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Presumptive Remedy for Metals-in-Soil Sites

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Quick Reference Guide

Since Superfund's inception in 1980, the U.S. Environmental Protection Agency's (EPA) remedial and removal programs have found that certain categories of sites have similar characteristics, such as the types of contaminants present, sources of contamination, or types of disposal practices. Based on the information acquired from evaluating and cleaning up these sites, the Superfund program has developed presumptive remedies to accelerate cleanups at certain categories of sites with common characteristics. This directive identifies a presumptive remedy for metals-in-soil sites, and summarizes technical factors (including limitations on the applicability of this directive) that should be considered when selecting a presumptive remedy for these sites. Development of this presumptive remedy has been a joint effort between the EPA and the U.S. Department of Energy (DOE).

INTRODUCTION

Presumptive remedies are preferred technologies or response actions for sites with similar characteristics. The selection of presumptive remedies is based on patterns of historical remedy selection practices, EPA scientific and engineering evaluation of performance data on remedy implementation, and EPA policies. To date, EPA has issued presumptive remedies for municipal landfills, wood treatment facilities, and volatile organic compounds (VOCs) in soil. EPA also has developed a response strategy for sites with contaminated ground water. Implementation of presumptive remedies is addressed in both *Presumptive Remedies: Policy and Procedures* (OSWER Directive 9355.0-47FS, September 1993), which outlines and addresses issues common to all presumptive remedies, and *Presumptive Remedies and NCP Compliance* (memo from Costello and Wyeth to CERCLA Branch Chiefs, June 14, 1995), which explains their use in the context of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP, see 40 CFR 300).

This presumptive remedy directive establishes preferred treatment technologies for metals-in-soil waste that is targeted for treatment, and containment for low-level risk waste requiring remediation. Use of this presumptive remedy should streamline remedy selection for metals-in-soil sites by narrowing the universe of alternatives considered in the Feasibility Study (FS) or Engineering Evaluation/Cost Analysis (EE/CA). Specifically, the national administrative record for metals-in-soil sites established in this directive can be used to shorten the screening and detailed analysis steps in the FS. In addition, this directive identifies technical considerations that guide selection of an appropriate presumptive remedy based on site-specific factors, and describes waste management requirements that may arise at metals-in-soil sites.

THE METALS-IN-SOIL PRESUMPTIVE REMEDY

As summarized in **Highlight 1**, the presumptive

Highlight 1
The Metals-in-Soil Presumptive Remedy

The presumptive remedy for **principal threat** metals-in-soil waste that is targeted for treatment is (see Highlight 4 for an explanation of principal threat wastes):

Reclamation/Recovery (when feasible) - Reclamation/recovery is a permanent treatment that separates metal contaminants from soil in the form of metal, metal oxide, ceramic product, or other useful products that have potential market value. Reclamation/recovery is usually preceded by physical separation and concentration (e.g., soil washing) to produce uniform feed material and/or to upgrade metal content or enhance separation performance. Reclamation/recovery may be the primary treatment and may include hydrometallurgical or leaching processes. Compounds in waste can also be converted to metal or matte by transferring undesirable components to a separate slag phase. Subsequent treatment can be performed to upgrade the metal or matte. Further management of materials left over may be required to protect human health and the environment once metals are recovered.

Immobilization - Immobilization includes processes that change the physical or chemical properties that impact the leaching characteristics of a treated waste or decrease its bioavailability and concentration. This treatment locks metals within a solidified matrix (solidification) and/or converts the waste constituent into a more immobile form, usually by chemical reaction (stabilization). The process involves mixing a reagent (usually cement kiln dust, proprietary agents, cement, fly ash, blast furnace slag, bitumen) and generally solidifying the material with the contaminated soil. Reagents are selected based on soil characteristics and metal contaminants present. The treatment can be performed ex-situ or in-situ, and in either on- or off-site units. Immobilized materials generally are managed in a landfill with the associated containment barriers (e.g., caps).

The presumptive remedy for **low-level threat** metals-in-soil waste that is not targeted for treatment is:

Containment - Containment of metals-in-soil waste includes vertical or horizontal barriers. These remedial technologies can provide sustained isolation of contaminants and prevent mobilization of soluble compounds over long periods of time. They also reduce surface water infiltration, control odor and gas emissions, provide a stable surface over wastes, limit direct contact, and improve aesthetics. Institutional controls generally are used in conjunction with containment to further limit the potential for unintended access to the waste materials.

remedy for contaminated soils constituting **principal threat wastes** (see **Highlight 4**) at metals-in-soil sites is:

(1) reclamation/recovery, where it is well-suited to the waste present at the site; or

(2) immobilization.

In this directive, EPA identifies reclamation/recovery as a presumptive remedy where it is well-suited to the type of waste at the site. See page 8 and Appendix E of this directive for guidance on determining the type of waste to which this technology is well-suited. If the site-specific determination is made that reclamation/recovery is not well-suited for the waste at a site, immobilization is the presumptive remedy for principal threat waste.

For **low-level threat waste** found at metals-in-soil sites, the presumptive remedy is containment.

In many cases, EPA expects to use a combination of methods, as appropriate, to achieve protection of human health and the environment. EPA indicates in the NCP that it expects to use treatment to address the principal threats posed by a site, wherever practicable, and engineering controls, such as containment, for waste that poses a relatively low long-term threat or where treatment is impracticable. Therefore, site managers can expect to use a combination of the presumptive technologies identified in this directive to address metals-in-soil sites, if appropriate (see section 300.430 of the NCP).

EPA selected the technologies identified as presumptive for metals-in-soil sites on the basis of a national feasibility study analysis conducted on 51 sites. As shown in **Highlight 2**, one of the three presumptive remedies was selected at 39 of the 51 sites (nearly 80 percent) evaluated in detail in the feasibility study analysis. Appendix A provides a summary of the methodology and results of the historical remedy review that supports establishing the national administrative record for metals-in-soil sites. Appendices B-D provide information on how the presumptive remedy technologies were evaluated using the nine NCP criteria at sites included in the feasibility study analysis.

Highlight 2
Summary of Site Analysis Supporting Metals-in-Soil Presumptive Remedy*

Technologies Selected to Address Contaminated Metals-in-Soil Waste at Sites Selected for this Analysis	Total Number of Sites Selecting Remedy (of 51 sites)
Immobilization	**17**
Reclamation/Recovery	**9**
Containment	**13**
Institutional Controls	3
Other On-Site Treatment	2
Off-Site Disposal	7

* Bold indicates that the technologies are included in the presumptive remedy.

SCOPE AND USE OF THIS DOCUMENT

Historically, activities that result in contamination at metals-in-soil sites are diverse, including chemical and textile manufacturing; electroplating; smelting; wood treating, and mining and milling. Soils often are contaminated with metals as a result of direct contact with plant waste discharges, fugitive emissions, or leachate from waste piles, landfills, or sludge deposits.

This presumptive remedy is intended for use at sites (or areas of sites) where metal contamination in soils is a primary problem, including, where appropriate, areas where metals may be co-located with other contaminants. These contamination problems are often complex. For example, organics as well as metals may be present, and metals may be migrating into the ground water. These conditions do not preclude use of this presumptive remedy, but site managers should use site-specific information available to determine whether metals are a primary problem, and whether the presumptive remedy approaches are viable. Site managers also should assess if contaminants such as mercury, which are not within the scope of this presumptive remedy, are present in concentrations that will affect remediation.

Finally, site managers should determine if other presumptive remedies (e.g., VOCs in soils, ground-water presumptive site strategy) are appropriate to consider and integrate with the remediation of metals problems. If metals are a primary contaminant of concern, this presumptive remedy guidance should be used unless site-specific factors suggest a contrary approach.

The following sections identify the types of sites and contaminants that are addressed by this presumptive remedy. Specifically, these sections:

(1) identify contaminants that are addressed and not addressed by the metals-in-soil presumptive remedy guidance;

(2) provide a definition of the soils included in the “metals-in-soil” category;

(3) address use of the presumptive remedy at mining and milling sites;

(4) highlight the role of ground water considerations in the overall site-specific remediation strategy;

(5) outline use of the presumptive remedy by other programs; and

(6) discuss the link between this presumptive remedy and innovative technologies.

Contaminants at Metals-in-Soil Sites. This presumptive remedy is directed at sites or areas of sites that primarily contain metals in soil or related media (e.g., sludges and excavated sediments containing metals that are amenable to treatment, consistent with the definition that follows). The contaminants within the scope of this directive and the frequency with which they were found at the evaluation sites are listed in **Highlight 3**. This presumptive remedy guidance is applicable to sites with the contaminants or combinations of contaminants in **Highlight 3**, with the exception of mercury, as noted below.

Highlight 3
Contaminants Found at Metals-in-Soil Sites Evaluated for this Presumptive Remedy (of 51 sites)

Contaminant	Number of Sites Where Found
Lead	37
Arsenic	35
Cadmium	26
Zinc	24
Copper	20
Chromium	20
Mercury	15
Nickel	13
Antimony	9
Manganese	9
Selenium	8
Iron	7
Barium	6
Beryllium	5

Note: Numbers represent number of times contaminant was identified as being present in the FSs or RODs used to develop the presumptive remedy, and does not necessarily indicate the contaminant was found in any specific concentration, or was identified as a principal threat waste.

Mercury. Because of data limitations in the analysis, management of soils containing concentrations of **mercury** at levels that constitute principal threat wastes is **not** addressed by this presumptive remedy guidance. According to available literature, including work done by EPA's Office of Research and Development (ORD), soils with mercury at higher concentrations may not be amenable to the technologies that make up the presumptive remedy for other metals. Site-specific consideration of mercury remediation technologies and approaches will be needed where mercury wastes are present at levels constituting a principal threat waste. However, remediation methods for mercury may potentially be combined with presumptive remedy technologies for metals (e.g., pre-treatment of soil for mercury followed by presumptive remedy for metals).

Definition of Soils and Sediments. This presumptive remedy is directed at sites with metals in soil. Soils are defined as loose material on the surface and in the subsurface of the earth consisting of mineral grains and organic materials in varying proportions. It also applies to sites with related media that have similar treatment characteristics (e.g., dewatered sludges and sediments).

This presumptive remedy is not necessarily appropriate for all sediments contaminated with metals, in part because in situ sediments often pose additional restoration issues, or because their excavation or treatment must be balanced with the potential for harm to sensitive ecosystems. This presumptive remedy may be appropriate, however, for sediments once they are excavated, dewatered, and determined to be amenable to treatments similar to those described in this document for soils and sludges. Eleven of the 51 sites studied in this analysis treated sediments with one of the three presumptive technologies.

Use at Mining and Milling Sites. Thirteen of the 51 sites studied for this presumptive remedy are mining and milling sites. EPA expects that site managers can use this presumptive remedy directive for discrete metals-in-soil problems at mining sites, particularly when the problems resemble those found in more common industrial settings. In many cases, however, unique site features at these often large mining sites (e.g., site size, extent of contamination, nature of metals present, complexities associated with sensitive ecosystems, speciation of metals) may lead a site manager to determine that the presumptive remedy is not practicable to pursue. EPA is studying alternate remediation strategies for mining-related problems.

Ground Water Considerations. Site managers should consider and integrate the remedial actions planned for metals-in-soil with the overall remediation strategy for the site, including other actions that may be needed for source control or for remediation of contaminated ground water. In general, site managers should determine whether the remedy components selected for metals-in-soil (i.e., containment of low-level threat waste and treatment of principal threat waste) will be effective in minimizing further migration of metals to ground water. If site ground water is contaminated and will be restored, minimizing migration of metals to ground water probably will be necessary to allow ground water cleanup levels to be attained. If site ground water is not contaminated, minimizing migration of metals to ground water may be necessary to prevent ground water from becoming contaminated in the future. For further information concerning remediation of contaminated ground water, site managers should consult *Presumptive Remedy Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites, Final Guidance*, (OSWER Directive 9283.1-12, October 1996).

Application to Other Programs. This directive is designed to assist Superfund site managers (i.e., Remedial Project Managers (RPMs) and On-Scene Coordinators (OSCs)) and other personnel in selecting remedies for cleaning up metals in soil. Site managers in other programs, such as the Resource Conservation and Recovery Act (RCRA) corrective action program, or managers conducting state or voluntary remediation in the private sector, should also find the information in this document useful. For example, the information contained in this document could be used to eliminate the need for an alternatives screening step and streamline the detailed analysis of alternatives in the RCRA Corrective Measures Study (CMS), which is analogous to the FS under CERCLA. Federal facility site managers can use this document to expedite decision making for all metals-in-soil sites regardless of the regulatory program to which they are subject.

Use of Innovative Technologies. Innovative technologies are generally not identified as presumptive remedies because they have not been used historically with sufficient frequency. Nevertheless, some presumptive remedy categories, such as volatile organic compounds in soil and wood treatment sites, do include innovative technologies based on historic remedy selection and other pertinent considerations. For metals in soil, new technologies currently being developed focus on more effective separation/recovery of metals from soils (such as soil washing, which has been used at several NPL sites and in other countries), composting, and phytoremediation. To the degree that any innovative technologies show promise of performance or cost advantages, EPA will develop supplemental bulletins, or update this presumptive remedy.

As indicated in the *Presumptive Remedy Policies and Procedures* directive (OSWER Directive 9355.0-47FS), EPA expects to consider using innovative technologies when such technologies offer the potential for comparable or superior treatment performance and implementability, fewer or lesser impacts than other available approaches, or lower costs for similar levels of performance than demonstrated technologies. Specifically, as stated in the *Presumptive Remedies: Policy and Procedures*, OSWER Directive 9355.0-47FS, September, 1993:

> *"The use of the presumptive remedies may tend to reduce the frequency of full evaluation of innovative technologies. However, as indicated previously, the presumptive remedies provide a tool for streamlining the remedy selection process. They do not preclude the consideration of innovative technologies should the technologies be demonstrated to be as effective or superior to the presumptive remedies. Innovative technologies may be evaluated and recommended in addition to the presumptive remedies where these criteria are met.*
>
> *EPA encourages review of the latest Innovative Technologies Semi-Annual Reports [now entitled Treatment Technologies for Site Cleanup: Annual Status Report] or Engineering Bulletins [see http://www.clu-in.org for the latest information on treatment technologies] for the up-to-date information on the potential effectiveness and applicability of various innovative technologies. Site managers are strongly encouraged to involve the site-expert team to determine whether unusual*

circumstances exist to consider a non-presumptive remedy based on site-specific conditions, and/or community, state, and PRP concerns, or the availability of a potentially promising innovative technology."

THE PRESUMPTIVE REMEDY PROCESS FOR METALS-IN-SOIL SITES

When developing a strategy for implementing this presumptive remedy for metals in soil, site managers should be aware of three objectives that data collection in the RI/FS needs to support. The technologies included in this presumptive remedy are categorized according to the nature of the metal wastes found at the site, i.e., whether or not the wastes are **principal threat wastes**. Therefore, the **first** objective at a metals-in-soil site is to make an early determination as to whether any **source** material wastes are considered principal threat wastes based on their toxicity or mobility (see **Highlight 4**). As discussed on page 8, this determination is based on waste characteristics (e.g., mobility and concentrations), degree of risk, or other site-specific factors.

Once the determination has been made that principal threat waste is present at a site, the **second** objective is to decide whether the waste present at the site is well-suited for recovery/reclamation. This determination is based on the waste characteristics and technical factors identified on page 8. For example, reclamation/recovery is usually well-suited for situations with high concentrations of valuable or easily volatilized material. Data will be needed to answer the question of whether reclamation/recovery is a viable alternative, or whether it should be eliminated from further consideration. If reclamation/recovery is not well-suited, immobilization is the other available presumptive remedy treatment technology for principal threat wastes at metals-in-soil sites.

Highlight 4
Description of Principal and Low-Level Threat Wastes

Identification of principal threat and low-level threat wastes should occur, on a site-specific basis, when characterizing **source** materials. "Source material" is defined as material that includes or contains hazardous substances, pollutants, or contaminants that act as a reservoir for migration of contamination to ground water, surface water or air, or act as a source for direct exposure. Contaminated soil, sediments, and sludges can all be classified as source materials.

Principal threat wastes are source materials considered to be highly toxic or highly mobile that generally cannot be reliably contained or would present a significant risk to human health or the environment should exposure occur. Examples include surface soil or subsurface soil containing high concentrations of contaminants of concern that are (or potentially are) mobile due to wind entrainment, volatilization, surface runoff, or sub-surface transport; and highly-toxic source material, such as soils containing significant concentrations of highly toxic materials. No "threshold level" of toxicity/risk has been established to equate to "principal threat." However, where toxicity and mobility of source material combine to pose a potential risk of 10^{-3} or greater, generally treatment alternatives **should be evaluated**.

Low-level threat wastes generally include contaminated source material of low to moderate toxicity, such as surface soil containing contaminants of concern that generally are relatively immobile to air or ground water (i.e., non-liquid, low volatility, low leachability contaminants such as high molecular weight compounds) in the specific environmental setting; and low toxicity source material, such as soil and subsurface soil concentrations not greatly above reference dose levels or that present an excess cancer risk near the acceptable risk range.

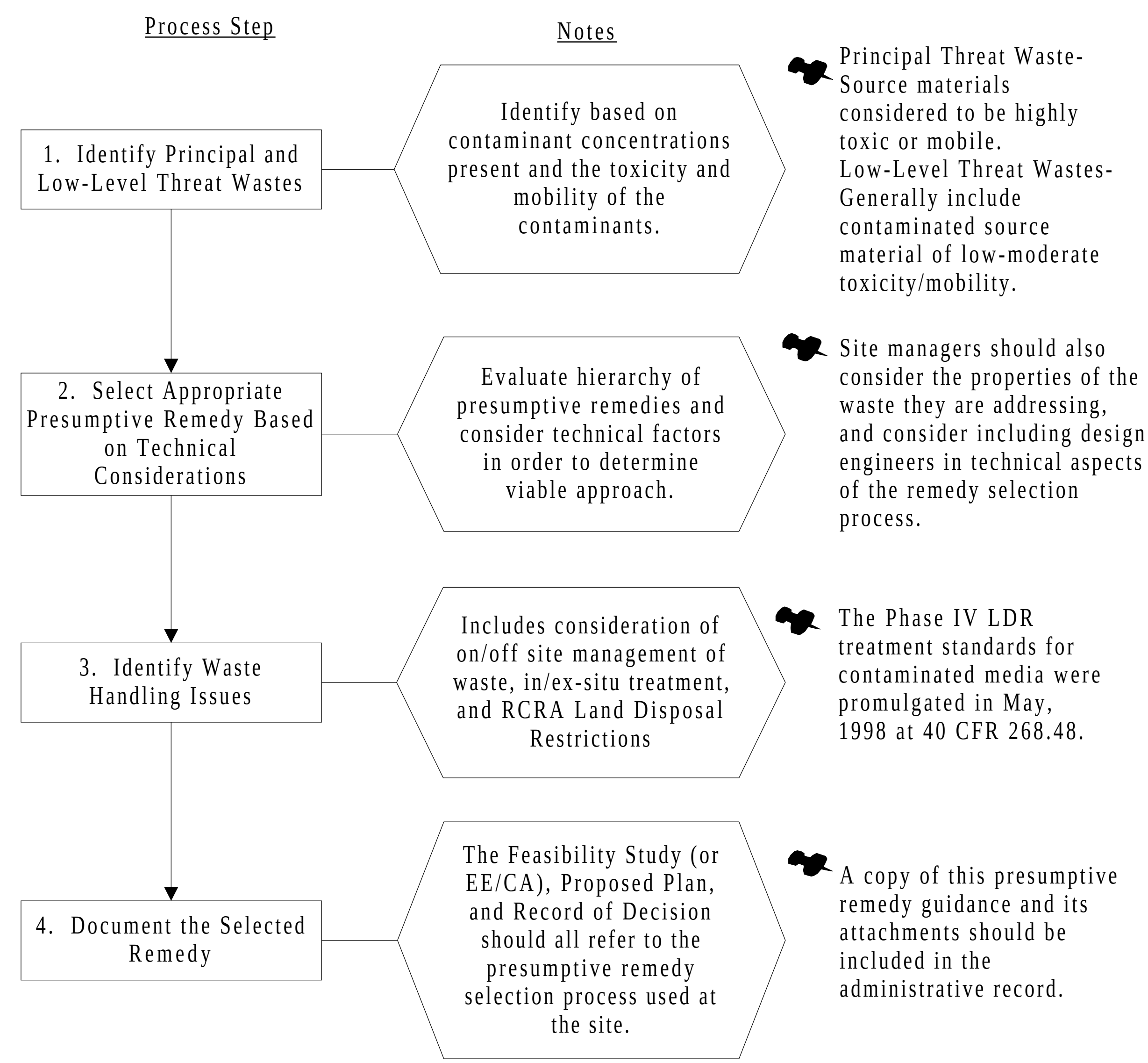
For more information, see *A Guide to Principal Threat and Low Level Threat Wastes* (9380.3-06FS, Nov. 1991).

The **third** objective to be accomplished at metals-in-soil sites is to identify waste handling issues that can be anticipated based on the waste present and the presumptive remedy selected. For example, at many metals-in-soil sites, the land disposal restrictions (LDRs) under RCRA will be applicable or relevant and appropriate requirements (ARARs), and may affect waste handling practices and development of remedial responses (e.g., treatment levels) depending on the presumptive remedy selected. Page 12 provides an explanation of waste handling issues.

The numbered steps provided in **Highlight 5** are explained below and outline the process that site managers should generally follow in:

(1) identifying principal and low-level threat wastes for metals-in-soil sites through site characterization;

Highlight 5
Process for Selecting Presumptive Remedies



(2) selecting the most appropriate presumptive remedy technology for metals-in-soil waste based on technical considerations;

(3) considering waste handling issues such as the land disposal restrictions, and

(4) documenting in the FS, Proposed Plan, and ROD how the presumptive remedy process was used to select the remedy.

As with any presumptive remedy, early involvement of the PRP, State, and community stakeholders is a fundamental part of the process, where the intent is to streamline the response selection process. Starting at scoping, site managers should elicit stakeholder input about the presumptive remedy process. If the public expresses strong opposition to the presumptive remedy under consideration, site managers may need to include non-presumptive remedy options in the evaluation. In this case, site managers may evaluate alternative technologies along with the presumptive remedy. Technology evaluation and screening information must be developed and included in the site Administrative Record for the alternative technologies.

1. Identify Principal and Low-Level Threat Wastes. During this step, the site manager characterizes the nature and extent of the contamination problem, and determines whether wastes should be characterized as principal threat waste and/or low-level threat waste (**Highlight 4**).

Principal threat wastes generally should be addressed through treatment-oriented remedies, unless impracticable, while engineering controls, such as containment, generally are the preferred remedial approach for low-level threat wastes. Any remedy selected for a metals-in-soil site should be consistent with reasonably anticipated future land uses, where possible. Therefore, early identification of reasonably anticipated future land uses will help in the determination of whether a presumptive remedy is appropriate and which of the technologies best meets future land uses. For example, containment of metals in soil in place may be inconsistent with a residential future land use. Future land uses also are part of the judgments needed to conduct a baseline risk assessment, which in turn may help determine whether or not principal threat waste and/or low-level risk waste is present at a site. Site managers should consult EPA's guidance on land use in the Superfund remedy selection process (See *Land Use in the CERCLA Remedy Selection Process*, OSWER Directive No. 9355.7-04, May 25, 1995). The key to assessing this factor is early and continued interaction with citizens, local governments, and community organizations.

In some cases, metals concentrations will be low enough that a response action is not warranted for portions of a site. Site managers should review the Soil Screening Level Guidance (SSL) (see *Soil Screening Guidance: Users' Guide*, OSWER Directive 9355.4-23, April 1996), other pertinent EPA policies, and risk assessment results to determine if no further action is warranted. By providing information to assist site managers in screening out certain areas containing metals in soil from further study, the SSL guidance streamlines the data collection process and focuses the remedy selection on the metal contaminants of concern at the site. **In residential scenarios, where contaminant concentrations equal or exceed SSLs, further study or investigation, but not necessarily cleanup, generally is warranted.**

2. Select Appropriate Presumptive Remedy Based on Technical Considerations. For principal threat wastes, this directive offers two technologies for site managers to evaluate, both of which have proven successful in meeting a wide range of remedial objectives. As discussed below, reclamation/recovery is well-suited to certain types of wastes (see also Appendix E). If the waste at the site is amenable to reclamation/recovery, then site managers should consider reclamation/recovery before considering use of immobilization.

Site managers may want to have design engineers participate in the determination of which presumptive remedy alternatives are appropriate for consideration. One advantage of presumptive remedies is that it may be possible to accelerate initiation of the remedial design (and therefore remedial action) by focusing on a limited set of approaches from the beginning; therefore, site managers should focus as early as possible on the design aspects of the selected technology, particularly by identifying what data are needed for design.

Technical Considerations For the Metals-in-Soil Presumptive Remedy. There are many technical

Highlight 6
Reduction/Separation Technologies (e.g., Soil Washing)

Reduction/separation technologies (e.g., soil washing) used as part of a treatment train may make a remedy more cost effective by removing metal contaminants from soil; thereby reducing the toxicity, mobility, and volume of waste requiring treatment.

Reduction/separation technologies are ex-situ remediation technologies that use a combination of physical separation and aqueous-based separation unit operations to reduce contaminant volume and concentrations to site-specific remedial goals. Technologies such as soil washing are performed on excavated soils and may involve some or all of the following depending on the contaminant-soil matrix characteristics, cleanup goals, and specific process employed: (1) mechanical screening, (2) crushing, (3) physical processes to liberate weakly bound agglomerates, (4) treatment of coarse-grained soil fraction(s), (5) treatment of fine-grained fraction(s), and (6) management of generated residuals.

considerations that site managers may need to examine when applying the presumptive remedy and other aspects of this directive to metals-in-soil sites. When addressing sites contaminated with metals in soil, site managers should consider, on a site-specific basis, the use of reduction/separation technologies in conjunction with the identified presumptive remedies, when appropriate. **Highlight 6** and Appendix D provide additional information on remediation technologies, and Appendix E identifies data requirements to help determine the applicability of presumptive technologies to metals contamination.

Considerations When Selecting Reclamation/ Recovery. Multiple factors may influence the choice to recover or separate metals, such as the economic viability of recovery, vendor availability, post-treatment requirements depending on the metals present; and concentration of the mixture of volatile and nonvolatile metals that require multiple process steps. Reclamation/recovery often is amenable to situations with high concentrations of valuable or easily volatilized materials. For zinc, lead, cadmium, nickel, and chromium it may be economically viable to recover metals from large volumes of waste with high concentrations at 5-20%. In addition, proven technology exists for recovering material containing greater than 40% lead.

Reclamation/recovery may be appropriate for sites with lower metal concentrations if the metals easily reduce and vaporize (e.g., mercury) or are particularly economically valuable (e.g., gold). Lower concentrations of metals typically are processed by hydrometallurgical methods. Due to economies of scale, reclamation/recovery technologies generally work best for a continuous feed of large volumes of metals.

A limited range of suitable particle sizes is associated with reclamation/recovery. Large clumps or debris tend to slow heat transfer and require removal prior to treatment. Fine particles tend to become entrained in gas flows that increase the dust generated. Moisture also has a negative effect on the process by increasing energy requirements and causing material-handling problems. Thus, free moisture should not be present during the process. Higher temperatures for processing are preferred as the treatment requires the ability to transfer heat into the matrix. Nitrates, sulfur compounds, phosphates, and halides may form corrosive gases, nonvolatile sulfides, and volatile metal species that may impede effective treatment.

Reclamation/recovery often is not practicable for projects that lack economic viability (i.e., the cost of implementing the technology significantly outweighs revenues generated by the resale/re-use of recovered materials); however, if the total costs of reclamation/ recovery are comparable with other protective alternatives, then reclamation/recovery should still be considered. For more information, see *Contaminants and Remedial Options at Selected Metal-Contaminated Sites* (EPA/540/R-95/512, July 1995).

Considerations When Selecting Immobilization. Immobilization satisfies CERCLA's preference for treatment of principal threat wastes, is generally effective for metals, and is a commercially available and demonstrated technology. Immobilization works well for particular oxidation states of arsenic and chromium. When addressing lead and cadmium, immobilization may be more effective when a single metal is present.

The effectiveness of immobilization treatment, however, is dependent on several factors. First, identifying a suitable reagent (e.g., fly ash, Portland cement) may be difficult. Without a reagent that has the ability to mix with waste uniformly and thoroughly, contamination may not be significantly reduced. Second, it may be difficult to identify a reagent that simultaneously reduces the mobility of multiple contaminants. Third, the presence of organics may interfere with the bonding of wastes with reagents.

Other contaminants can present additional problems. For example, VOCs may vaporize during the process. (If VOCs are present in high concentrations, they should be addressed prior to treatment.) Contaminants such as oil, grease, phenol, soluble salts of some metals, cyanide, and sulfate may inhibit proper bonding of reagent with waste; retard setting of treated material; and/or reduce durability, bearing strength, and leach resistance of the final product.

If a site manager chooses to use immobilization, performance standards should be established in the ROD, which may be based on risk to human health or the environment, or ARARs. For example, if the RCRA Land Disposal Restrictions (LDRs) are ARARs, then specific leaching performance standards and tests may be required to be met. Off-site disposal of RCRA hazardous waste will also need to comply with RCRA LDRs. Disposal of the immobilized material on-site may also mean that risk-based performance standards need to be set to ensure that the remedy is protective of human health and the environment, and will maintain integrity over time due to such factors as freezing conditions, or load. Risk-based standards should be considered particularly if there is the potential for leaching to ground water or emissions to air. Standards that may need to be set based on disposal on-site include: contaminant leaching level determined based on ground-water modeling or potential air emissions; bearing strength; and freeze-thaw durability. In addition, the NCP preamble states that the Superfund program uses as a guideline for effective treatment the range of 90 to 99 percent reduction in the concentration or mobility of contaminants of concern. (55 FR page 8701, March 8, 1990). Furthermore, site managers should also note that a treatability study is generally recommended before implementing an immobilization remedy. As with other technologies cited in this presumptive remedy, proper treatment and disposal for the final product is assumed.

As an in-situ treatment, immobilization has been demonstrated to be effective at depths up to 30 feet and may be feasible up to 150 feet. The presence of subsurface barriers, debris, and boulders impedes delivery of the reagent to contaminated soil and impedes the complete and uniform mixing of the reagent with the waste. Further, because the presence of clays and oily sands may limit the effectiveness of in-situ immobilization, these composites can be more effectively treated if ex-situ. For more information, see *Contaminants and Remedial Options at Selected Metal-Contaminated Sites* (EPA/540/R-95/512).

<u>Treatment of Chromium</u>. Although historical analysis shows that immobilization can be effective for treating Cr(VI), other treatment methods, singly or in combination with immobilization, may improve immobilization's effectiveness. For example, reduction of Cr(VI) to principally insoluble Cr(III) reduces many of the mobility and toxicity concerns otherwise present with Cr(VI). However, establishing conditions that maintain irreversibly the Cr(III) and prevent oxidation back to Cr(VI) can be difficult, particularly if the treatment is done in-situ. If treatment takes place ex-situ, maintaining the Cr(III) oxidation state may be easier in the long term. Final disposal units may also require long-term monitoring to ensure that the Cr(III) valence is maintained.

<u>Treatment of Arsenic</u>. Treatment of arsenic may be strongly affected by the species present, reactions with other compounds, and soil and site conditions. Research by EPA's Office of Research and Development, summarized in *Engineering Bulletin: Technology Alternatives for the Remediation of Soils and Sediments Contaminated with Arsenic, Cadmium, Chromium, Mercury, and Lead* (EPA/540/S-97/500, August 1997), shows that most arsenic compounds are strongly sorbed by soils and sediments at pH 4.5 to 5.0 and thus are relatively immobile, but other arsenic compounds in other conditions are much more mobile. Site managers should use caution when selecting immobilization for arsenic due to sensitivity in the effectiveness of treatment in different pH conditions. The Bulletin states that "EPA does not preclude use of [immobilization] for treatment of arsenic (particularly

inorganic arsenic) wastes, but recommends that its use be determined on a case-by-case basis." This should be accomplished through use of a site-specific treatability study to supplement the administrative record.

Considerations When Selecting Containment of Metals in Soil. Containment is often a relatively inexpensive, commercially available, and demonstrated technology for remediating metals contamination in soils. Also, containment generally is protective and cost-effective for areas of shallow, wide-spread, and low-level contamination.

Caps and vertical barriers must be designed to conform to any ARARs (unless waived) such as RCRA landfill closure requirements, and/or to address exposure pathways of concern (e.g., dermal exposure). Within these constraints, the type of cap or vertical barrier needed also may be partially dependent upon climate-related factors, including levels of rain and snow fall, and also dependent upon the amount of surface run-on and run-off. Cost and implementability issues may make containment preferable for large areas of contamination.

Containment may not be effective, however, for sites with a high ground-water table or sites located on a floodplain. Furthermore, containment does not involve treatment, nor does it reduce toxicity or waste volume, and generally will restrict future uses of a site.

For more information on containment, see *Contaminants and Remedial Options at Selected Metal-Contaminated Sites* (EPA/540/R-95/512, July 1995).

Co-Mingled/Located Waste (e.g., organics) and Related Issues. In many cases, metals contamination will be co-located with other contaminants, such as organics, or it will be found at types of sites for which EPA has already issued a presumptive remedy (e.g., wood treater sites) or other remediation guidance. The presence of other contaminants such as organics does not automatically preclude the use of this directive. Rather, site managers need to determine how to apply this directive and to evaluate whether the presence of certain other contaminants, such as organics in high concentrations, may limit the effectiveness of the identified presumptive remedy technologies. Organics were present in varying concentrations at 30 of the 51 sites evaluated in the accompanying Feasibility Study Analysis Report, and in 22 of these 30 cases (73 percent), one of the three presumptive technologies was still selected.

Where metals are co-located with other contaminants, site managers should evaluate the following key questions in order to use the information in this presumptive remedy effectively and obtain the intended benefits.

- Can metals problems be addressed separately from other problems co-located at the site (e.g., are they found in discrete geographic locations within the same site)? Are wastes with other contaminants amenable to effective treatment by the presumptive remedy technologies selected? If so, the guidance in this presumptive remedy can be applied without significant modification. Within the Proposed Plan and ROD, site managers should clearly indicate the portion of the site's problems to which this directive is being applied and for what portions a more site-specific analysis of alternatives was conducted.

- If metals problems cannot be considered separately from other problems (or other contaminants lessen a treatment's effectiveness), has EPA issued a presumptive remedy or other remediation guidance that addresses the other problems? For example, if the co-located problem with metals is volatile organic compounds (VOCs) in soils, site managers should consult the existing presumptive remedy for VOCs in soil, and consider whether information from both presumptive remedy documents can be used to select a remedy that addresses the co-located problems. This situation often will require a treatment train using a combination of technologies to meet both risk-based objectives as well as any additional requirements such as those posed by RCRA LDRs. Presumptive remedy benefits (e.g., streamlined screening and analysis of alternatives in the feasibility study) should still be available by relying on the national administrative records available for each presumptive remedy.

In cases where other presumptive remedies already address metals-in-soil problems (e.g., wood treater sites where chromium and arsenic problems are often found), the more site-specific presumptive remedy (in this example, wood treaters) should be followed.

Finally, if other presumptive remedy guidance is not available for the co-located problem, site managers should use this directive to the extent possible to select a remedy that complies with CERCLA and the NCP. Consultation with stakeholders, internal counsel, and technical experts will be important in finalizing the remediation action decision.

3. Identify Waste Handling Issues. Several interrelated issues often arise at metals-in-soil sites that have important impacts on planning the implementation of the presumptive remedy outlined in this directive. These issues include on-site vs. off-site management of wastes, in-situ vs. ex-situ treatment of the wastes, and compliance with a variety of RCRA requirements, including land disposal restrictions (LDRs).

On/Off-Site Management of Metals-in-Soil Waste. Analysis of the 51 Records of Decision evaluated for this directive indicate that management of metals-in-soil waste can occur on and/or off site. If off-site management of the wastes is selected, which may be appropriate in certain cases on a site-specific basis, treatment to applicable RCRA and other standards often will be required. Site managers also must comply with the provisions of the Off-Site rule (see 40 CFR 300.440) in selecting a facility to manage the wastes. This selection includes evaluating the compliance status of the receiving facility and conducting appropriate waste characterization during a remedial investigation to meet the receiving facility's waste acceptance criteria. (On-site management may also trigger the RCRA land disposal restriction standards if the materials contain a RCRA waste, and it is placed outside the area of contamination.) This presumptive remedy directive does not preclude reclamation/recovery, immobilization, or containment from taking place either on- or off-site.

In/Ex-Situ Treatment. None of the 51 sites evaluated for this directive had in-situ treatment of the metals-in-soil waste. However, in-situ treatment is often an effective option for managing metals-in-soil waste, particularly when this option is used in conjunction with containment options. Both in- and ex-situ immobilization are included as options for implementing the presumptive remedy in the scope of this directive.

Key factors to evaluate in determining whether in- or ex-situ treatment of metals-in-soil waste should occur include: (1) the effectiveness of the treatment option; (2) the long-term impact on land use of the option selected; (3) the availability and implementability of ex-situ management, particularly if off-site options are preferred; and (4) the ability to meet ARARs (see RCRA Land Disposal Restriction discussion below).

RCRA Land Disposal Restrictions. Many metal wastes found at Superfund sites will be hazardous under the Resource Conservation and Recovery Act (RCRA). Depending on the source of these wastes, the contaminant types and concentrations, and the remedy selected, these wastes often may be subject to RCRA Subtitle C regulations, such as the treatment standards under the land disposal restrictions (LDRs), as an ARAR. In addition, State hazardous waste regulatory programs also may have requirements that must be met as ARARs. The following are the key RCRA and hazardous waste management issues that site managers must evaluate when using this directive:

- <u>Determine if the soil is or contains a RCRA hazardous waste and, if it is a hazardous waste, determine the waste code(s)</u>. If the soil is a RCRA characteristic waste or if the soil contains a listed RCRA waste, certain RCRA requirements may apply when carrying out this presumptive remedy. The RCRA waste codes determine the specific RCRA requirements that will apply, including the universal treatment standards (UTSs) under LDRs. In addition, LDRs require waste characterization to determine the presence of any underlying hazardous constituents reasonably expected to be present, which also may be subject to the UTSs contained in 40 CFR 268.48 for soil, and 40 CFR 268.45 for debris.

- <u>Evaluate whether placement occurs</u>. LDRs are triggered when restricted RCRA hazardous wastes are "placed" or "land disposed" (i.e., placed in a landfill, surface impoundment, waste pile, injection well, land treatment facility, salt dome formation, salt bed formation, or underground mine or cave (see RCRA section 3004(k)) or other units where waste is placed on the land). Determining the waste codes will be especially important when remediation occurs ex-situ or off-site because wastes managed in these ways often are considered to be "placed" or "land disposed." Wastes treated in-situ, or consolidated within an area of contamination, or an LDR-exempt unit (such as a corrective action management unit, described below) may not trigger LDR requirements because they are not "placed" during the implementation of the remedy; however, in some cases, waste managed on-site may trigger the LDR standards.

- <u>If LDRs are triggered, evaluate compliance options</u>. A variety of options are available to comply with the LDR standards. Under current policy, the preferred approach to complying with LDRs is treatment to the contaminated media standards (see 40 CFR 268.49). EPA promulgated the final LDR treatment standards for soil in May 1998. Prior to this ruling, soil that contained listed hazardous waste or exhibited a characteristic of hazardous waste was prohibited from land disposal unless it had been treated to meet the treatment standards promulgated for pure industrial hazardous waste; in other words, the same treatment standards that applied to a pure, industrial hazardous waste also applied to soil contaminated with that waste.

  EPA chose to develop soil treatment standards that can be achieved using a variety of non-combustion treatment technologies that achieve substantial reductions in concentration or mobility of hazardous constituents. The final rule requires all hazardous contaminated soil, including soil contaminated by listed hazardous waste, to be treated for each underlying hazardous constituent reasonably expected to be present when such constituents are initially found at concentrations greater than ten times the universal treatment standard. The treatment standards promulgated in this rule may be applied to any contaminated soil that is restricted from land disposal, including but not limited to soil contaminated by metal and mineral processing wastes (refer to the memorandum entitled *Management of Remediation Waste Under RCRA*, distributed October 14, 1998 (EP530-F-98-026).

  Other LDR compliance options also continue to exist. For example, under current regulations, "remediation wastes" can be managed in corrective action management units (CAMUs) or temporary units and not be subject to LDR requirements. In addition, a unit receiving LDR-restricted waste can receive a no-migration variance and not have to meet LDR treatment standards. Another compliance option is the site-specific treatability variance for contaminated soil and debris. This variance may still be used if the LDR standard cannot be met (although the LDR standard for soil is no longer considered to be presumptively inappropriate (see 63 FR 28,621, May 26, 1998). The variance does not remove the requirement to treat restricted soil and debris wastes; rather the variance establishes alternate treatment levels based on data from actual treatment of soil. This option may be appropriate to pursue when materials will be managed ex-situ on site and may not meet the LDR requirements for all underlying hazardous constituents.

- <u>Evaluate other RCRA regulations that could interact with the LDRs.</u> RCRA regulations other than the LDRs can apply when implementing the metals-in-soil presumptive remedy. For example, where RCRA hazardous wastes are contained on-site, RCRA closure requirements may be ARARs. EPA has issued a wide variety of policy guidance on complying with these and other RCRA requirements.

<u>**4. Document the Selected Remedy.**</u> When implementing this presumptive remedy, a general explanation of how the presumptive remedy process affects remedy selection should appear in the FS,

Proposed Plan, and ROD, along with a discussion of any site-specific factors that significantly affected selection of the remedy. The following sections provide a brief summary of the type of information that should be included. For additional information, refer to the *Guidance on Preparing Superfund Remedial Decision Documents*, (EPA 540-R-98-031) (expected final date is 1999).

In addition, a copy of this presumptive remedy guidance and its accompanying attachments should be included in the Administrative Record for the site. These materials will assist in supporting the selection of the presumptive remedy and will constitute the initial screening step of the FS or EE/CA and support the streamlining of the detailed analysis portion of the FS or EE/CA. The site-specific administrative record should be prepared and contain the elements outlined in **Highlight 7**. More information about administrative record requirements in general can be found in *Presumptive Remedies and NCP Compliance* (memo from Costello and Wyeth to CERCLA Branch Chiefs June 14, 1995).

> **Highlight 7**
> **Required Elements of the Administrative Record for Presumptive Remedy Sites**
>
> In order to meet the Administrative Record requirements for presumptive remedies, the site-specific Administrative Record should include the following*:
>
> 1) Relevant OSWER generic presumptive remedy documents;
> 2) A "bridging" memorandum or other documentation which shows whether the presumptive remedy fits the site;
> 3) A site-specific analysis discussing how the presumptive remedy fits under the three site-specific remedy selection criteria (ARAR compliance, state acceptance, and community acceptance);
> 4) EPA's written responses to comments which pertain to EPA's decisions regarding the use of presumptive remedies;
> 5) A site-specific response to any comments regarding new technology; and
> 6) A notice in the Administrative Record file index regarding the availability of the data upon which any presumptive remedy is based.
>
> * summarized from memo, *Presumptive Remedies and NCP Compliance*, from Costello and Wyeth to CERCLA Branch chiefs, June 14, 1995.

The Feasibility Study. The FS should explain that the nationwide Feasibility Study Analysis report, prepared in support of this presumptive remedy, substitutes for the site-specific technology identification and screening steps of the FS. For sites with principal threat wastes that will be treated, if reclamation/recovery was found to be well-suited for the waste, consideration of additional treatment technologies generally is not necessary. In this case, the FS should only include the reclamation/recovery alternative(s) and the no action alternative for the principal threat waste. The finding that reclamation/recovery is not well-suited can be a relatively simple determination based on an evaluation of existing data and the technical considerations provided in this directive; it generally need not entail additional data collection or complex feasibility evaluations. In this case, treatment alternatives considered in the FS for principal threat waste generally will include only those related to immobilization and the no action alternatives. As noted in the June 14, 1995 memo from Costello and Wyeth to CERCLA Branch Chiefs, if outside parties submit comments in support of technologies other than those identified in the FS, then such comments must be adequately addressed.

Feasibility Studies for sites implementing this presumptive remedy likely will contain an array of alternatives that include the presumptive treatment technologies combined with other treatment/containment features, or responses to other site-specific contamination problems. For example, alternatives for a given site could include some or all of the following:

- pre-treatment steps (e.g., reduction/ separation technologies, soil washing) in combination with presumptive remedy treatment technologies;

- more than one containment option;

- containment of low-level waste in combination with treatment technologies;

- alternatives to address ground-water contamination; and/or

- provisions for institutional controls.

In the FS, site managers must evaluate each of the alternatives being considered against the nine criteria set forth in section 300.430(e)(9) of the NCP. This evaluation is a key component of the Administrative Record. Appendix B provides a generic evaluation of each of the technologies in the presumptive remedy against these criteria (excluding state and community acceptance and state ARARs). After augmenting or modifying them as necessary with site-specific information, site managers can use these analyses to support final remedy selection.

The Proposed Plan and ROD. Certain sections of the Proposed Plan and ROD should clearly describe the presumptive remedy selection process. In general, references to the presumptive remedy should be included in the following sections, as appropriate: Community Participation Section, Scope and Role of Operable Unit or Response Action Section, Site Characteristics Section (if streamlining occurred as a result of presumptive remedy); and Description of Alternatives Section.

References. **Highlight 8** provides a list of EPA policies and documents that may be relevant to consider when applying the presumptive remedy guidance described in this directive.

Highlight 8
Other Relevant EPA Policy and Technical Documents

EPA numbers, and OSWER numbers when available, are listed. To obtain copies of a document, call the RCRA/CERCLA hotline at 1-800-424-9346. Documents can be ordered using either an EPA number or an OSWER number.

1. U.S. EPA, *Groundwater Issue, Behavior of Metals in Soils*, by Joan E. McLean and Bert E. Bledsoe. EPA 540/S-92/018, October, 1992.
2. U.S. EPA, *A Guide to Principal Threat and Low Level Threat Wastes,* OSWER 9380.3-06FS, November 1991.
3. U.S. EPA, *Presumptive Remedies: Site Characterization and Technology Selection for CERCLA Sites with Volatile Organic Compounds in Soils*. OSWER 9355.0-48 FS, EPA/540-F-93-048, September, 1993.
4. U.S. EPA, *Presumptive Remedy for CERCLA Municipal Landfill Sites*. OSWER 9355.0-49FS, EPA/540-F-93-035, September, 1993.
5. U.S. EPA, "Feasibility Study Analysis and Administrative Record for Presumptive Remedies" memorandum from David A. Bennett, September, 1994.
6. U.S. EPA, *Feasibility Study Analysis for CERCLA Sites With Volatile Organic Compounds in Soil,* August, 1994. OSWER 9356.0.01, EPA 540/R/94/080.
7. U.S. *EPA, Groundwater Issue, Natural Attenuation of Hexavalent Chromium in Groundwater and Soils,* by Carl D. Palmer and Robert W. Puls. EPA/540/S-94/505, October, 1994.
8. *U.S. EPA, Engineering Bulletin, Selection of Control Technologies for Remediation of Soil Contaminated with Arsenic, Cadmium, Chromium, Lead, or Mercury,* EPA/540/S-97/500, March 1997.
9. U.S. EPA, *Contaminants and Remedial Options at Selected Metal-Contaminated Sites*. EPA/540/R-95/512, July, 1995.
10. U.S. EPA, "Land Use in the CERCLA Remedy Selection Process," OSWER Directive 9355.7-04, May, 1995**.**
11. U.S. EPA, *Presumptive Remedies and NCP Compliance* memorandum from James E. Costello and George B. Wyeth, June 14, 1995.
12. U.S. EPA, *Technology Screening Guide for Radioactively Contaminated Sites*, EPA/402/R-96/017, November, 1996.
13. U.S. EPA, *Presumptive Remedies for Soils, Sediments, and Sludges at Wood Treater Sites*. EPA/540/R-95/128, December, 1995. OSWER 9200.5-162.
14. U.S. EPA, *Soil Screening Guidance: User's Guide*. OSWER 9355.4-23, EPA/540/R-96/018, July, 1996.
15. U.S. EPA, *Stabilization/Solidification Technology for Mixed Wastes*. February, 1996.
16. U.S. EPA, *Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites*. OSWER 9283.1-12, EPA/540/R-96/023, October, 1996.
17. U.S. EPA, *Presumptive Remedies: Policy and Procedures*, September, 1993, OSWER 9355.0-47 FS.

APPENDIX A
TECHNICAL BASIS FOR PRESUMPTIVE REMEDIES

This Appendix summarizes the analyses that EPA conducted on Feasibility Study (FS) and Record of Decision (ROD) data from Superfund metals sites that led to reclamation/recovery, immobilization, and containment in place as the presumptive technologies for metals sites with contaminated soil. EPA conducted the following activities:

- Identified all metals-in-soil sites (270) and analyzed in detail a subset (51) of Feasibility Studies and Records of Decision for metals-in-soil sites to determine what technologies were selected and the circumstances of their selection;

- Reviewed EPA and other policies and technical literature associated with the metals found at Superfund sites and technologies for remediating metals, including information about any emerging technologies that might be appropriate for use in the future;

- Evaluated EPA and other policies and requirements for implementing remedies for metals, such as best demonstrated available technologies established under RCRA land disposal restrictions; and

- Reviewed the results of the analysis to determine if the technologies selected based on analyzing either historical patterns or emerging issues should be modified based on technical judgment.

Of the documents identified in Exhibit 4, EPA relied significantly on the following in this process:

- *Presumptive Remedies: Policies and Procedures* (EPA540-F-93-047, September 1993);

- *Contaminants and Remedial Options at Selected Metal-Contaminated Sites* (EPA 540-R-95-512, July 1995)

<u>Identification of the Universe of Metals Sites</u>

EPA started by reviewing abstracts and databases of all Superfund Records of Decision from 1988 to 1994. This group was screened to identify sites that had metals as a primary contaminant of concern (i.e., metals were identified as a risk driver or a contaminant for which active management would be required). Approximately 270 sites were identified in this category. From this set of 270 sites, EPA used expert judgment and analytical tests to select a representative sample of 51 sites for detailed analysis. This subset is consistent with EPA policy guidelines that between 10 and 20 percent of sites require review when evaluating a presumptive remedy (*Presumptive Remedies: Policy and Procedures*, September 1993, EPA 540-F-93-047). In addition, EPA also evaluated in detail metal-contaminated sites at which “no action” or “institutional controls” only were selected as the remedy. These sites were used to determine under what circumstances, if any, limited remediation of metal contaminated sites was warranted. Detailed discussion of the methodology for site selection is available in two working papers included in the national Administrative Record for this presumptive remedy.

From the sample of 51 sites, EPA reviewed in detail the data in the documents prepared during the remedy selection process. These data were used to identify the technologies selected and to identify site circumstances that led to the selection of one remedy rather than others. Types of data evaluated included information related to site conditions (e.g., type of site, waste units present), contaminant characteristics (e.g., species, mobility), waste characteristics (e.g., volume, physical relationship to ground water), and the remedial alternatives accepted and rejected (e.g., cost, analysis against the NCP screening and detailed analysis criteria). A complete list of data gathered for each site and sample site report compiled is shown in the Feasibility Study Analysis Report.

Based on the data collected, EPA analyzed several variables in detail:

- Frequency of selection of the preferred remedial alternative;

- Rationale for selection of the preferred remedial alternative; and

- Rationale for rejection of other alternatives proposed in initial lists of potential remedies but either screened out or not selected after the detailed analysis of alternatives.

EPA also evaluated how combinations of site factors affected the pattern of remedy selection. For example, EPA tried to discern whether mobility of metals or the presence of ground-water contamination affected the pattern of remedy selection and led to explanatory patterns of remedy selection. If factors strongly suggest a preference for a specific remedy, EPA intended to incorporate this information into this guidance on how to obtain the maximum benefits from this presumptive remedy.

Frequency of Technology Selection for Metals Sites

Exhibit A-1 presents the distribution of remedial technologies selected at the 51 metals-in-soil sites evaluated. It demonstrates that the three presumptive technologies were selected more often (39 out of the 51 sites, or approximately 80% of the time) than the other applicable technologies. Immobilization was the remedy selected more often than any other technology (17 of the 51 sites, or approximately 33% of the time). Exhibit A-1 also summarizes how a variety of factors (e.g., site characteristics, contaminant characteristics, risk exposure pathways, volume of materials, land use) affected, if at all, selection of technologies. These factors may provide site managers and other users with important information about the characteristics that have historically led to using the techniques indicated as part of the presumptive remedy.

Exhibit A-2 summarizes the results of the screening analysis for all technologies considered for the 51 metals-in-soil sites studied. It shows the number of times a technology passed screening in the feasibility study (i.e., was considered in more detail in the detailed analysis of alternatives), the number of times it was screened out, and the reason given for the screening out. Exhibit A-3 provides a similar summary for the detailed analysis of alternatives phase.

Exhibit A-4 summarizes the characteristics of each of the technologies not selected as the presumptive remedy against the seven Detailed Analysis criteria. This table provides site managers with part of the rationale necessary to eliminate these technologies from further consideration.

Review of Technical Literature. Substantial literature exists on the characteristics of metals in soil and the technologies that are effective in remediating these contaminants in accordance with Superfund statutory and regulatory concepts. EPA relied significantly on this literature for two purposes in this analysis:

- To identify the key characteristics of metals that affect remediation, both to ensure that they were evaluated during the presumptive remedy process as well as to supplement and support the pattern of remedy selection that was identified; and

- To identify specific circumstances under which technologies have been successful in remediating different metals-in-soil problems.

EPA reviewed the relevant work of the Office of Research and Development (ORD) and other offices and agencies to ensure that the presumptive remedy developed was consistent with policy considerations and the technical advantages and limitations identified through past applications and scientific research. In general, the technical literature supports the presumptive technologies selected and indicates the types of site-specific circumstances that exist when presumptive technologies both are and are not appropriate. In some cases, the literature also identified emerging trends in metals-in-soil remediation that were incorporated into this directive.

Appendix B evaluates the selected presumptive technologies against the appropriate NCP criteria. Appendices C and D summarize the findings of the technical literature. Appendix E summarizes the data requirements generally needed to select the technologies included as part of the presumptive remedy.

Review of EPA policies. EPA has established policies and made technical and regulatory decisions under Superfund and other programs that affect the selection of a presumptive remedy for metals-in-soil contamination. For example, EPA has established which technologies under the RCRA land disposal restrictions (LDR) program are the best demonstrated available technologies (BDAT) and, therefore, are the basis for setting treatment standards. These policies have important impacts for metals such as mercury and arsenic, for which BDAT is generally not the solidification and stabilization approach typically applicable and most commonly used for other metals when treatment is selected.

EXHIBIT A-1: REMEDIES SELECTED AND SITE CHARACTERISTICS AT METALS SITES (51 SITES EVALUATED FOR METALS-IN-SOILS SITES)

Site or Contamination Problem Characteristic	Remedy Selected (percentage of sites)						
	Recovery	Immobilization	Containment	**Presumptive Remedy Technologies**	Institutional Controls Only	Other On-site Treatment	Off-site Disposal
All Sites (51)	16% (8)	33% (17)	29% (15)	**78% (40)**	6% (3)	4% (2)	14% (7)
Anionic metal drives remedy selection (12)	25% (3)	34% (4)	25% (3)	**84%(10)**	0	8%(1)	8% (1)
Cationic metal drives remedy selection (21)	24% (5)	29% (6)	19% (4)	**72% (15)**	9% (2)	5% (1)	14% (3)
Organics present (30)	13% (4)	43% (13)	17% (5)	**73% (22)**	10% (3)	4% (1)	13% (4)
Organics NOT present (21)	24% (5)	19% (4)	38% (8)	**81% (17)**	0	5% (1)	14% (3)
Contaminants Migrating to Groundwater (25)	16% (4)	32% (8)	24% (6)	**72% (18)**	8% (2)	4% (1)	16% (4)
Contaminants NOT Migrating to Groundwater (26)	19% (5)	34% (9)	27% (7)	**80% (21)**	4% (1)	4% (1)	12% (3)

EXHIBIT A-1: REMEDIES SELECTED AND SITE CHARACTERISTICS AT METALS SITES (51 SITES EVALUATED FOR METALS-IN-SOILS SITES) (continued)

Site or Contamination Problem Characteristic	Remedy Selected (percentage of sites)						
	Recovery	Immobilization	Containment	**Presumptive Remedy Technologies**	Institutional Controls Only	Other On-site Treatment	Off-site Disposal
All Sites (51)	16% (8)	33% (17)	29% (15)	**78% (40)**	6% (3)	4% (2)	14% (7)
Contaminants Migrating to Groundwater, Current or Future Anticipated Use (17)	18% (3)	35% (6)	18% (3)	**71% (12)**	0	6% (1)	23% (4)
Contaminants Migrating to Groundwater, Anionic metal drives remedy selection (7)	14% (1)	29% (2)	29% (2)	**72% (5)**	0	14% (1)	14% (1)
Contaminants Migrating to Groundwater, Cationic metal drives remedy selection (8)	25% (2)	38% (3)	0	**63% (5)**	25% (2)	0	12% (1)
Direct Contact Pathway (45)	18% (8)	35% (16)	27% (12)	**80% (36)**	7% (3)	0	13% (6)

EXHIBIT A-1: REMEDIES SELECTED AND SITE CHARACTERISTICS AT METALS SITES (51 SITES EVALUATED FOR METALS-IN-SOILS SITES) (continued)

Site or Contamination Problem Characteristic	Remedy Selected (percentage of sites)						
	Recovery	Immobilization	Containment	**Presumptive Remedy Technologies**	Institutional Controls Only	Other On-site Treatment	Off-site Disposal
All Sites (51)	16% (8)	33% (17)	29% (15)	**78% (40)**	6% (3)	4% (2)	14% (7)
NO Direct Contact Pathway (6)	17% (1)	17% (1)	17% (1)	**51% (3)**	0	33% (2)	16% (1)
Direct Contact Pathway, Anionic Metal Drives Remedy Selection (11)	27% (3)	37% (4)	27% (3)	**91% (10)**	0	0	9% (1)
Direct Contact Pathway, Cationic Metal Drives Remedy Selection (18)	22% (4)	28% (5)	22% (4)	**72% (13)**	11% (2)	0	17% (3)
Inhalation Pathway (16)	19% (3)	19% (3)	43% (7)	**81% (13)**	0	0	19% (3)
Inhalation Pathway, anionic metals present (13)	23% (3)	23% (3)	39% (5)	**85% (11)**	0	0	15% (2)

EXHIBIT A-1: REMEDIES SELECTED AND SITE CHARACTERISTICS AT METALS SITES
(51 SITES EVALUATED FOR METALS-IN-SOILS SITES)
(continued)

Site or Contamination Problem Characteristic	Remedy Selected (percentage of sites)						
	Recovery	Immobilization	Containment	**Presumptive Remedy Technologies**	Institutional Controls Only	Other On-site Treatment	Off-site Disposal
All Sites (51)	16% (8)	33% (17)	29% (15)	**78% (40)**	6% (3)	4% (2)	14% (7)
Volume to be treated <200,000 cy (42)	19% (8)	33% (14)	22% (9)	**74% (31)**	7% (3)	5% (2)	14% (6)
Volume to be treated >200,000 cy (8)	13% (1)	25% (2)	50% (4)	**88% (7)**	0	0	12% (1)
Residential land use scenario assumed for risk assessment (29)	17% (5)	31% (9)	28% (8)	**76% (22)**	7% (2)	3% (1)	14% (4)
Non-residential land use scenario assumed for risk assessment (19)	21% (4)	37% (7)	21% (4)	**79% (15)**	5% (1)	5% (1)	11% (2)

EXHIBIT A-2: SUMMARY OF INITIAL SCREENING PHASE AGAINST NCP SCREENING CRITERIA FOR METALS-IN-SOILS SITES

Technology	# FSs Technology Passed Screening	# FSs Technology Screened Out	REASON FOR REJECTION DURING PRELIMINARY SCREENING		
			Cost	Effectiveness	Implementability
Recovery					
Leaching	3	5	1	3	1
Lead recovery [1]	7	0	0	0	0
Metallurgical Treatment	0	1	1	0	0
Hydrometallurgical Treatment	2	3	0	1	2
Immobilization					
Solidification/stabilization	32	7	1	1	5
Containment					
Capping	32	5	1	1	3
Barrier Walls	0	3	0	1	2
No Action					
No Action	51	0	0	0	0

[1]The numbers for this technology include one ROD specifying a reclamation facility as the means for recovery.

EXHIBIT A-2: SUMMARY OF INITIAL SCREENING PHASE AGAINST NCP SCREENING CRITERIA FOR METALS-IN-SOILS SITES (continued)

Technology	# FSs Technology Passed Screening	# FSs Technology Screened Out	REASON FOR REJECTION DURING PRELIMINARY SCREENING		
			Cost	Effectiveness	Implementability
Institutional Controls					
Institutional controls	9	3	0	3	0
Other Treatment					
Excavation & Off-site Disposal[2]	15	3	2	0	1
Neutralization	2	2	0	2	0
Soil washing/ flushing	5	11	0	5	6
Vitrification	3	14	1	4	9

[2]Excavation and off-site disposal would most likely include treatment, but specific treatment(s) were not identified in ROD.

EXHIBIT A-3: SUMMARY OF DETAILED ANALYSIS PHASE AGAINST NCP CRITERIA FOR METALS-IN-SOILS SITES

Technology	# FSs Technology Passed Screening	# RODs Technology Rejected	REASON FOR REJECTION DURING DETAILED ANALYSIS						
			Overall Protection	Compliance with ARARs	Reduction of Toxicity Mobility Volume	Long-term Effectiveness	Short-term Effectiveness	Cost	Implementability
Recovery									
Leaching	3	3	0	0	0	0	0	1	2
Lead recovery [3]	7	0	0	0	0	0	0	0	0
Metallurgical Treatment	0	0	0	0	0	0	0	0	0
Hydrometallurgical Treatment	2	1	0	0	0	0	0	0	1
Immobilization									
Solidification/ Stabilization	32	15	0	1	2	1	2	5	4
Containment									
Capping	32	17	2	1	4	6	1	1	2
Barrier Walls	0	0	0	0	0	0	0	0	0

[3] The numbers for this technology include one ROD specifying a reclamation facility as the means for recovery.

EXHIBIT A-3: SUMMARY OF DETAILED ANALYSIS PHASE AGAINST NCP CRITERIA FOR METALS-IN-SOILS SITES (continued)

Technology	# FSs Technology Passed Screening	# RODs Technology Rejected	REASON FOR REJECTION DURING DETAILED ANALYSIS						
			Overall Protection	Compliance with ARARs	Reduction of Toxicity Mobility Volume	Long-term Effectiveness	Short-term Effectiveness	Cost	Implementability
No Action									
No Action	51	51	21	17	3	9	1	0	0
Institutional Controls									
Institutional Controls	9	6	2	2	1	1	0	0	0
Other Treatment									
Excavation & Off-Site Disposal[4]	15	9	0	1	2	0	0	4	2
Neutralization	2	1	0	0	0	0	0	1	0
Soil washing/ flushing	5	4	0	0	0	0	1	1	2
Vitrification	3	3	0	0	0	1	0	0	2

[4]Excavation and off-site disposal would most likely include treatment, but specific treatment(s) were not identified in ROD.

EXHIBIT A-4: EVALUATION OF NON-PRESUMPTIVE REMEDY TECHNOLOGIES AGAINST SEVEN NCP DETAILED ANALYSIS CRITERIA:[1]

EXCAVATION AND OFF-SITE REMOVAL OF WASTES FOR APPROPRIATE DISPOSAL

CRITERIA						
Overall Protection of Human Health and the Environment	**Compliance with ARARs**	**Long-Term Effectiveness**	**Reduction of Toxicity, Mobility, or Volume Through Treatment**	**Short-Term Effectiveness**	**Implementability**	**Cost[2]**
Protectiveness achieved by offsite removal and proper disposal of contaminated soil (e.g., RCRA disposal of hazardous materials)	**If RCRA waste, requires compliance with RCRA transportation and land disposal restrictions**	High long-term effectiveness for site; protective-ness at disposal site dependent on offsite management choices	Disposal reduces mobility; reduction of toxicity and volume depends on offsite management choices	Requires standard precautions necessary to protect worker and resident safety and environment Special measures may be required to protect residents during transportation	Easily implementable given facility with adequate capacity for waste type, located within reasonable distance of site Uses standard construction equipment and labor	Reasonable for small to medium volumes of contaminated soil **May be cost-prohibitive for large volumes**

[1] Bold denotes major reasons, in terms of frequency cited in Feasibility Study Analysis Report, the remedy does not meet NCP criteria.

[2] Actual cost of a remediation technology is highly site-specific and dependent upon target cleanup levels of contaminants, soil characteristics, and the design and operation of the remediation technology used.

EXHIBIT A-4: EVALUATION OF NON-PRESUMPTIVE REMEDY TECHNOLOGIES AGAINST SEVEN NCP DETAILED ANALYSIS CRITERIA:[1]
(continued)

SOIL WASHING/FLUSHING

CRITERIA						
Overall Protection of Human Health and the Environment	**Compliance with ARARs**	**Long-Term Effective-ness and Permanence**	**Reduction of Toxicity, Mobility, or Volume Through Treatment**	**Short-Term Effectiveness**	**Implementability**	**Cost[2]**
Highly effective if high removal efficiencies are attained **Washing fluid which contains high metal concentrations must be treated to achieve complete protection**	**Excavation (soil washing) may activate action-specific ARARs** **Must ensure that washing solution into soil (flushing) complies with any chemical- or location-specific ARARs**	When metals successfully removed from soil, eliminates risk associated with contact with soils and contaminant migration off site Provides permanent solution	Permanently reduces toxicity and mobility by removing metals Soil washing concentrates contaminants into much smaller volume **Process must include proper treatment of washing fluids**	**Injection of the washing solution into soil (flushing) may be harmful to human health and/or the environment if washing fluids/vapors are not collected and treated properly** **Washing requires standard precautions necessary to protect worker and resident safety and environment during excavation and treatment**	**Applicable to relatively narrow range of soil types and contaminant combinations:** **- Soil with high percentage of small particles (clay, silt, fines) difficult to treat** **- Most extraction solutions effective only for narrow range of metals and matrix combination** **High removal efficiencies can be difficult to achieve or require complex process** **Requires standard equipment and labor**	Potential to remove marketable metals removed in sufficiently high concentrations may partially offset treatment costs

[1] Bold denotes major reasons, in terms of frequency cited in Feasibility Study Analysis Report, the remedy does not meet NCP criteria.

[2] Actual cost of a remediation technology is highly site-specific and dependent upon target cleanup levels of contaminants, soil characteristics, and the design and operation of the remediation technology used.

EXHIBIT A-4: EVALUATION OF NON-PRESUMPTIVE REMEDY TECHNOLOGIES AGAINST SEVEN DETAILED ANALYSIS CRITERIA:[1] (continued)

VITRIFICATION

CRITERIA						
Overall Protection of Human Health and the Environment	**Compliance with ARARs**	**Long-Term Effectiveness and Permanence**	**Reduction of Toxicity, Mobility, or Volume Through Treatment**	**Short-Term Effectiveness**	**Implementability**	**Cost[2]**
Highly effective if successfully implemented Products have potential reuse options	**Generally activates action-specific ARARs** **Generation of offgas likely to trigger chemical-specific ARARs**	If successfully implemented, results in inert solid with low leachability Incorporation of metals into vitrified mass significantly reduces risk associated with contaminated soil and potential for offsite migration **Limited data on long-term effectiveness**	Immobilizes metals reducing toxicity and mobility Generally reduces volume Some metals must be converted to less volatile form prior to treatment to prevent release	**Tends to generate significant amounts of offgas which may be harmful to human health and the environment; may require extensive controls, including: respiratory protection, fugitive dust control procedures, and air monitoring**	**Limited commercial availability** **Significant offgas production may preclude implementation due to community concern, ARARs; permits for operation may be difficult to obtain** **Requires substantial energy source** Extensive pilot scale testing required Labor intensive; requires highly skilled personnel, facilities, and equipment Presence of other constituents may impede effective implementation	**High cost and energy intensive; often cost-prohibitive**

[1] Bold denotes major reasons, in terms of frequency cited in Feasibility Study Analysis Report, remedy does not meet NCP criteria.

[2] Actual cost of a remediation technology is highly site-specific and dependent upon target cleanup levels of contaminants, soil characteristics, and the design and operation of the remediation technology used.

EXHIBIT A-4: EVALUATION OF NON-PRESUMPTIVE REMEDY TECHNOLOGIES AGAINST SEVEN NCP DETAILED ANALYSIS CRITERIA:[1] (continued)

INSTITUTIONAL CONTROLS

CRITERIA						
Overall Protection of Human Health and the Environment	**Compliance with ARARs**	**Long-Term Effectiveness and Permanence**	**Reduction of Toxicity, Mobility, or Volume Through Treatment**	**Short-Term Effectiveness**	**Implementability**	**Cost[2]**
May reduce potential exposure of receptors by restricting access and future land use **Does not reduce certain contaminant migration pathways offsite such as leaching to groundwater, fugitive dust, surface runoff**	**May not comply with federal and state ARARs**	Provides some level of protection over No Action **Does not *permanently* address contamination problem therefore long-term effectiveness *is uncertain***	***Not considered a treatment remedy.***	**Does not create any potential risks to human health or the environment during implementation**	Easily implemented	Typically the lowest cost remediation alternative

[1] Bold denotes major reasons, in terms of frequency cited in Feasibility Study Analysis Report, the remedy does not meet NCP criteria.

[2] Actual cost of a remediation technology is highly site-specific and dependent upon target cleanup levels of contaminants, soil characteristics, and the design and operation of the remediation technology used.

APPENDIX B
EVALUATION OF SELECTION CRITERIA FOR TECHNOLOGIES USED TO TREAT CONTAMINATED SOILS AND RELATED MEDIA AT METALS-IN-SOIL SITES

RECOVERY

CRITERIA						
Overall Protection of Human Health and the Environment	**Compliance with ARARs**	**Long-Term Effectiveness**	**Reduction of Toxicity, Mobility, or Volume Through Treatment**	**Short-Term Effectiveness**	**Implementability**	**Cost[1]**
Protectiveness and permanent solution achieved by removing contaminants from soil; also converts metals to useful form	Removing metal contaminants from waste eliminates need to comply with land disposal restrictions for metals only Action-specific ARARs may be activated by use of treatment processes Compliance with ARARs is often met by further waste management	Very high if contaminants successfully removed from soil; risks associated with soil are permanently eliminated or greatly reduced; no continued site monitoring required to ensure effectiveness	Permanently removes majority of contaminants thereby reducing toxicity, mobility, volume; any remaining metals immobilized in slag or residue	Requires standard precautions necessary to protect worker and resident safety and environment Thermal air emissions may require treatment	Based on current knowledge, several metals in various forms can be successfully recovered from soils; however, pilot testing may be required Commercial smelting facilities may not have permits for hazardous waste; requires specialized facilities and highly trained labor	Production of potentially marketable materials potentially mitigates costs associated with treatment; depends on metal concentration, marketability of metal, and the form of metal in waste

[1] Actual cost of a remediation technology is highly site-specific and dependent upon target cleanup levels of contaminants, soils characteristics, and the design and operation of the remediation technology used.

APPENDIX B
EVALUATION OF SELECTION CRITERIA FOR TECHNOLOGIES USED TO TREAT CONTAMINATED SOILS AND RELATED MEDIA AT METALS-IN-SOIL SITES
(continued)

IMMOBILIZATION

CRITERIA						
Overall Protection of Human Health and the Environment	**Compliance with ARARs**	**Long-Term Effectiveness**	**Reduction of Toxicity, Mobility, or Volume Through Treatment**	**Short-Term Effectiveness**	**Implementability**	**Cost[1]**
Protectiveness achieved by reducing ability of contaminant to migrate	Excavation, construction, and operation of on-site treatment unit may require compliance with location- and/or action-specific ARARs Can immobilize metals such that TCLP standards are met, eliminating need to dispose of as hazardous waste	May require maintenance to ensure durability and continued leach-resistance of treated material Data on long-term effectiveness limited	Immobilizes contaminants, but does not reduce toxicity; may increase volume	Requires standard precautions necessary to protect worker and resident safety and environment May pose some short term risks if ex-situ treatment is performed	Widely implemented and reliable Commercially available, demonstrated technology; extensive vendor capacity	Generally, lowest cost treatment alternative because of extensive commercial availability and demonstrated status

[1] Actual cost of a remediation technology is highly site-specific and dependent upon target cleanup levels of contaminants, soil characteristics, and the design and operation of the remediation technology used.

APPENDIX B
EVALUATION OF SELECTION CRITERIA FOR TECHNOLOGIES USED TO TREAT CONTAMINATED SOILS AND RELATED MEDIA AT METALS-IN-SOIL SITES
0(continued)

CONTAINMENT OF METALS IN SOIL IN PLACE

CRITERIA						
Overall Protection of Human Health and the Environment	**Compliance with ARARs**	**Long-Term Effectiveness**	**Reduction of Toxicity, Mobility, or Volume Through Treatment**	**Short-Term Effectiveness**	**Implementability**	**Cost[1]**
Contaminated material remains onsite but risk of exposure to public significantly reduced through engineered barriers Environment is protected by minimizing migration of contaminants and likelihood of direct exposure	Hazardous waste disposal will require compliance with ARARs	Long-term protection can be ensured through continued maintenance Reduces contaminant release rates, but not considered a ***treatment*** remedy for principal threat wastes	***Not considered a treatment remedy.***	Requires standard precautions necessary to protect worker and resident safety and environment	Commercially available, demonstrated technology. Necessary materials easily attainable. Uses standard construction equipment and labor	Generally less expensive than most forms of treatment

[1] Actual cost of remediation technology is highly site-specific and dependent upon target cleanup levels of contaminants, soil characteristics, and the design and operation of the remediation technology used.

APPENDIX C
SUMMARY OF METAL CONTAMINANTS COMMONLY FOUND AT SUPERFUND SITES[1]

Metal	Physical/Chemical Characteristics (including common forms)	Mobility, migration information	Proven Treatment and Technology (including BDAT)
Arsenic (As)	a semi-metallic element or metalloid which has several allotropic forms commonly found at metal contaminated sites: As_2O_3 and As species which have leached from As_2O_3 oxide to As(V) and then sorbed onto Fe-bearing minerals in soil As(V) exhibits anionic behavior in presence of water; may form insoluble metal arsenates As(V) less mobile and toxic than As(III) solubility of other forms, including organometalloids depends on pH, other soil constituents, presence of water, etc.	leaching distance generally short because of tendency to sorb onto soils and sediments; however soluble forms move easily with water and may be carried long distances via rivers tendency to adsorb onto soils and sediments increases when clays, iron oxides, aluminum hydroxides, manganese compounds, and organic materials are present therefore, leaching tendency is higher when levels of these minerals are low presence of ions and organic compounds can increase mobility because of competitive sorption and formation of organoarsenic complexes	BDAT is vitrification Possible to recover, for sale, through incineration or other thermal processes; not sufficiently economically attractive to be generally available *Implementation of Solidification/Stabilization* EPA does not preclude use of S/S for treatment of As but recommends its use be determined on site by site basis long-term stability is questionable and volume increase may be unacceptable Oxidation of As(III) to As (V) improves effectiveness of this technology; however, effectiveness may still be limited because species that exist as ions difficult to stabilize High concentrations may increase setting time As(III) and As(V) do not form insoluble hydroxides or carbonates; this reaction is mechanism of immobilization for cement-based S/S; thus, this technology is not applicable to As

[1]The majority of the information in this table was obtained from *Contaminants and Remedial Options at Selected Metal-Contaminated Sites*, Office of Research and Development (ORD), U.S. EPA, EPA/540/R-95/512, July 1995. This table summarizes the information and does not provide the level of description and analysis that is contained in the ORD document. Site managers employing this presumptive remedy should refer to *Contaminants and Remedial Options at Selected Metal-Contaminated Sites* for more detail on the information presented in this table.

APPENDIX C
SUMMARY OF METAL CONTAMINANTS COMMONLY FOUND AT SUPERFUND SITES
(continued)

Metal	Physical/Chemical Characteristics (including common forms)	Mobility, migration information	Proven Treatment and Technology (including BDAT)
Cadmium (Cd)	exists as Cd^{2+}ion, Cd-CN^{-} complexes, or $Cd(OH)_2$ sludge at most metal-contaminated sites depending on pH and treatment that wastes receive before disposal at low pH occurs as Cd^{2+}ion or aqueous sulfate as pH increases, Cd precipitates to form $Cd(OH)_2$ and $CdCO_3$ does not form volatile compounds	precipitation and adsorption onto soils and sediments govern transformation and mobility at low pH, Cd is not generally removed from water at lower pH, Cd may be completely removed from water adsorption is a function of cation exchange capacity of clay and carbonate minerals, oxides and organic matter sulfate and chloride ions reduce adsorption, primarily due to competitive adsorption; ligands may increase adsorption	BDAT for nonwastewater Cd other than batteries is Solidification/Stabilization BDAT for Cd-containing batteries is thermal recovery Recovery is preferred over treatment for wastes with Cd concentrations similar to concentrations in batteries; specific concentration level was not established *Implementation of Solidification/Stabilization* Particularly effective if Cd is only contaminant

APPENDIX C
SUMMARY OF METAL CONTAMINANTS COMMONLY FOUND AT SUPERFUND SITES
(continued)

Metal	Physical/Chemical Characteristics (including common forms)	Mobility, migration information	Proven Treatment and Technology (including BDAT)
Chromium (Cr)	most common forms are Cr(VI) and Cr(III) valence is dependent on pH and redox potential Cr(VI) exists in more oxidized soils and sediments Cr(VI) is highly toxic, soluble, and mobile in soils; Cr(III) is significantly less toxic, soluble, and mobile Cr(VI) precipitates with metal cations and soils surfaces with positively charged sites Cr(VI) is reduced to Cr(III) in presence of organic matter and Fe(II) minerals; rate of reaction increases with decreasing soil pH in most soils and sediments Cr will eventually be present as Cr(III) Cr(III) may oxidize to Cr(VI) in presence of MnO_2	mobility depends on sorption characteristics of soil; depends on content of clay, Fe_2O_3, and organic matter adsorption of Cr(VI) occurs only at an acidic or neutral pH Cr(III) tends to adsorb onto clays below pH 4; formation of complexes with soluble organic matter increases Cr(III) mobility in soils surface runoff can transport both soluble and bulk precipitates to surface water soluble and unabsorbed Cr(VI) and Cr(III) complexes in soil will leach into groundwater leachability of Cr(VI) increases as soil pH increases; conversely lower pH of acid rain may enhance leaching of acid-soluble Cr compounds in soil Cr transported through water generally deposited in sediment	BDAT is Solidification/Stabilization *Implementation of Solidification/Stabilization* BDAT includes reduction of Cr (VI) to Cr (III) prior to S/S; Cr(III) is readily precipitated by hydroxide over a wide pH range acidification followed by reduction and neutralization is common approach to Cr(VI) reduction; chemical treatments available for Cr reduction in neutral pH ranges; Note: injection of treatment chemicals may create requirement for land disposal

APPENDIX C
SUMMARY OF METAL CONTAMINANTS COMMONLY FOUND AT SUPERFUND SITES
(continued)

Metal	Physical/Chemical Characteristics (including common forms)	Mobility, migration information	Proven Treatment and Technology (including BDAT)
Lead (Pb)	most of Pb released in form of metal, oxides, hydroxides, oxy-anion complexes most common oxidation forms are Pb(0) and Pb(II); Pb(II) is most stable species under most conditions Pb also forms stable complexes with organic and inorganic ligands present in soil reacts with carbonates, sulfides, sulfates, and phosphates to form low-solubility compounds	most Pb retained strongly in soil ion exchange, precipitation, or sorption/complexation to organic matter; depending on pH may form organic- or hydrous Pb oxide- lead complexes or Pb carbonate or phosphate precipitates; in these forms, very little transported to surface or ground water at pH of 4-6, organic Pb complexes become more soluble and may leach at surface Pb may be converted to Pb sulfate which is relatively more soluble than Pb forms found beneath surface	BDAT for non wastewater other than battery waste and explosive compounds is Solidification/Stabilization; BDAT for organolead wastes is incineration and stabilization of ash if needed BDAT for wastes from lead-acid battery recycling is thermal recovery in secondary Pb smelter Recovery appropriate for Pb non wastewater with concentrations up to 50,000 mg/kg of Pb; research indicates concentration must be >25% Pb for recovery to be economically viable *Implementation of Solidification/Stabilization* treated waste is subject to leaching and solubilization if pH is not carefully controlled; this may occur evenly at mildly acidic conditions Particularly effective if Pb is only contaminant

APPENDIX C
SUMMARY OF METAL CONTAMINANTS COMMONLY FOUND AT SUPERFUND SITES
(continued)

Metal	Physical/Chemical Characteristics (including common forms)	Mobility, migration information	Proven Treatment and Technology (including BDAT)
Mercury (Hg)	exists in mercuric, mercurous, elemental or alkylated forms form is dependent on redox potential and pH of soil in soil, exists primarily in mercuric and mercurous forms as a number of complexes with varying water solubilities alkylated forms are most toxic and are volatile and soluble in water under mildly reducing conditions, organically bound and inorganic compound may be degraded readily to alkylated form	volatile forms evaporate to atmosphere; solid forms partition to particulate tendency of Hg to sorb with soil and sediment increases with pH; generally sorbs strongly to organic materials leaching is a relatively insignificant transport process in soils; but surface runoff may remove Hg from soil to water, particularly for soils with high humic content depending on pH, salt content, and composition of soil solution, mercury forms various complexes with chloride and hydroxide ions in soil some forms also immobilized in soils and sediments by forming precipitates with carbonate, phosphate, sulfate, and sulfide	BDAT for Hg >260 mg/kg is thermal recovery including roasting or retorting (thermal processes which sublimate Hg from waste and capture metal for refining prior to reuse); pyrolysis and infrared thermal destruction also identified as appropriate thermal recovery process BDAT for inorganic Hg non wastewater below thermal recovery limit (<260 mg/kg) is acid leaching followed by chemical precipitation and dewatering high volatility makes thermal recovery feasible at relatively low concentrations relative to other metals *Implementation of Solidification/Stabilization* difficult to stabilize because Hg does not have low-solubility hydroxide; effectiveness particularly limited when present at high concentration or in elemental form in low concentrations, Hg can be stabilized to meet leachability requirements for land disposal

APPENDIX D
SUMMARY OF REMEDIATION TECHNOLOGIES APPLICABLE TO METALS-IN-SOILS CONTAMINATION

Technology	Description of Technology	Benefits/Limitations of Technology	Factors Influencing Effectiveness, Implementability, and Cost-Effectiveness
Containment (includes capping, vertical and horizontal barriers)	Result: provides sustained isolation of contaminants and prevents mobilization of soluble compounds over a long period Processes: *Cap, cover:* design usually conforms to RCRA landfill closure requirements; however this may not be necessary in areas where precipitation is low, capped waste is not leached by precipitating water, or risk is due to dust generation or direct contact; often includes regrading, revegetation *Vertical Barriers:* includes slurry walls, grout curtains, sheet pile walls to be effective, must extend and key to impervious layer beneath contaminated area (e.g., bedrock or competent aquitard) *Horizontal Barriers*: an emerging technology, not yet demonstrated at any site; "lines" contaminated site by placing physical barrier beneath contaminated area or making underlying soil less permeable; objective is to prevent downward migration of contaminants (because of limited data will not be further addressed in this table)	*Benefits* considered proven technology for site remediation; readily available; relatively inexpensive addresses contaminated soil where remedial treatments not appropriate (because of cost, risk, or implementation issues) reduces surface and/or ground water infiltration, direct contact, and dust generation; improves aesthetics and provides stable surface over waste may be used for wastes that contain mixtures or concentrations of metals which impede effectiveness or preclude implementation of other technologies *Limitations* Does not involve treatment or provide permanent solution; does not reduce toxicity or volume Requires long-term maintenance and monitoring Restricts site from certain future uses Once in place, may hinder future treatment	*Extent of contamination*- capping may be more protective and cost-effective for areas of shallow, wide-spread contamination *Depth to groundwater*- capping may not be effective for sites with high groundwater table or located on floodplain *Climate*- type of cap needed partially dependent on rain and snow fall *Site topography, geology*- generally better suited to level areas (particularly pertinent to vertical barriers); type of cap needed partially dependent on amount of surface run-on and run-off; depth to continuous impermeable strata or competent bedrock needed for design of slurry wall *Presence of Other Constituents*- slurry wall may be degraded by strong acids or bases, sulfates, and strong electrolyte solutions

APPENDIX D
SUMMARY OF REMEDIATION TECHNOLOGIES APPLICABLE TO METALS-IN-SOIL CONTAMINATION
(continued)

Technology	Description of Technology	Benefits/Limitations of Technology	Factors Influencing Effectiveness, Implementability, and Cost-Effectiveness
Immobilization	Result: Physically locks waste constituents within solidified matrix (solidification) and/or converts waste constituents to more immobile form, usually by chemical reaction (stabilization) Process: Involves mixing reagent with waste matrix; reagents selected based on medium and waste constituents; reagents include cement, fly ash, blast furnace slag and organic materials such as bitumen Can be done either in situ or ex situ Mixing techniques for in situ include: - in place mixing - vertical auger mixing - injection grouting Effectiveness dependent on ability to uniformly and thoroughly mix reagent with waste Mechanism: Mobility is reduced by formation of insoluble hydroxides, carbonates or silicates; substitution of metal into mineral structure; sorption; or physical encapsulation	General *Benefits* Reduces mobility of metal contaminants; improves waste handling and other physical characteristics Commercially available, established technology; many vendors available at competitive prices *Limitations* Increases volume; percentage increase dependent on amount of reagent used as needed to immobilize contaminants Ex situ *Benefits* Allows for screening and crushing of large materials prior to treatment which may be necessary to ensure proper mixing *Limitations* Excavation increases energy and labor costs; difficult to implement at small sites In situ *Benefits* Eliminates labor and energy expenses associated with excavation, transport, replacement or disposal of waste Enables small sites that do not have space for material stockpiling and treatment to realize cost savings and satisfy SARA's preference for onsite treatment *Limitations* Not applicable for deep contamination	General *Metal Contaminants Present*- metal and species of metal determines behavior and reaction of metal; more effective for particular oxidation states of As, Cr; if single metal is present, Pb and Cd most amenable to treatment *Multiple contaminants*- may be difficult to identify reagent that simultaneously reduces mobility of all contaminants *Presence of organics*- <20-45 percent by weight; may interfere with bonding of wastes with binders; VOCs may vaporize during process; if present in high concentrations must be addressed prior to treatment; S/S can be used for wastes that contain low levels of organics; addition of silicates or modified clays may improve performance with organics *Particle size*-limited amount of insoluble particulate passing through a 200 mesh screen; fine particles delays setting, weakens bonds *pH*- 9.0-11.5; required for setting and to minimize metal solubility; pH level must be maintained to ensure continued immobilization *Presence of Other Constituents*- a range of constituents may inhibit proper bonding of reagent with waste, retard setting of treated material and/or reduce durability, compressive strength, and leach resistance of final product; these include oil, grease, phenol, soluble salts of some metals, cyanide, sulfate In situ *Depth of contamination*- Process is demonstrated at depths up to 30' and may be applicable up to 150' *Subsurface geology*- presence of subsurface barriers, debris, boulders impedes delivery of reagent to contaminated soil and complete and uniform mixing of reagent with waste *Composition of soil*- presence of clay, oily sands, cohesive soils may impede effectiveness; these can be separated if treated ex situ

APPENDIX D
SUMMARY OF REMEDIATION TECHNOLOGIES APPLICABLE TO METALS-IN-SOIL CONTAMINATION
(continued)

Technology	Description of Technology	Benefits/Limitations of Technology	Factors Influencing Effectiveness, Implementability, and Cost-Effectiveness
Soil Washing	Result: extraction of contaminant from solid matrix that lowers metal concentrations to specified levels Process: may involve one or both of following stages: -physical separation of soil particle size fractions -use of washing solution to remove contaminants treatments that combine both techniques are most effective; contaminants tend to sorb to smaller particles; by removing particle size fraction of soil which is not associated with contaminant, physical separation reduces volume needing treatment washed soil may be returned to site or reclaimed; small particle size fraction or wash residuals are generally highly contaminated and must be properly disposed of Mechanism: physical separation scours and separates silts and clays from clean sand and gravel particles; wash solution transfers metal from matrix into solution or converts it into compound that can be separated from matrix	*Benefits* Removes metal contaminants from soil; thereby reducing toxicity, mobility, and volume of waste and providing permanent treatment Extraction fluid may be processed to recover metals with market value If metal concentration is low, this process provides less costly method to recover potentially valuable metals *Limitations* Extraction fluids generally specific to limited range of chemical forms of metal; one treatment usually only effective for a narrow range of contaminant and matrix combinations Not extensively demonstrated at metals-in-soil sites Extraction fluid necessary to remove metals may have toxic characteristics and ***may*** have undesirable side reactions ***when mixed with*** contaminants present	*Particle size-* >2mm: presence of large clumps or debris interferes with good contact between washing solution and soil; pretreatment needed to remove or crush oversize material 0.25-2mm: effective; 0.063-0.25: effectiveness limited; <0.063: clay and silt fraction- difficult soil washing *Composition of soil*- more effective for homogeneous material; complex mixture increases difficulty in formulation of suitable extraction fluid *Volume of Waste*- treatment of larger volumes more cost-effective because of economies of scale *Contaminant solubility in water*- >1,000 mg/L; soluble compounds can be removed by water flushing; decreases costs and risks to worker safety and environment *pH*- low pH more effective for acid extraction *Presence of Other Constituents*- cyanides, sulfides, fluorides may generate fumes at low pH *Conditions which enhance sorption*- high CEC and humic content enhance sorption and therefore make extraction more difficult

Technology	Description of Technology	Benefits/Limitations of Technology	Factors Influencing Effectiveness, Implementability, and Cost-Effectiveness
Soil Flushing	Result: extracts metal contaminants from soil in situ Process: water or an aqueous solution (chemicals in water) or organic extractant is injected into or sprayed onto contaminated area, contaminated elutriated, collected, and pumped to surface for removal, recirculation, or onsite treatment and reinjection subsurface contaminated barriers may be used in conjunction with flushing to control flow of flushing fluids Mechanism: contaminants mobilized by solubilization, formation of emulsions, or chemical reaction with flushing solutions water will extract only water soluble or water mobile constituents (e.g., carbonates of Ni, Zn, Cu)	*Benefits* Removes metal contaminants from soil; thereby reducing toxicity, mobility, and volume of waste and providing permanent treatment Avoids cost and implementability issues associated with excavation *Limitations* treatment for inorganics less well developed than for organics; limited bench- or pilot-scale testing may not be able to identify solution necessary to extract some metals which does not cause harm to in situ environment and complies with LDRs and other regulatory requirements	*Metal contaminants present*- flushing solution used depends on metals present; fluids vary according to toxicity, cost, regulatory compliance *Contaminant distribution and subsurface geology*- affects ability to deliver and recover flushing solution effectively *Hydraulic conductivity of soil*- $>10^{-3}$ cm/sec and low clay content; allows for efficient delivery of flushing fluids *Equilibrium partitioning of contaminant between soil and extraction fluid*- high partitioning decreases amount of fluid needed to attain cleanup goals *Composition of soil*- more effective for homogeneous material; complex mixture or spatial variation in waste composition increases difficulty in formulation of suitable extraction fluid *Contaminant solubility in water*- >1,000 mg/L; soluble compounds can be removed by water flushing; decreases costs and risks to worker safety and environment *Presence of Other Constituents*- cyanides, sulfides, fluorides may generate fumes at low pH *Conditions which enhance absorption*- high cation exchange capacity, humic content, and surface area of matrix enhance sorption and therefore make extraction more difficult

APPENDIX D
SUMMARY OF REMEDIATION TECHNOLOGIES APPLICABLE TO METALS-IN-SOIL CONTAMINATION
(continued)

Technology	Description of Technology	Benefits/Limitations of Technology	Factors Influencing Effectiveness, Implementability, and Cost-Effectiveness
Vitrification	<u>Result</u>: Immobilizes metals into chemically durable, leach-resistant solid; may also be used to vaporize or destroy organic contaminants <u>Processes</u>: can be done ex situ or in situ *ex situ*- Heat can be applied through combustion of fossil fuels (coal, natural gas, and oil) in melter or input of electric energy by direct joule heating *in situ (ISV)*- heat applied through electric current passed though soil using array of electrodes inserted into soil <u>Mechanism</u>: Metals retained in melt during heating and incorporated into vitrified mass that forms as melt cools; metals convert to oxides, silicates of other compounds with high boiling points	*Benefits* Immobilization of metals; generally decreases volume of waste Can simultaneously treat a wide variety of contaminants, both organic and inorganic, in a range of matrix types Capable of transforming waste into useful, recyclable products such as clean fill, erosion control blocks, road dividers Because most soils naturally composed of glass-forming materials, usually processible without additives Most systems do not require pretreatment *Limitations* Limited current commercially available capacity for hazardous waste vitrification Expensive to implement; cost highly dependent on waste, throughput capacity, local energy costs, site location	<u>General</u> *Metal contaminants present*- Ba, Be, Cr, Cu, Ni, Ag, Th, Zn easily incorporated into oxide melt; more difficult to incorporate As, Pb, Se; volatile metals (e.g., Hg, Cd) may exist in offgas thus requiring treatment of offgas *Concentrations of metal contaminants*- if concentration for a metal exceeds its solubility in silicate, it may form crystalline phases which can decrease leach resistance *Waste volume*- as batch process, economics improve with increased volume *Moisture content*- <25% by wt. high moisture content may require dewatering and increase energy requirement *Presence of organics*- release energy on oxidation and thereby reduces energy requirements of process *Particle size*- may need to be controlled to achieve reference throughputs and a homogenous melt; appropriate size dependent on melter system used *Presence of Other Constituents*- sulfates and chlorides may react to volatile metal species, which may be difficult to retain in melt, or corrosive acids, which reduce durability <u>In Situ</u> *Contaminant Depth*- >6 ft and <20 ft; uncontaminated overburden helps retain volatile metals *Surface slope*- <5%; melt may flow under influence of gravity *Presence of underground structures, utilities, sealed containers*- items located <20ft must be protected from heat *Presence of groundwater*- water inflow increases energy

APPENDIX E
DATA REQUIREMENTS TO FOCUS ON TO DETERMINE POTENTIAL FOR APPLICABILITY OF PRESUMPTIVE REMEDIES FOR METALS-IN-SOIL SITES

Reclamation/Recovery

Purpose

Reclamation/recovery technologies separate metal contaminants from soil in the form of metal, metal oxide, ceramic product, or other useful products that have potential market value. Reclamation/recovery is consistent with EPA national policies on pollution prevention and waste minimization. Reclamation/recovery is a permanent treatment that removes contaminants from the soil.

Description of the Technology

The process for reclamation/recovery is usually preceded by physical separation and concentration to produce uniform feed material and/or to upgrade metal content. This may be the primary treatment and may include hydrometallurgical or leaching processes. Compounds in waste can also be converted to metal or matte by transferring undesirable components to a separate slag phase. Subsequent treatment is performed to upgrade the metal or matte. The equipment used for the process typically includes rotary kilns, hearth or arc furnaces. Volatile metals (e.g., As, Cd, Pb) enter off-gas stream, are oxidized and then recovered by filtration or scrubbing; nonvolatile metals (e.g., Ni, Cr) remain in a furnace and are purified by slagging. See Exhibit E-1 for details about data requirements for reclamation/recovery.

EXHIBIT E-1
DATA REQUIREMENTS TO FOCUS ON TO DETERMINE POTENTIAL FOR APPLICABILITY OF RECLAMATION/RECOVERY

CATEGORY	DATA REQUIREMENT	IMPORTANCE OF INFORMATION
Metal Contaminants	Metals/chemical form	Particular metals and chemical forms ***are*** more amenable to recovery because of marketability or ease of recovery, such as lead. Mixtures of volatile and non-volatile metals require complicated process
	Concentrations	High concentrations generally necessary to make process feasible, economically viable; hydrometallurgical methods generally used for wastes with low metal concentrations
Soil Characteristics	Particle size	Specific processes well-suited to particular particle sizes
	Volume	Processing typically operates best with continuous feed
	Moisture content	Presence of water increases energy requirements and may cause material handling problems
	Thermal conductivity of waste	Treatment requires ability to transfer heat into waste matrix
Other Contaminants and Constituents Present	Combustibles	May provide heating and thereby lower energy requirements

CATEGORY	DATA REQUIREMENT	IMPORTANCE OF INFORMATION
	Nitrates, sulfur compounds, phosphates, halides	May form corrosive acid gasses; sulfur forms nonvolatile sulfides; halides may form volatile metal species
	Alkaline metals	Metals such as Na, K decrease slag formation temperature and increase corrosiveness of slag
Treatability Study Testing (factors to be evaluated during treatability study which influence effectiveness)	Ash content of waste	Helps quantify expected slag volume

Immobilization

Purpose

Immobilization changes the physical or chemical properties that impact the leaching characteristics of a treated waste or decreases its bioavailability and concentration. Immobilization is designed to accomplish one or more of the following objectives:

- Improve the physical/chemical characteristics of the waste, without necessarily reducing aqueous mobility of the contaminant;
- Reduce the contaminant solubility;
- Decrease the exposed surface area across which mass transfer loss of contaminants may occur; or
- Limit the contact of transport fluids and contaminants.

Description of the Presumptive Remedy

This treatment locks metals within a solidified matrix (solidification) and/or converts the waste constituent into a more immobile form, usually by chemical reaction (stabilization). The process involves mixing a reagent (usually kiln cement dust, proprietary agents, cement, fly ash, blast furnace slag, bitumen) with the contaminated soil. Reagents are selected based on soil characteristics and metal contaminants present. Exhibit E-2 provides details about data requirements for immobilization. The treatment can be performed ex situ or in situ.

EXHIBIT E-2
DATA REQUIREMENTS TO FOCUS ON TO DETERMINE POTENTIAL FOR APPLICABILITY OF IMMOBILIZATION

CATEGORY	DATA REQUIREMENT	IMPORTANCE OF INFORMATION
Metal contaminants	Metal speciation: oxidation states of Cr and As	Chemical form determines behavior of metal and likely reactions with treatment reagents; Cr(VI), As(III) and As(V) difficult to stabilize
Metal mobility	Leachability of metals; results of equilibrium and/or diffusion-controlled leach tests that mimic expected post-treatment disposal conditions	In order to meet RCRA LDRs, metals need to become or remain immobile under expected disposal conditions as treated materials age (e.g. TCLP)

CATEGORY	DATA REQUIREMENT	IMPORTANCE OF INFORMATION
Soil characteristics	pH and Eh; buffering capacity	Specific pH range and redox condition favors effective setting; useful in determining conditions leading to lowest solubility of metals; factor in identifying solubility of metals
	Particle size	Fine particulate may coat waste particles and weaken bond between waste solids and cement
	Particle size distribution	May be easier to obtain uniform, complete mixing of reagent with homogenous soil
	Moisture content	Water may need to be added or removed to ensure proper mixing of reagent with soil
	In-Situ	
	Subsurface conditions	Presence of subsurface barriers or debris and depth to first confining layer may affect ability to achieve proper mixing
	Depth of contamination	In-situ mixing demonstrated to 30 feet; new equipment may be applicable to 150 feet
Other contaminants and constituents present	Total organic content; including: VOCs, SVOCs, PAHs, etc.	Organic materials may interfere with bonding of reagent with waste particles
	VOC content	VOCs can vaporize during process or curing
	Oil and grease content	May interfere with bonding of reagent with waste particles
	Phenol content	May reduce compressive strength of final product
	Halide content	May alter cement setting rate; are soluble and can leach from cement
	Soluble salts of Mn, Sn, Zn, Cu, Pb	May reduce physical strength and dimensional stability of cured matrix and/or cause large variations in setting time
	Cyanide content	May interfere with bonding of reagent with waste particles
	Sulfate content	May retard setting and/or cause cement to spall after setting
Treatability Study Testing (factors to be evaluated during treatability study which influence effectiveness)	Volume increase following treatment; estimate total increase based on increase in treatability study	Increases transportation and disposal costs; may eliminate possibility of onsite disposal
	Bearing strength; evaluate changes in response to overburden stress between treated and untreated waste; cone index	Must exceed intended use limits

CATEGORY	DATA REQUIREMENT	IMPORTANCE OF INFORMATION
	Flexural strength; evaluate treated materials ability to withstand loads over large areas	Must exceed intended use limits
	pH, alkalinity; evaluate changes in leaching as a function of pH	Immobilization of metals may not be effective if pH of treated matrix changes

Containment

Purpose

For purposes of this presumptive remedy, containment of wastes in place includes vertical ***and*** horizontal barriers. This remedial technology can provide sustained isolation of contaminants and can prevent mobilization of soluble compounds over long periods of time. It also reduces surface water infiltration, controls odor and gas emissions, provides a stable surface over wastes, limits direct contact, and improves aesthetics.

Description of the Presumptive Remedy

Specific factors influence the selection of containment materials and design including the cost of cap materials, the local availability of capping materials, projected future use of the site, desired function of the cover material, the nature of the waste, local climate and hydrogeology, and ARARs. Containment often includes regrading and revegetation above the cap. See Exhibit E-3 for details about data requirements for containment.

EXHIBIT E-3
DATA REQUIREMENTS FOR CONTAINMENT OF METALS IN SOILS ON SITE 1

CATEGORY	DATA REQUIREMENT	IMPORTANCE OF INFORMATION
Site Characteristics	Extent of contamination	Determines cost-effectiveness of remedy
	Climate	Water infiltration rate is a determinant of type of cover needed
	Depth to groundwater	May not be effective in areas with high groundwater table

[1]The majority of the information in this table was obtained from *Contaminants and Remedial Options at Selected Metal-Contaminated Sites*, Office of Research and Development (ORD), U.S. EPA, EPA/540/R-95/512, July 1995. This table summarizes the information and does not provide the level of description and analysis that is contained in the ORD document. Site managers employing this presumptive remedy should refer to *Contaminants and Remedial Options* for more detail on the information presented in this table. Information on containment taken from Lawrence A. Smith, et al. *Remedial Options for Metals-Contaminated Sites*. CRC Press, 1995.