, sandy soils to > 20 percent, and the chemistry of the organic portion of the soils is complex. The soil organic content consists of high-molecular-weight humic materials and lower-molecular weight organic acids and bases. The high-molecular weight organic materials in soil have low water solubility and high affinity for metals and account for most of the metal immobilization due to soil organic matter (USEPA 1995). These high-molecular-weight organic acids immobilize metals by complexation and chelation mainly due to acidic sites. The lower-molecular-weight organic acids tend to mobilize metals by forming soluble complexes with metals. The solubility of metals in soil is controlled by factors such as pH, redox potential, the ion exchange capacity, and complexing and chelation effects of organic matter (USEPA 1995).

A number of researchers have described factors affecting lead mobility in soils. The primary parameters affecting the association of heavy metal with soil and sediment include grain size and surface area, the nature of geochemical substrate, metal species, and affinity of the metals for the soil.

Physical factors subdivide sediments or soils according to their physical properties: grain-size distribution, surface area, surface charge, density, or specific gravity. Chemical phase groups describe the different geochemical substrates that form the basis of the soil such as carbonates, clay minerals, organic matter, iron and manganese oxides and hydroxides, sulfides, or silicates.

Chemical interactions characterize the different types of association between metals and the geochemical substrates. The most important interactions are adsorption, precipitation, organometallic bonding, and incorporation into crystal lattices (Brika 1994). These chemical and physical factors affecting the association of heavy metals with soils are listed in Table A1.

Brika described two major approaches used to characterize the association of heavy metals with soil and sediment. The chemical interaction approach focuses on the different surface effects that adsorb metals on soil particles. The five major mechanisms for the collection and retention of heavy metals in soil and sediments include: adsorption, precipitation and coprecipitation, organometallic bonding, and incorporation of the metals into crystalline minerals (substitution). The phase approach identifies the type of geochemical substrates that interact with the heavy metals and characterizes the association of heavy metals in terms of the phase in which they are located. The most important phases are interstitial water, clay minerals, sulfides, carbonates, organic matter, hydrous iron, and manganese oxides and silicates (Brika 1994).

The fate of lead in soil is affected primarily by processes such as adsorption, ion exchange, precipitation, and complexation. After being released to a contaminated site, most lead is retained strongly in soil (by ion exchange, precipitation, or sorption/complexation to organic matter); very little is transported into surface water or groundwater (USEPA 1995). Soil properties relevant to the mobility of lead in the subsurface include: permeability, variability of the soil types at a site, and humus and clay content. Humus content refers to the natural organic matter present in soils. Higher humus content results in a greater affinity for contaminants, both organic and inorganic.

Changes in soil conditions, such as degradation of organic matrices and changes in pH, redox potential, or soil solution composition, due to various remediation schemes or to natural weathering processes, also may change metal mobility (USEPA 1995).

Other researchers have also considered the important role that the affinity of metal ions for the soil particle surface plays in the chemical mobilization of metals from soil particles. Heavy metal contaminants may be distributed among many components of the soil and may be associated with them in different ways. Li refers to the nature of this association as "speciation." It is the chemical

Table A1. Factors affecting the association of heavy metals with soils.

Physical Factors	Chemical Interactions	Chemical Phase Groups
Grain size	Adsorption	Interstitial water
Surface area	Precipitation or coprecipitation	Carbonates; clay minerals
Specific gravity	Organometallic bonding	Hydrous Fe and Mn oxides
Surface charge	Cation exchange	Sulfides
Water content	Incorporation in mineral lattices	Silicates
Source: Brika 1994		

species or form that determines the mobility and bioavailability of the soil metals to their surrounding environment. Li concluded that determining the speciation of metals in soils may eventually provide a comprehensive technical basis to select remediation techniques for contaminated sites, such as soil washing or flushing, addition of chelating agents, or application of electrochemical techniques. In addition, it may be possible to predict heavy metal removal efficiencies and establish realistic, site-specific cleanup levels for the target heavy metals (Li 1995).

Moreno reviewed studies of the many factors influencing the dynamics of heavy metal mobility in soil, and described soil structure as playing a fundamental role. Soils containing a large clay fraction generally have an elevated cation exchange capacity, while sandy soils do not. The metal in soil can remain in an exchangeable form or be irreversibly bound in the small particle fraction (Moreno 1993). In a study of soil parameters contributing to soil dynamics, the researchers found that for soil samples containing 20 percent clay or more, which also had a high lead content, concentrations of lead were higher in the clay fraction of the tested soils. Concentrations of metals in clay fractions followed the sequence $Zn > Pb > Cu > Cd$. Another soil component that may affect the heavy metal mobility in soil is calcium carbonate, which can adsorb the metal, leading to the formation of hydroxide and carbonate precipitates (Moreno 1993).

A very strong correlation exists between decreasing grain size and the amount of heavy metal held by the soil fraction. As particle size decreases, surface area per mass increases. Surface area is the most important property in interpreting chemical data because it "integrates" all the surface effects of geochemical substrates such as surface charge and cation exchange capacity. The demarcation line between very fine sand and coarse silt is defined at 63 μm . Brika's review of research in this area describes work by Horowitz, which supports a strong correlation between total metals content and the metal content of the < 63 μm fraction. Increased surface area per mass thus magnifies any tendency for geochemical substrates to collect metals (Brika 1994).

Lead has been shown to be strongly bound to soil with a high organic matter. In soil with a high organic matter and a pH of 6 to 8, lead may form insoluble organic lead complexes; if the soil has less organic matter at the same pH, hydrous lead oxide complexes or lead carbonate or lead phosphate precipitates may form. At a pH of 4 to 6, the organic lead complexes become more soluble and may leach out. Lead may also be converted, at the soil surface, to lead sulfate, which is relatively more soluble than lead carbonates or lead phosphates (USEPA 1995).

Researchers have considered the extent to which lead is leached from soils high in organic matter to be uncertain because of the difficulty of measuring lead at the very low levels occurring in soil water and groundwater. To evaluate leaching from soils of this type, a study of forested ecosystem soils was conducted at the Hubbard Brook Experimental Forest. The study showed that the ecosystem is an excellent "filter" that completely retains industrial contaminant lead in its soil profile. The ecosystem also completely retains lead leached from the forest floor in mineral subsoil (Wang 1995). Wang has also conducted lead speciation

studies that indicate that lead is mobilized from the O_a horizon primarily through: (a) association with mobilized colloids, and (b) partitioning of Pb^{2+} between aqueous and solid phases. Lead complexes with truly dissolved organic and inorganic ligands were found to be insignificant. Both Pb^{2+} and colloidal lead from the O_a horizon were found to be effectively adsorbed down the soil profile, albeit independently of each other (Wang 1995).

Lead Mobility in Sediments

Several investigators have recently focused on the issue of lead mobility in sediments. The processes involved in the accumulation of heavy metal contaminants in a sediment are sensitive to pH of the sediment environment, i.e., sediment-interstitial water environment. This is largely because of the solubility of the hydroxide species of the heavy metals and the processes associated with precipitation of the metals (Yong 1995). Lead in contaminated sites is strongly retained in soil and sediment in the form of divalent lead cation, lead carbonates, lead sulfate, and lead sulfide. Lead may also form complexes with soil organic matter. Tetra methyl lead, a relatively volatile organolead compound, may form as a result of biologically alkylation of organic and inorganic lead by microorganisms in anaerobic sediments (USEPA 1995).

Partially to develop methods of assessment of the mobility of lead and other heavy metals in sediments, researchers at McGill University studied the distribution and fate of heavy metal contamination of sediment samples. They determined the partitioning of the heavy metals between the various sediment fractions such as clay minerals, carbonates, soil organics, and amorphous materials using selective sequential extraction analyses. Speciation of the metals in the aqueous phase were determined with the aid of geochemical metal speciation modeling. The interaction mechanisms operating between contaminants and the sediment fraction within a sediment responsible for accumulation of heavy metal contaminants in the sediment are largely sensitive to the pH of the sediment environment. The term "accumulation" is meant to include contaminant adsorption and precipitation processes as in the "retention" of contaminants in the sediment. The pH sensitivity of the accumulation mechanisms is to a very large extent due to the solubility of the hydroxide species of the heavy metals (Yong 1995).

Extent of Lead Migration at Metal Recycling Sites

Field sampling, which was conducted at two metal recycling sites, showed that metals including lead, zinc, and cadmium had migrated less than 0.5 m below the surface during approximately 25 years of activity at the sites, except at car battery destruction locations (Jensen 1995). Average velocity of metal migration was determined to be approximately 1.5 cm per year. The limited leaching or migration was attributed to high pH (ranging from pH 6.5 to pH 7.5) in the soils at the sites. At one site associated with battery destruction, lead had migrated to approximately 0.8 m below the surface. At the other site, which had sandy coarse subsoils, elevated lead concentrations were found to a level of about 3 m below the ground surface. In the unsaturated soil, pH had decreased to about

3.5, facilitating migration of lead and other metals. The low pH was probably due to acids from the car batteries. At a level of approximately 3 m below the surface, which was the groundwater level at this site, an increase in soil pH was detected, probably because of the buffering with unacidified groundwater. An accumulation of lead in soil particles was measured at this level. Experiments were also conducted to measure lead in leachates obtained from soil column representing sites covered with organic rich soil. Water passing through organic rich soils are assumed to have a high content of dissolved organic matter, which would form complexes with lead and other metals, and therefore increase the dissolved concentrations in leachates. The stability of the complexes during migration through the subsurface is unknown. The investigators concluded that migration of lead to groundwater is limited as long as the pH stays high in top soils containing high metal concentrations (Jensen 1995).

Chen describes several retention mechanisms that can be operative within a soil system. Cation exchange (weak outer sphere complexation) and specific adsorption (strong inner sphere complexation) are two weak mechanisms controlling metal adsorption. Heavy metals can also be retained by mechanisms other than sorption (e.g., solid state diffusion and precipitation reactions), especially when lead exists as PbCO_3 , PbSO_4 , or as an organic lead form. Cline reported on research to identify parameters controlling retention and release from soils. Lead retention was found to generally increase with increased soil pH, cation-exchange capacity (CEC), organic content, clay content, and the metal oxide content of the soil. While metal oxides can be both crystalline and amorphous in nature, amorphous metal oxides such as allophanes usually sequester heavy metals to a larger extent than do crystalline metal oxides such as goethite. Cline found that the strength of lead retention generally increases as the initial concentration of the contaminant decreases. The conclusion reached was that the average binding strength of a soil decreases once the high energy binding sites are filled and these sites are selectively filled first (Cline 1993, 1995).

Transport of Lead in Clay Liners

To further the understanding of permeability and adsorption characteristics of natural soils or clay liners in controlled landfills, researchers examined clay adsorption of lead from leachates originating in controlled landfill for solid municipal wastes. The investigators evaluated lead adsorption based on characterization of the leachate and theoretical speciation to determine the extent to which an isotherm model represents the system. The researchers reported that lead adsorption is satisfactorily described at constant pH by using a commonly used (Langmuir/Freundlich) adsorption isotherm model over the entire pH range examined (4.0 to 8.5). The research demonstrated that, in terms of free lead at the various pH levels, the adsorption increases as pH decreases. On the contrary, the adsorption of total lead first increases and then decreases as pH increases in the alkaline range. The investigators concluded that, by using theoretical speciation, adsorption was related to free lead (Pb^{2+}) in solution, making the results more generalizable than in terms of total lead. Theoretical

speciation also allows for interpreting the pH effect on adsorption: as pH increases, adsorption of free Pb increases, but at the same time, free lead decreases. Depending on which effect prevails, adsorption at a fixed total lead concentration can increase or decrease as pH changes. An environmental implication is that an increase in pH does not always entail stronger attenuation of pollutants by soil adsorption (Majone 1993).

The results of studies with soil suspensions consisting of clay soil fractions and heavy metal contaminated leachates, confirm that accumulation of the heavy metal pollutants increases with increasing pH, and that precipitation of the heavy metals at around neutral pH and above results in the formation of compounds such as hydroxides, sulfates, and chlorates species. At acidic pH values, heavy metals become mobile and adsorption onto clay soil particles becomes less effective due to competition from H^+ ions. The amount of heavy metals retained and selectivity of retention depend on soil and its composition. The researchers reviewed information gained from soil suspension tests conducted earlier by the principal investigator and others using heavy metal enhanced contaminant leachates, and concluded that these studies can provide insight into the various processes and mechanisms involved in heavy metal-soil interaction at variable pH conditions (Yong 1995).

One investigator has developed a calculation methodology or model for simulating long-term heavy metal transport through clay barriers. The model calculates the amount of ions remaining in soil solution under dynamic acidic conditions. The model can be used to determine the optimal thickness of clay liner. The overall performance of the model suggests that this computational tool could be useful in the study of a variety of problems involving flow and solute transport in soil continuum such as the selection of the best soil materials and barrier thickness that retains contaminants that are generated in landfill sites (Al-Soufi 1995). In waste disposal areas, heavy metals can become adsorbed by soil and organic substances; therefore, movement of the metals slows substantially. In the long term and after the remediation of a waste site, this zone may become a source of heavy metal to the lower saturated soil strata.

Dissolved humic acids generated in disposal sites facilitate the transport of metal ions and neutral hydrophobic organic pollutants. Clay materials designed to sorb humic acids will control this facilitated transport mechanism, and therefore mitigate the flux of pollutants. The use of clay materials coated with humic acid in conjunction with a commercially available clay liner material (Claymax™) was evaluated. Batch sorption experiments and hydraulic conductivity tests were conducted to compare pollutant attenuation and hydraulic conductivity of the liner materials. Claymax™ was determined to have a greater adsorption maximum for Pb^{2+} than for the humic acid-modified clay, but the partition coefficients of the organics to the modified clay were 14 to 25 times greater than to Claymax™. The investigators concluded that the two layer system would achieve the required hydraulic conductivity with a high sorption capacity for heavy metals (Lo 1994).

Facilitated Transport

The mobility of heavy metals in soils systems is, in general, severely limited by virtue of the strong adsorption reactions between metal ions and the surface of soil particles. The term "facilitated transport" describes phenomena that result in contaminant transport at rates greater than those determined from consideration of ground water hydrodynamic flow and the adsorption of the groundwater to the stationary medium (Chen 1995).

Recent studies and research have shown that contaminant transport to and within groundwater can be significantly enhanced by association with inorganic and organic colloids. Ryan et al. reviewed numerous field studies that show that certain low-solubility contaminants, including lead, are susceptible to colloid-facilitated transport (USEPA 1995). These low-solubility contaminants are generally those that are surface-reactive; they adsorb strongly to mineral and organic colloids. This facilitated transport has been observed in the field for copper and lead in the cationic form. Further research is needed to clearly identify what types of subsurface environments pose the greatest risk for this mode of contaminant transport (USEPA 1995b).

The mobility of cationic trace metals, such as lead and cadmium, in porous media can be severely limited by their sorption at the solid/solution interface. Chen reported that the transport of metals can be enhanced by complexation with a ligand or "carrier" that is soluble in water and does not strongly sorb to surfaces, has a high metal binding affinity, and is not readily altered in soil or aquifer systems. The researcher reviewed studies that suggested that bacterial extracellular polymers of bacterial origin are carriers for metals including lead in soil or aquifer systems. Bacterial extracellular polymers occur naturally in groundwater and such polymers have well established metal binding properties (Chen 1995). In a study conducted at Cornell, extracellular polymers from 13 bacterial isolates, including five subsurface isolates, were screened for their ability to mobilize lead and cadmium adsorbed to an aquifer sand. The researcher suggested that extracellular polymers of bacterial origin are plausible carriers for metals in soil or aquifer systems. All of the extracellular polymers tested reduced the linear distribution coefficients of Cd and Pb. The results of the study indicate that the extracellular polymer could facilitate metal transport. The high mobility of extracellular polymers coupled with their metal binding affinity allowed them to act as a "carrier" of cadmium and lead in a sand media. The researcher suggested that the generality of this behavior must be demonstrated for other metals and other porous media (Chen 1995).

Effects of Phosphorus on Lead Mobility

Several research efforts have been conducted to determine the potential for immobilizing lead in soil by phosphate addition. One Harvard researcher based research on several studies that indicate that the geochemical behavior of lead is affected by phosphate, which when present in sufficient amounts, immobilizes lead, even at low pH. The researcher measured the amount of leachable lead in soil and the effect of addition of phosphate. The results indicate that phosphate

treatment reduced the amounts of lead mobilized from test soils from 33 to 76 percent (Rabinowitz 1993). Ruby et al. reported that geochemical modeling indicated that the addition of a phosphate amendment would result in lead phosphate formation with a very low solubility (0.1 $\mu\text{g/L}$) in soil. The results suggest that in situ lead stabilization through phosphate amendments may provide a cost-effective method for reducing the leaching, migration, and bioavailability of lead from soils (Ruby 1994).

A research team reported that lead-contaminated soil could be immobilized by covering affected areas with finely ground phosphate rocks. The work first looked at the effectiveness of hydroxyapatite, a synthetic compound made from phosphate rocks, in immobilizing lead in soil. When applied to the contaminated soil, hydroxyapatite breaks down into calcium and phosphate. The phosphate combines with lead to form lead phosphate, which is insoluble (Ma 1993). The researchers reported that the mechanism of lead immobilization in soils and in aqueous solutions occurs through hydroxyapatite dissolution and hydroxypyromorphite precipitation or through hydroxypyromorphite precipitation or through chloropyromorphite and fluoropyromorphite precipitation in the presence of Cl^- and F^- , respectively (Ma 1994).

The research team investigated the effects of metals such as Zn, Cd, Ni, Cu, Fe^{2+} , and Al on lead immobilization by hydroxyapatite as well as the effectiveness of hydroxyapatite in the attenuation of these metals in soils. They showed that, not only do these metals have no significant effect on lead immobilization by hydroxyapatite at low concentrations (<20 mg/L), but also these metals themselves are removed by hydroxyapatite. The amounts of metals removed depends on the concentrations of lead and metals, as well as the types of metals. At higher concentrations (>20 mg/L), Cu is most effective in inhibiting lead immobilization by hydroxypyromorphite, followed by Fe^{2+} , Cd, Zn, Al, and Ni (Ma 1994). They also demonstrated that hydroxyapatite is effective in immobilizing lead not only in aqueous solution, but also from contaminated soil. They concluded that the interaction of lead and phosphorus, possibly forming hydroxypyromorphite, chloropyromorphite, or fluoropyromorphite, is an important buffer mechanism controlling the migration and fixation of lead in water, soils, and wastes, thus reducing lead solubility as well as bioavailability (Ma 1995).

Conclusions

The foregoing presentation is intended to provide a review of the recent research undertaken on factors that may affect the movement of lead through the subsurface environment. From the discussions presented above, it is clear that the need for understanding of lead migration has generated a great deal of interest and research on lead transport parameters during the past 3 calendar years. Additional research to develop information on the chemical fate of lead in subsurface environments is continuing and a future review of the research will be needed.

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Appendix B: State Resources for Lead-Based Paint Disposal and Abatement Regulations

State	Point of Contact	Phone No.	Area of Expertise
Alabama	Dave Davis	(334) 217-7755	Waste disposal
	Salvador Gray	(334) 613-5373	Regulatory requirements
Alaska	Janice Adair	(907) 269-7500	Lead program coordinator
	Eric Shortt	(907) 269-4940	Abatement standards and enforcement
Arizona	Michael Goldwater	(602) 542-1525	Abatement standards and enforcement
	Patrick Kuefler	(602) 207-4105	Waste disposal
Arkansas	Jerry Hill	(501) 661-2574	Director of lead programs
	Jeff Purtle	(501) 562-7444	Waste disposal
California	Simone Brumis	(510) 597-8057	Abatement standards and enforcement
	Ted Rauh	(916) 324-7193	Waste disposal
Colorado	Jacqueline Hernandez Berardini	(303) 692-3005	Director of lead programs
	Michael P. Wilson	(303) 692-2646	Environment (general)
Connecticut	Ross Bunnell	(860) 424-3274	Waste disposal
	Alan Buzzetti	(860) 240-9225	Abatement standards and enforcement
District of Columbia	Hampton Cross	(202) 645-6617	Director of lead programs
	Ella Witherspoon	(202) 727-9850	Abatement standards and enforcement
Delaware	Nicholas Dipasquale	(302) 739-4764	Waste disposal
	Paul Pusey	(302) 995-8698	Abatement standards and enforcement
Florida	Joe Sekerke	(904) 488-3385	Abatement standards and enforcement
	Stephen Arms	(904) 791-1502	Environment (general)
Georgia	Harold Reheis	(404) 656-4713	Waste disposal
	Dane Screws	(404) 657-8805	Abatement standards and enforcement
Hawaii	Bruce Anderson	(808) 586-4424	Deputy director lead programs
	Leslie Au	(808) 586-7534	Environment (general)
Idaho	Stephen E. West	(208) 334-6584	Coordinates state lead activities
	Donna Julian	(208) 334-0606	Public outreach
Illinois	George Michael Brandt	(217) 782-5830	Abatement standards and enforcement
	Mark Vassmer	(217) 782-5830	Abatement standards and enforcement
Indiana	David L. Ellsworth	(317) 233-1237	Director of lead program
	Stacy Jones	(317) 233-4984	Environment (general)
Iowa	Rita Gergely	(515) 242-6340	Director of lead program
	Dennis Alt	(515) 281-8998	Environment (general)
Kansas	John Irwin	(913) 296-1542	Director of lead program
	Ronald Hammerschmidt	(913) 296-1535	Environment (general)
Kentucky	Michael Easley	(502) 564-7398	Director of lead program
	David Nichols	(502) 564-4856	Abatement standards and enforcement
Louisiana	William E. Coltrin	(504) 765-0898	Abatement standards and enforcement
	Lourdes Iturralde	(504) 765-0880	Waste disposal
Maine	Lani Graham	(207) 287-4631	Director of lead program
	Steve Zayszly	(207) 287-4311	Abatement standards and enforcement

State	Point of Contact	Phone No.	Area of Expertise
Maryland	Susan Guyaux	(410) 631-3825	Abatement standards and enforcement
	Ed Hammerberg	(410) 631-3345	Waste disposal
Massachusetts	Paul Hunter	(617) 753-8400	Abatement standards and enforcement
	William Siruill	(617) 292-5838	Waste disposal
Michigan	James K. Haveman Kenneth Burda	(517) 335-8024 (517) 373-0530	Director of lead program Waste disposal
Minnesota	Patricia Bloomgren Placida Venegas	(612) 215-0731 (612) 297-8370	Director of lead program Waste disposal
Mississippi	Danny Jackson	(601) 961-5225	Chief of air toxics branch
	Jerry Banks	(601) 961-5221	Waste disposal
Missouri	Michael Carter	(314) 526-5873	Abatement standards and enforcement
	James Williams	(314) 368-2100	Waste disposal
Montana	Thomas Danehower	(406) 227-8451	Abatement standards and enforcement
	Roger Thorvilson	(406) 444-1430	Waste disposal
Nebraska	Adi M. Pour	(402) 471-2541	Contact for lead programs
	John Hall	(402) 471-2541	Public outreach
Nevada	David Going	(702) 687-5240	Coordinates lead activities
	Terry R. Hall	(702) 687-6615	Environment general
New Hampshire	Tod Leedberg	(603) 271-2942	Waste disposal
	Martha T. Wells	(603) 271-4507	Abatement standards and enforcement
New Jersey	Robert Tucker	(609) 984-6071	Environment (general)
	Chrystene Wyluda	(609) 530-8812	Abatement standards and enforcement
New Mexico	Mark Wiedler	(505) 827-2850	Contact for lead program
	David Nelson	(505) 827-3709	Environment (general)
New York	William Stasiuk	(518) 458-6400	Contact for lead programs
	Eileen Franko	(518) 458-6706	Abatement standards and enforcement
North Carolina	Linda Sewall	(919) 733-2870	Contact for lead program
	Margaret Babb	(919) 733-2178	Waste disposal
North Dakota	Francis Schwindt	(701) 328-5150	Contact for lead activities
	Myra Kosse	(701) 328-6119	Lab contact
Ohio	Pamela Allen	(614) 644-2934	Waste disposal
	Phillip Hyde	(614) 644-1894	Abatement standards and enforcement
Oklahoma	Lawrence Gales	(405) 271-8062	Director of lead program
	Chris Crosley	(405) 271-1400	Waste disposal
Oregon	Grant Higginson	(503) 731-4000	Director of lead program
	Gary Calaba	(503) 229-6534	Waste disposal
Pennsylvania	Fred Marroco	(717) 787-9037	Director of lead programs
	James Roof	(717) 787-2761	Waste disposal
Rhode Island	James Ballin	(401) 277-3424	Abatement standards and enforcement
	Thomas Epstein	(401) 272-2797	Waste disposal
South Carolina	Sam Mcnutt	(803) 935-7896	Abatement standards and enforcement
	G. Randall Thompson	(803) 896-4171	Waste disposal
South Dakota	Nettie Myers	(605) 773-3212	Contact for lead programs
	Sherrie Fines	(605) 773-3737	Public outreach
Tennessee	Don Dills	(615) 532-0109	Contact for lead programs
	Tom Tiesler	(615) 532-0780	Waste disposal
Texas	Glen Provost	(512) 458-7541	Abatement standards and enforcement
	Quade Stahl	(512) 834 6600	Environment (general)
Utah	Larry Larkin	(801) 536-4000	Contact for lead programs
	Richard Clark	(801) 538-6856	Inspections
Vermont	William Bess	(802) 863-7220	Environment (general)
	Karen Champton	(802) 863-7231	Abatement standards and enforcement
Virginia	Eileen Mannix	(804) 786-7367	Responsible for state lead program
	David E. Dick	(804) 367-8595	Abatement standards and enforcement
Washington	Lew Kittle	(360) 753-3855	Public outreach
	Stacia Singleton	(360) 407-6753	Waste disposal

State	Point of Contact	Phone No.	Area of Expertise
West Virginia	William T. Wallace William Pinnell	(304) 558-2971 (304) 558-2981	Director of lead program Abatement standards and enforcement
Wisconsin	Mark Chamberlain Joseph Schirmer	(608) 266-7897 (608) 266-5885	Abatement standards and enforcement Abatement standards and enforcement
Wyoming	Dennis Hemmer F. Gerald Blackwell	(307) 777-7938 (307) 777-7394	Environment (general) Waste disposal
American Samoa	Shelia Wiegman Edgar C. Reid	(684) 633-2304 (684) 633-4606	Abatement standards and enforcement Medical contact
Guam	O.V. Natarjan	(671) 734-7221	Contact for lead activities
Puerto Rico	Genarro Torres	(809) 766-2823	Responsible for lead activities
Virgin Islands	Leonard Reed	(809) 774-3320	Responsible for lead activities

Appendix C: Recyclers of LBP Wastes

SARCO, Inc.
180 Maiden Lane
New York, NY 10038
Contact: Glendon F. Archer
(212) 510-2215

The DOE Run Co.
Highway KK
Boss, MO 65440
Contact: Louis J. Magdits
(314) 626-3476

Encycle Texas, Inc.
5500 Up River Road
Corpus Christi, TX 78407
Contact: R.N. George
(512) 289-0300
(800) 443-0144

Exide Corporation
645 Penn St.
P.O. Box 14205
Reading, PA 19612-4205
Contact: Robert Jordan
(800) 437-8495

Noranda Minerals
Brunswick Mining & Smelting Corp
Ltd.
Belledune, New Brunswick
Canada E0B 1G0
Contact: P. Evans
(506) 522-2100

NOVA Lead, Inc.
1200 Garnier
Ville Ste. - Catherine
QuJbec, Canada JOL 1EO
Contact: Brian McIver
(514) 632-9910

Refined Metals Corporation
257 W. Mallory
Memphis, TN 38109
Contact: Bill Freudiger
(901) 775-3770

Schuykill Metals Corporation
Box 74040
Baton Rouge, LA 70874
Contact: Glen Krause
(800) 621-8236

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Chief of Engineers
ATTN: CEHEC-IM-LH (2)
ATTN: CEHEC-IM-LP (2)
ATTN: CECC-R
ATTN: CERD-L

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ATTN: CECW-EE
ATTN: Bolling Federal Building #647
ATTN: CESCO-I

OCE/Army Environmental Office 20310-2600
ATTN: DAIM-ED-C
ATTN: DAIM-ED-Q

USA ACSIM
ATTN: DAIM-FDF-B

US Army Center for Public Works
ATTN: CECPW-EB
ATTN: CECPW-ES

USA CHPPM, South 30330-5000
ATTN: DSA-S

USACOE
ATTN: CESWE-ED-GH

HQ FORSCOM
AFPI-ENO

USAEP1 30318
ATTN: Suite S-206

USA CHPPM, West 60045-5000
ATTN: FAMC

Aberdeen Proving Ground, MD 21010-5422
ATTN: USA CHPPM
ATTN: MCHB-DC-0FS (2)
ATTN: MCHB-MI

US Army Housing Division 22060-5516
ATTN: DAIM-FDH-F

HQDA
USA CHPPM, South 30330-5000
ATTN: DSA-S
ATTN: OASE (IL&E)

US Army Environmental Center
ATTN: SFIM-AEC-ECC
ATTN: SFIM-AEC-JA

Chief of Naval Operations
ATTN: N454D

Navy Environmental Center
ATTN: Code 425 93043-5003
ATTN: Norfolk, VA 23513

Navy Public Works Center 23511
ATTN: Code 414

US Navy 22202
ATTN: N453D

NAVFACENGCOM
ATTN: Code 1832/TFS

NFESC 93043-5003
ATTN: Code ESC63 (2)
ATTN: Code 501
ATTN: Code 425
ATTN: Code 41
ATTN: ESC63

NIBS
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Commandant of Marine Corps
ATTN: LFF-3

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ATTN: HQ AFCEA/CESE
ATTN: HQ FCEE/EP
ATTN: HQ USAF/MWP
ATTN: AL/OEMI 78235-5114(2)

HQ USAF
ATTN: CEHIE

US Air Force Conversion Agency 22209
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ATTN: Division A

US Dept of Energy 20585
ATTN: EH-412

Department of Housing and Urban Development 20410-6000

US Dept of Justice 20044
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US State Dept. 20520
ATTN: A/OPR/SHEM

USEPA 20460
ATTN: OPPT (2)

US Housing and Urban Development 20410
ATTN: B-133 (2)

National Institute of Standards and Technology 20899
ATTN: Bldg 226, Rm B348

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ATTN: MR R-7
ATTN: Center for Disease Control

OSHA
ATTN: DOL/OSHA

Center for Disease Control
ATTN: mailstop F-42

USEPA
ATTN: OPPT

US Coast Guard
ATTN: G-K-SE3

Defense Tech Info Center 22304
ATTN: DTIC-O (2)

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