INEL-96/0418

Subsurface Contamination Focus Area Technical Requirements

Volume I

Requirements Summary

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MASTER

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DISCLAIMER

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ABSTRACT

This document summarizes functions and requirements for remediation of source term and plume sites identified by the Subsurface Contamination Focus Area. Included are detailed requirements and supporting information for source term and plume containment, stabilization, retrieval, and selective retrieval remedial activities.

EXECUTIVE SUMMARY

This report presents requirements information that will be useful both to the decision-makers within the Subsurface Contamination Focus Area (SCFA) and to the technology providers who are developing and demonstrating technologies and systems. The requirements document consists of two volumes. Volume I contains the technical requirements, desirables, and trade studies. Volume II contains supporting information, approach, definitions, and calculations. Landfill and plume requirements are combined for containment/stabilization and retrieval configuration options since there were no identified additional requirements for plumes once requirements were established for landfills. Requirements are often expressed as graphs or charts, which reflect the site-specific nature of the functions that must be performed. Many of the tradeoff studies associated with cost savings are identified in the text.

Section 1 of Volume I is a short introduction and background. An expanded introduction is in Volume II.

Section 2 of Volume I contains the requirements for source term and plume containment and stabilization. Containment or stabilization, in the context of this document, includes any in situ barrier or treatment to prevent or limit contaminant migration from a designated source term or plume. Configuration options are depicted in a logic diagram, and requirements are developed in conjunction with the configuration options.

There are general requirements for containment and stabilization that apply to all remedial options. These include accommodating natural environmental extremes, being compatible with waste materials, meeting requirements of longevity, preventing transport of contaminants, and providing for long-term monitoring. Implementation of specific alternatives is predicated upon certain characterization requirements being met, including locating the boundaries, identifying and quantifying the contaminants, and for containment, measuring or calculating the soil permeability, conductivity, and pH. Subsurface structures must fully contain the waste or contaminant plume, be able to withstand the challenges of hydraulic pressure, earth movement, biological and chemical attacks, and must be verifiable.

Section 3 summarizes requirements for source term and plume retrieval. Source term retrieval is the removal of contaminants by excavation from a designated source term such as a landfill. Plume retrieval is the physical removal of contaminants from a groundwater or contaminated soil plume. Retrieval is classified as full or selective. Selective retrieval is the removal by excavation of selected contaminants of concern from a source term or plume. The requirements include source term and plume characterization that directly supports excavation, the excavation itself and associated support functions, and the identification and placement of the retrieved material. They do not include general site characterization that is not associated with a preferred option. Also not included are ex situ treatment, long-term storage, and final disposal. Within the three activities are 14 specific functions.

Characterization requirements include mapping the source term and contaminant boundaries. Excavation/removal requirements include ensuring compatibility with the waste characteristics and surrounding matrix, excavating or otherwise removing contaminants to the estimated depth of the source term or plume, and retrieving landfill waste and matrix material (including large and/or heavy objects) while providing for contamination control (where necessary) and personnel safety. Excavation/removal requirements also include classifying waste for treatment and placing the waste for transportation or storage.

Much of the information necessary to document and quantify these requirements is known and included in charts and graphs. For example, for retrieval, this information includes selected or assigned retrieval options (selective or full excavation, pump and treat, and vapor extraction), estimated facility depths, overburden thickness, predominant physical matrices and their densities, sites requiring contamination control or remote handling, known retrieval objects' dimensions and weights, classification and summary of contaminants, throughput rate, and treatment options for retrieved waste material. Similar types of information are included for the contain/stabilization options.

The site information gathering process is continuing, and the data presented herein reflect information available at the time this report was published. Even though some data are sparse, the information presented is the best available and can be used now to establish requirements for technology development.

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Subsurface Contamination Focus Area Technical Requirements

Volume I

Requirements Summary

1. INTRODUCTION

1.1 Report Objective

The objective of this report is to present requirements information that will be useful both to the decision-makers within the Subsurface Contamination Focus Area (SCFA) and to the technology providers who are developing and demonstrating technologies and systems.

1.2 Definitions and Report Organization

Volume I of the requirements document contains the technical requirements, desirables, and trade studies. Technical requirements are performance metrics that must be satisfied by a technology or system to meet site remediation requirements. Specifications or performance metrics whose effect is cost savings, but are not otherwise necessary to meet site remediation objectives, are labeled as desirables. The volume is brief in detailed descriptions so that one can readily find the requirements without reviewing details. Volume I contains requirements in a presentation outline format. Volume II contains supporting information, approach, definitions, and calculations. Landfill and plume requirements are combined for containment/stabilization and retrieval configuration options since there were no identified additional requirements for plumes once requirements were established for landfills. Requirements are often expressed as graphs or charts. These reflect the site-specific nature of many of the functions that must be performed. Cost and performance tradeoffs can be made and relative benefits inferred from many of the figures as they often present a performance parameter whose value varies as a function of number of facilities or incremental/total waste volume. Cost tradeoffs can also be calculated for the desirables. Many of the trades that can be made are identified in the text.

The site information gathering process is continuing and the data presented herein reflect information available at the time this report was published. Thus, some illustrations are based on more data than others. When data collection is complete, the data set supporting requirements will be combined for landfills and for plumes. Even though some data are sparse, the information presented is the best available and can be used now to establish requirements for technology development.

All requirements for each of the sites within the problem set will not be contained in a single report. Thus, requirements that directly support the objective of this report were identified and included.

1.3 Background

The former Plumes Focus Area and Landfill Stabilization Focus Area External Integration Team conducted site visits to nine field offices in 1995. They gathered information from Site Technology Coordinating Group (STCG) representatives, site managers, and Operable Unit managers. Following integration of the two focus areas into the SCFA in March 1996, this information was supplemented and organized into two summary reports: *Assessment of Treatment Capabilities for LSFA (Landfill Stabilization Focus Area) Retrieval Waste, Assessment of Containment/Stabilization Capabilities for LSFA*, March 25, 1996, and *Data Analysis Report: Plumes Data Collected during the Site Visits in the Spring of 1995*, August 15, 1996.

2. CONTAINMENT/STABILIZATION

Containment or stabilization, in the context of this requirements document, includes any in situ barrier or treatment to prevent or limit contaminant migration from a designated landfill or plume.

Containment and/or stabilization consists of four activities or functions: characterization for containment planning, preventing infiltration, stopping contaminant migration, and monitoring the effectiveness of the containment or treatment. Figure 1 is a summary of the requirements associated with every configuration option, i.e., generally applicable. Figure 2 shows the requirements associated with specific functions. Each of the requirements and desired attributes is presented and discussed in this requirements document.

2.1 Requirements That Apply to All Containment Functions

Function 1: Contain and/or stabilize the contaminants at a contaminated site.

Requirement: 1. Accommodate all expected extremes in freeze and thaw and precipitation (both wetness and drought) at the site of remediation.

Discussion: See Figure 3 and Table 1. Part of this requirement is stability of the remedial solution if the landfill is built on a hillside. Currently only one site reported a potential problem with a landfill located on a hillside.

Figure 3 is an illustration of the maximum depth, in inches, of frost penetration in the United States, extracted from *Introductory Soil Mechanics and Foundations*, George B. Sower, Section 4:7. Using information from such a figure, the technology developer can design a remedial solution to accommodate the frost line and avoid the consequences of freeze/thaw. The consequences are described as follows: as soil layers freeze, water drawn toward the freezing front can cause desiccation cracking, freeze/thaw cracking, and frost heaving.

Table 1 is a list of arid versus humid field offices with the average precipitation, in inches, over a period of 10 to 30 years from the United States Climate Page, http://www.cdc.noaa.gov/USclimate/states.fast.html. Arid is defined as receiving average annual precipitation of less than 19.5 inches.

There are 102 sites in the landfill baseline data set. Of the 33 candidate sites for containment (the other 69 consist of 26 candidate retrieval sites, 10 hot spots, and 33 sites where technology development would have no impact), 15 are arid sites and 18 are humid sites. Rocky Flats is not represented in the baseline data set. See Table 2.

There are 283 sites in the plume baseline data set. Of the 24 candidate sites for containment (the other 259 plume sites consist of 110 candidate retrieval sites, 3 hot spot retrieval, 33 no impact, and 93 unknown), 8 are arid sites and 16 are humid sites. Of the 8 arid sites, 6 are soil plumes and 2 are groundwater plumes. Of the 16 humid sites, 5 are soil plumes and 11 are groundwater plumes. The data are listed in Table 2.

Containment and/or Stabilization

REQUIREMENTS
- **Accommodate expected extremes in freeze/thaw and precipitation.**
- **Be compatible with waste materials.**
- **Have design life based upon half life of contaminants.**
  - **Prevent contaminants from reaching ground water.**
- **Prevent biological transport.**
- **Prevent exposure of buried waste.**
- **Maintain integrity.**
- **Be continuous.**
- **Meet requirement in DOE Order 5480.31 (ORR).**
- **Provide Radiological and hazardous monitoring.**
- **Meet schedules.**
- **Decontaminate or dispose of all equipment used in remediation.**

DESIRABLE
- **Support vehicular traffic on the ground surface.**
- **Eliminate path ways for water infiltration.**
- **Be a systems approach.**

Figure 1. Summary of the requirements that apply to every containment/stabilization configuration option.

Containment and/or Stabilization

Characterize for Containment Planning

REQUIREMENTS
- **Map the boundaries.**
- ***Determine the mass*** **or radioactivity and concentration of constituents.**
- **Determine the soil permeability conductivity, and pH.**

Prevent Infiltration

REQUIREMENT
- **Maintain the water balance.**

Stop Migration

***INSTALL VERTICAL BARRIERS**
<u>Requirement</u>
- **Extend from top of waste and keyed into bottom barrier.**

*** STABILIZE IN-SITU**
<u>Requirements</u>
- **Materials produce temperatures <100 degrees C.**
- **Chemical reactions not produce unacceptable products.**
- **Material after setting cannot pose threat.**
- **Use appropriate materials for pressure grouting.**
  - **Hydraulic properties pumiable liquid-like, viscosity <30Cp.**
  - **Particle size <3mm.**
  - **Have set time >120 minutes.**
- **Hydraulic conductivity $<10^{-6}$ cm/s.**
- **Compressive strength compa rable to existing soils.**
- **Resist thermal and moisture changes.**
- **Prevent containment migration.**
- **<5% Free liquids after solidification.**
- ***Resist Biodegradation.***
- **Chemical and radiological reactions not generate gases unless gases eliminated.**

*** TREAT IN-SITU**
<u>Requirement</u>
- **Chem/Bio Treatment change form or element to non EPA listed waste.**

Monitor Effectiveness

DESIRABLE
- **Verify properly functioning** ***structures and identify*** **failed structures.**
- **Measure effect (benefit) of solution**

Figure 2. Block diagram with a summary of function-specific requirements.

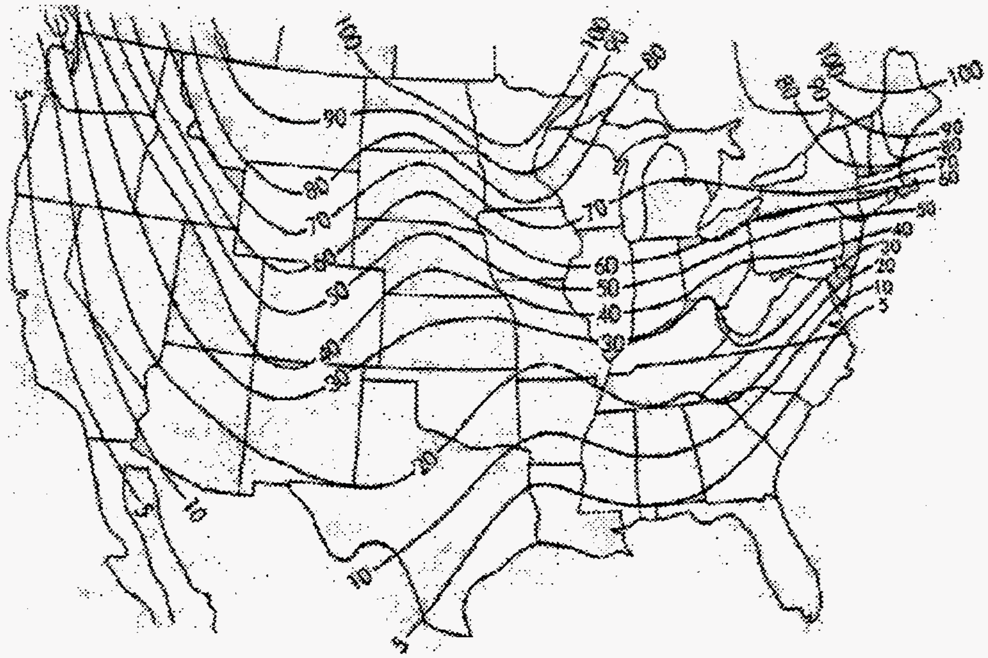

Figure 3. Maximum depth of frost penetration in the United States.

Table 1. Average yearly precipitation for each field office.

	Field Office	Average Precipitation (inches)	Number of Years Data 1961 to 1990
Arid	Albuquerque	8.9 (Pantex 19.5)	30
	Idaho	10.9	30
	Nevada	5.6 (Tonopah)	23
	Oakland	18.2	20
	Richland	12.1 (Lewiston, Id)	16
	Rocky Flats	15.4	30
Humid	Chicago	35.8	30
	Oak Ridge	47.1 (Knoxville)	30
	Ohio	35.7 (Columbus)	10
	Savannah River	38.3 (Asheville, NC)	10

Table 2. The numbers of landfill and plume sites separated by remediation option, arid versus humid site, and, for plumes, soil and groundwater.

	Total # of Sites	Contain Option				Retrieve Option	Hot Spots	No Impact	Unknown
		Arid		Humid					
Landfill	102	15		18		26	10	33	
		Soil	Water	Soil	Water				
Plume	283	6	2	5	11	110	3	33	93

Requirement: 2. Be compatible with waste materials.

Discussion: Figures 4 through 8 yield information about the constituents at the reporting sites. Constituents are categorized into volatile organic compounds (VOCs), non-VOCs, polychlorinated biphenyls (PCBs), radiological contaminants (rads) soluble in water, rads not soluble in water, tritium, metals, and high explosives. Figure 4 is a composite chart of the number of landfill sites with contaminants in each of eight categories. Figure 5 shows the number of landfill sites with a breakout of VOCs. Figure 6 shows the number of landfill sites with rads, by type, soluble in water. Figure 7 shows the number of landfill sites with rads, by type, not soluble in water. Figure 8 shows the number of landfill sites by type of metal.

Contaminant types located at plume sites are plotted in Figures 9 and 10. While there are more than 50 constituents at plume sites, Figure 9 shows the top 25 groundwater plume constituents and Figure 10 shows the top 25 soil contaminants. Figures 9 and 10 are a composite of contaminants located at plume sites; they are not separated by remedial option of containment or retrieval because of the high percentage of sites not reporting. They will be separated after additional data are collected.

Requirement: 3. Have a design life (durability) based upon the half-life of the contaminants in the buried waste.

Discussion: See Table 3. Design life is the period over which an engineered system or structure is expected to remain operational and perform its intended function. For example, long duration - uranium, plutonium, and iodine - would be greater than 10,000 years; short duration - cesium, strontium, tritium, cobalt - would be less than 30 years; organics are still to be determined.

Table 4 contains the number of sites, within the 50 sites with a containment option, sorted into short, long, or other durability considerations based upon the above definition, i.e., 10,000 years, 30 years, or to be determined. High explosive (HE), VOC, metal, and unknown categories should be included in the "to be determined category."

Trade study. There are trade-offs between reliability and maintainability in the area of performance, e.g., durability. There is no requirement for maintenance of the remedial solution; in fact, the regulatory guidelines state that there will be minimum maintenance. However, if durability is to be greater than 1,000 years, some maintenance is expected. In this regard, there is a trade between designing a solution to last a certain number of years versus designing a system to last fewer years and provide maintenance. Ultimately, the trades evolve to a life-cycle cost issue.

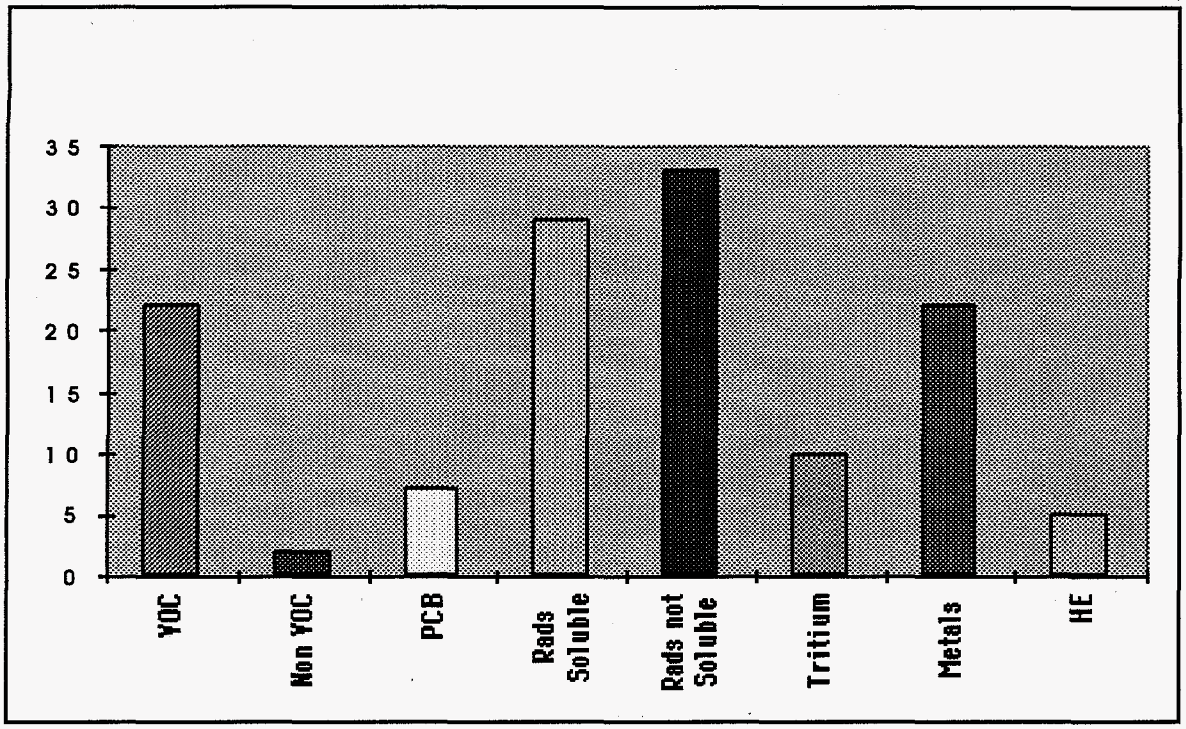

Figure 4. The number of landfill sites having a specific type, classification, of contaminants. A site may have one or more classes of contaminants.

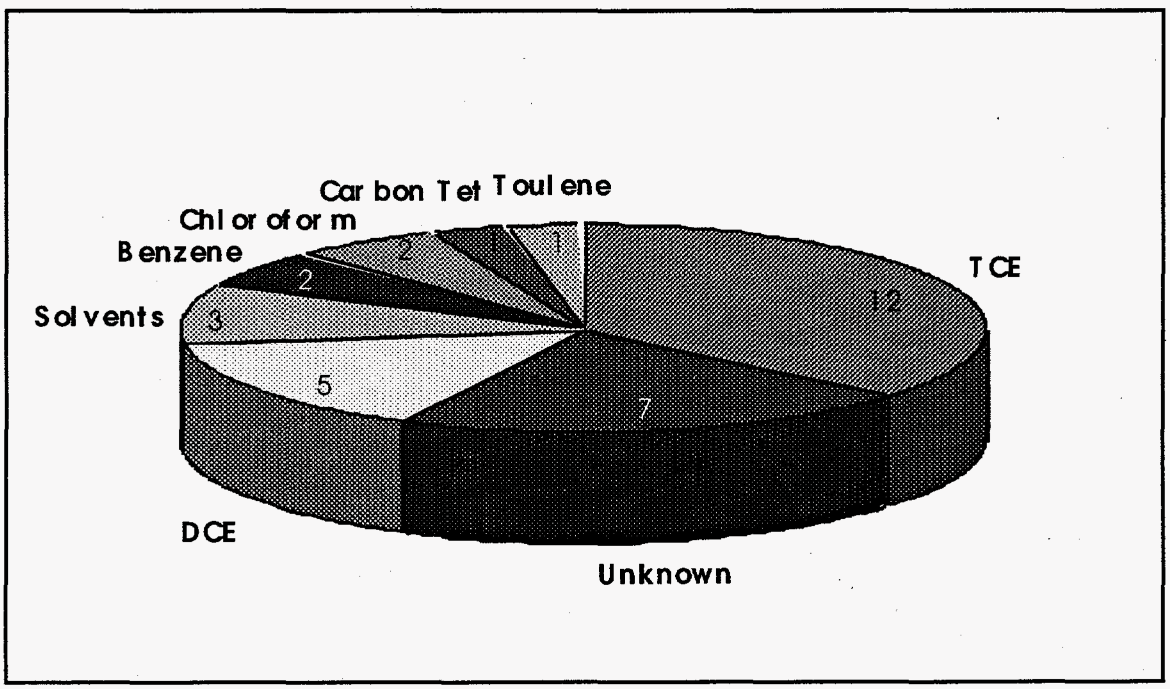

Figure 5. The number of landfill sites containing specific VOCs in the class of VOCs.

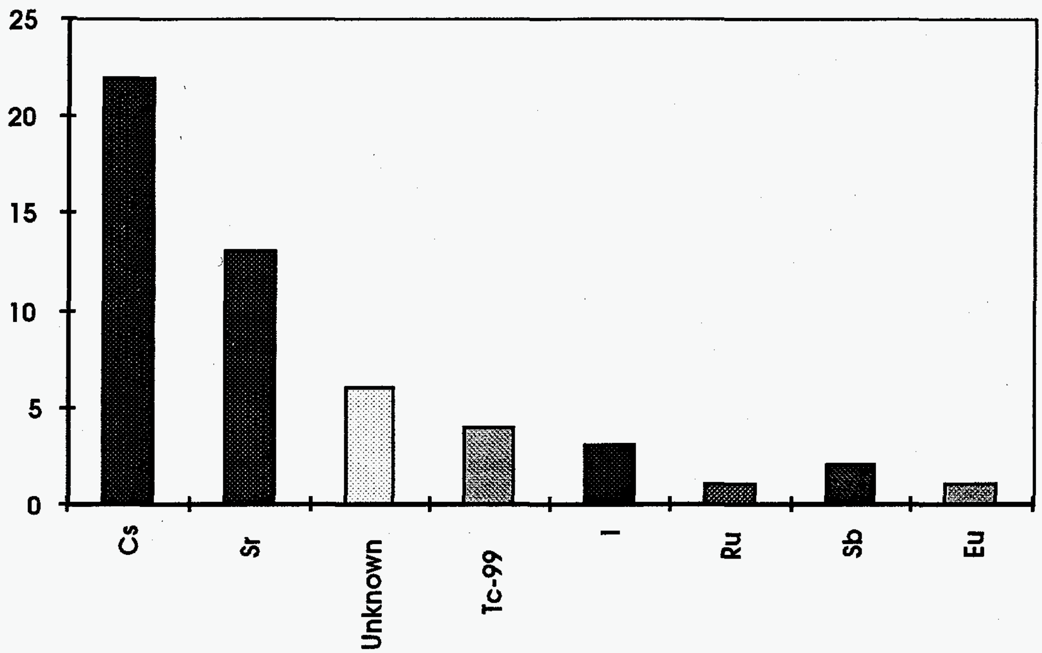

Figure 6. The number of landfill sites containing specific radiological contaminants (rads) in the class of rads, soluble in water.

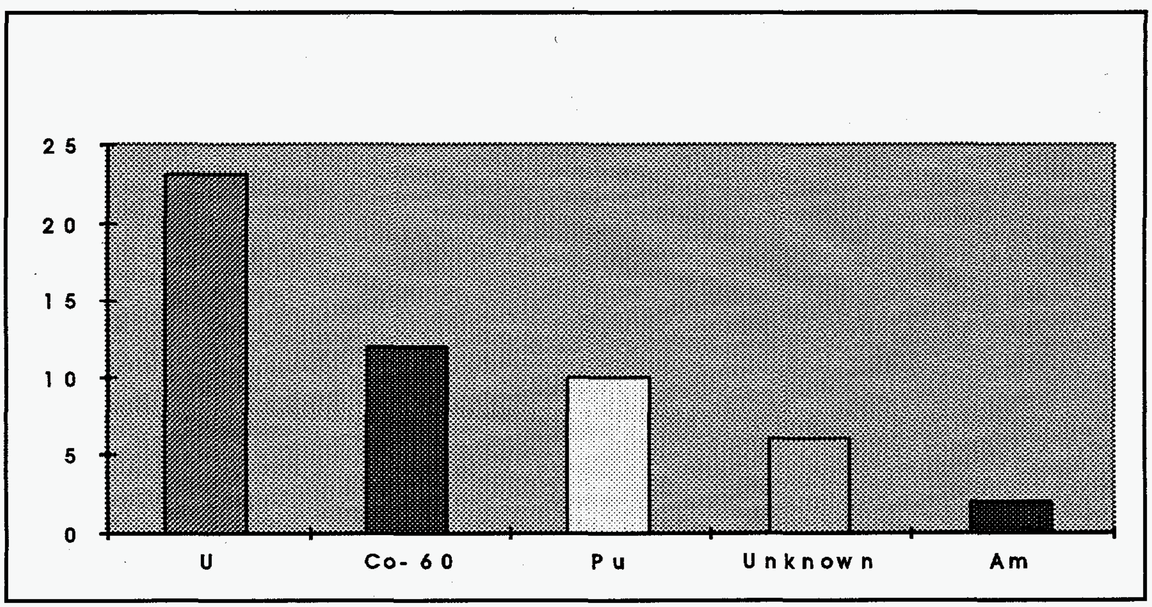

Figure 7. The number of landfill sites containing specific radiological contaminants (rads) in the class of rads, not soluble in water.

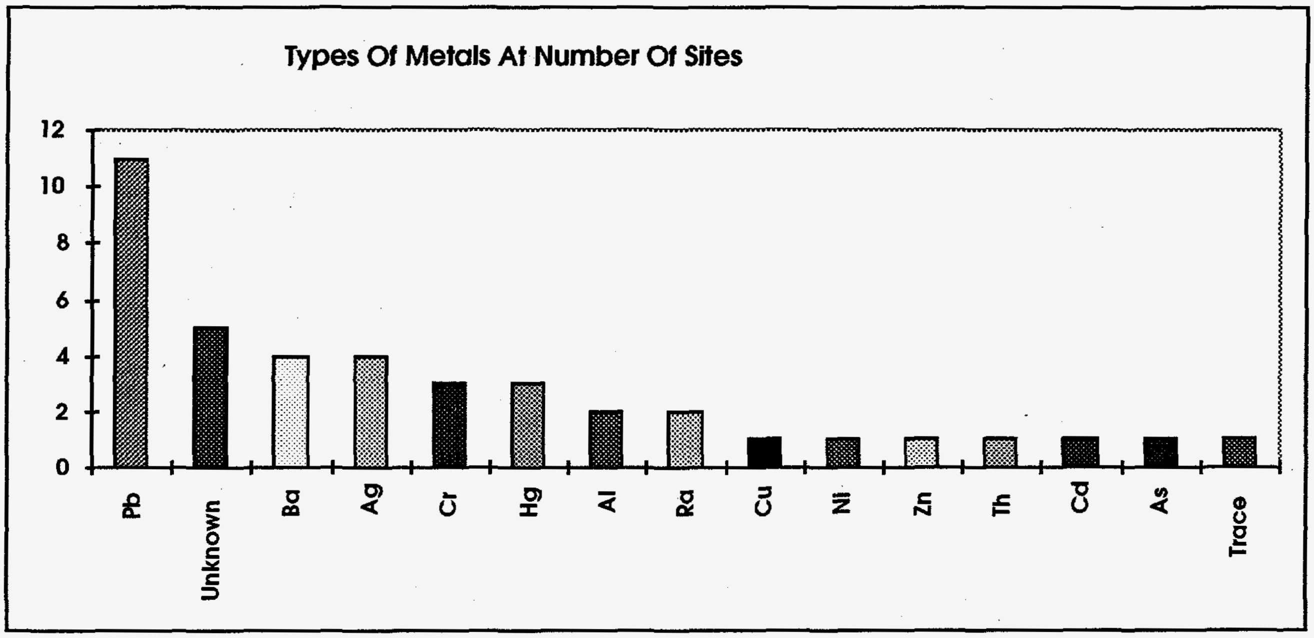

Figure 8. The number of landfill sites containing specific metal contaminants.

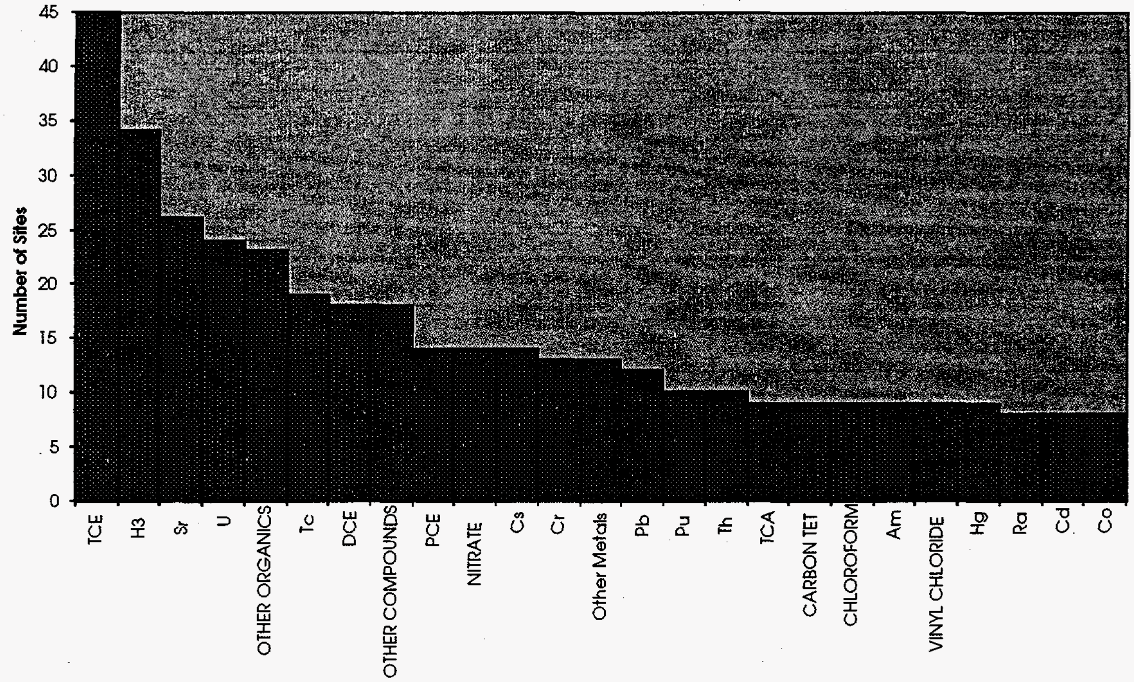

Figure 9. Top 25 groundwater plume constituents (independent of remedial option).

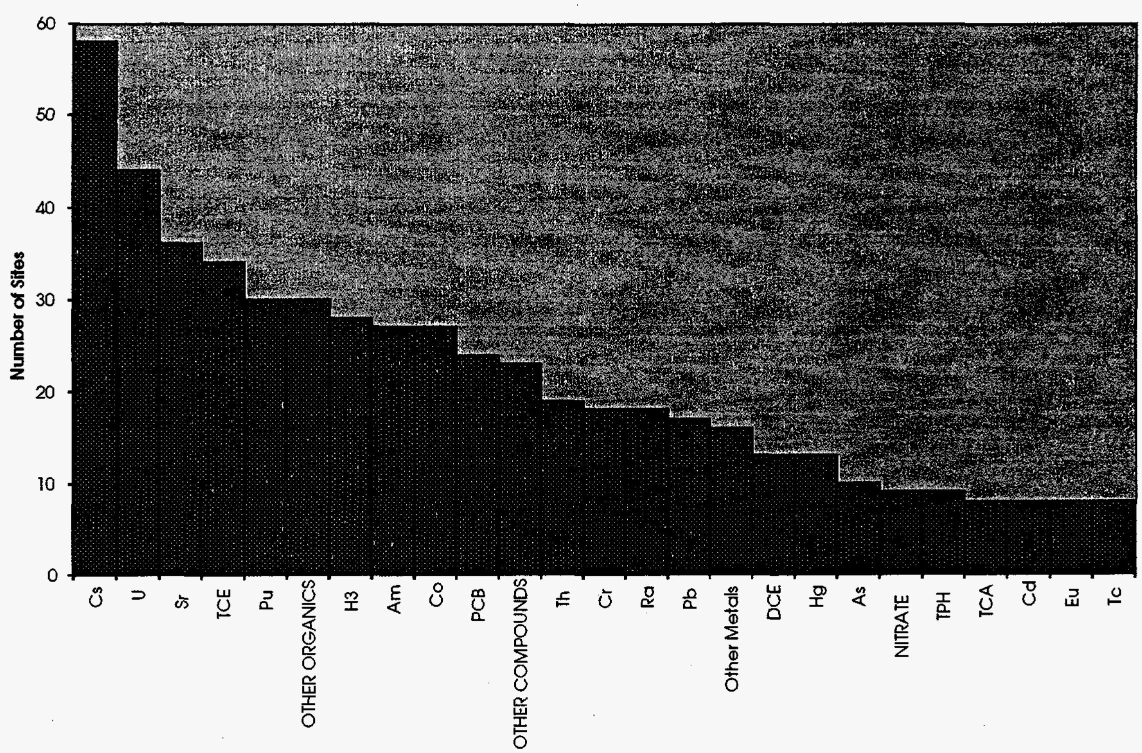

Figure 10. Top 25 soil contaminants at plume sites (independent of remedial option).

Table 3. List of half-lives for constituents sorted by half-lives and natural states on the left and sorted on the right by the number of sites with a specific constituent.

Constituents Ranked by Half-Life, Then Ranked by Natural State				Constituents Ranked by Number of Sites That Have a Specific Contaminant			
Item	Half-Life	State		Item	Half-Life	State	# Sites
U-238	4.50E+09			U-238	4.50E+09		23
Pu-244	7.60E+07			Cs-137	30		22
I-129	1.70E+07			Sr-90	27.7		13
Tc-99	2.12E+05			Co-59+	5.26		12
Ni	8.00E+04			Pb	3.00E+07	Natural	11
Am-243	7.95E+03			Pu-244	7.60E+07		5
C-14	5730			Tc-99	2.12E+05		4
Ra-226	1602			Ag		Natural	4
Cs-137	30			I-129	1.70E+07		3
Sr-90	27.7			Hg	1.00E+14	Natural	3
Eu-154	16			Cr-51		Natural	3
H-3	12.26			Ra-226	1602		2
Co-59+	5.26			Al-26	7.40E+05	Natural	2
Sb-125	2.71			Sb-125	2.71		2
Ba-133	7.2	Natural		Am-243	7.95E+03		2
Th-230	8.00E+04	Natural		H-3	12.26		1
Al-26	7.40E+05	Natural		Eu-154	16		1
Pb	3.00E+07	Natural		C-14	5730		1
Hg	1.00E+14	Natural		Ni	8.00E+04		1
Zn-64	8.00E+15	Natural		Ba-133	7.2	Natural	1
Cd-113	1.30E+15	Natural		Th-230	8.00E+04	Natural	1
Sb-123	1.30E+16	Natural		Zn-64	8.00E+15	Natural	1
Cr-51		Natural		Cd-113	1.30E+15	Natural	1
Cu		Natural		Sb-123	1.30E+16	Natural	1
Ag		Natural		Cu		Natural	1
As		Natural		As		Natural	1

Table 4. The number of sites in categories driving the durability of a containment solution.

Short	Long	HE	VOC	Metal	Unknown
9	27	3	6	1	4

Requirement: 4. Control advective and diffusive flow of contaminants, exceeding Environmental Protection Agency (EPA) guidelines, away from their place of disposal.

Discussion: The EPA guidelines for hazardous waste are contained in 40 CFR 261 subpart C, titled Characteristics of Hazardous Waste. More specific information on definitions and characteristics of hazardous waste is included in 40 CFR 261.21, Characteristic of Ignitability, 40 CFR 261.22, Characteristic of Corrosivity, and 40 CFR 261.23, Characteristic of Reactivity. 40 CFR 261.24, Toxicity Characteristic, includes a table with the maximum concentrations of contaminants for the toxicity characteristics. Appendix VIII to 40 CFR 261 lists the hazardous constituents.

Requirement: 4a. Control advective and diffusive flow of contaminants located from 1 to 250 feet below surface.

Discussion: Figure 11 plots the maximum depth of waste in feet from the surface. Where data was given in ranges, e.g., 10 to 20 feet, the depth was plotted as 20 feet. All of the waste depths are less than 50 feet from the surface except one at 250 feet. For purpose of scale, the one data point at 250 feet was excluded from the plot.

The maximum depth of plumes from the surface is contained in Figure 12. Figure 12 plots depths independent of contain or retrieve options and independent of soil or groundwater for plumes. For purposes of scale, two points at depths of 1,000 feet and 5,000 feet were not included in the data plot.

Requirement: 4b. Prevent contaminants from reaching the groundwater; groundwater depths are from 1 to 850 feet.

Discussion: Figure 13 plots the site data points of minimum depth, in feet, from the surface to the groundwater at the landfills. Where data was given in ranges, e.g., 10 to 20 feet, the depth was plotted at 10 feet. Most of the data points are less than or equal to 200 feet. For purpose of scale, a data point at 850 feet was excluded from the plot.

The minimum depth, in feet, from the surface to the groundwater at the plume sites will be included when additional data are collected. At this time, the maximum depth plot, Figure 12, for plumes gives a reasonable idea of the requirements across the complex to accommodate depth.

Of the 50 candidates for containment, currently six sites have reported potential problems with bottom water, one site with horizontal water, 17 sites with dense nonaqueous phase liquids (DNAPLs), and 2 sites with free liquids. Figure 14 is a potential problem summary chart. Similar information is not currently available for plume sites.

Requirement: 5. Prevent biological transport (i.e., intrusion of plants, animals, and insects) of contaminated waste to the surface.

Discussion: Plant roots could root into buried waste, actively translocating and disseminating contaminants in aboveground tissues. Roots may alter waste chemistry potentially mobilizing contaminants. Macropores left by decomposing plant roots act as channels for water and gases. Plant roots may concentrate in and extract water causing desiccation and cracking.

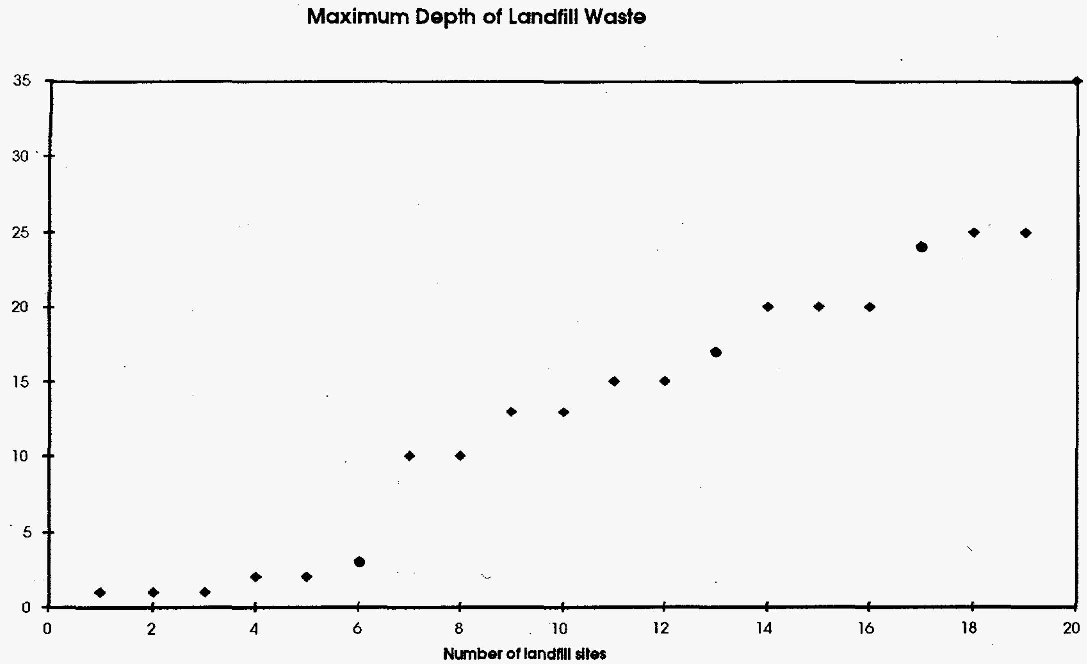

Figure 11. Plot of the maximum depth (in feet) of waste from the surface reported by 20 of the 50 candidate landfill containment sites.

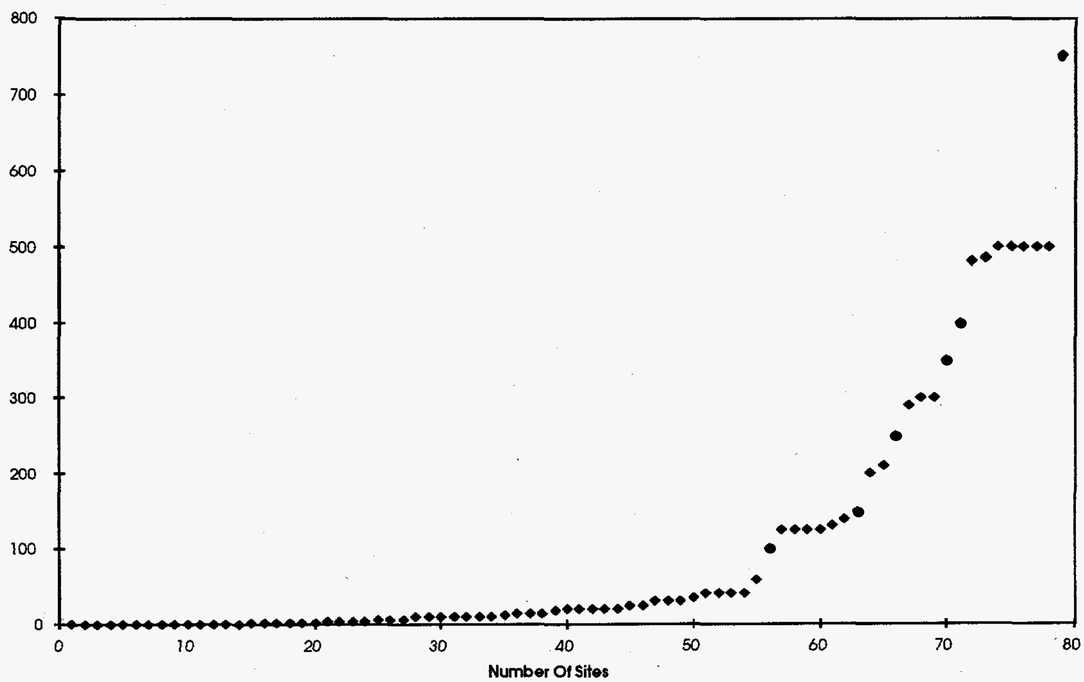

Figure 12. Plot of maximum depth (in feet) of waste from the surface reported by plume sites.

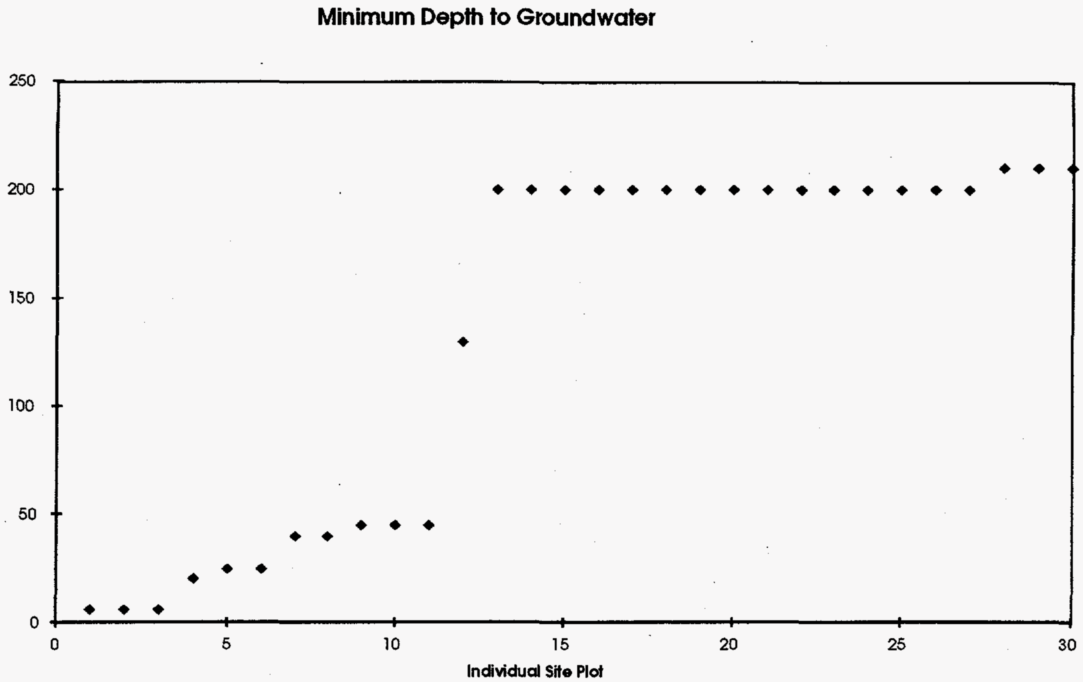

Figure 13. Plot of the minimum depth (in feet) from the surface to the groundwater reported by 30 of 50 candidate landfill containment sites.

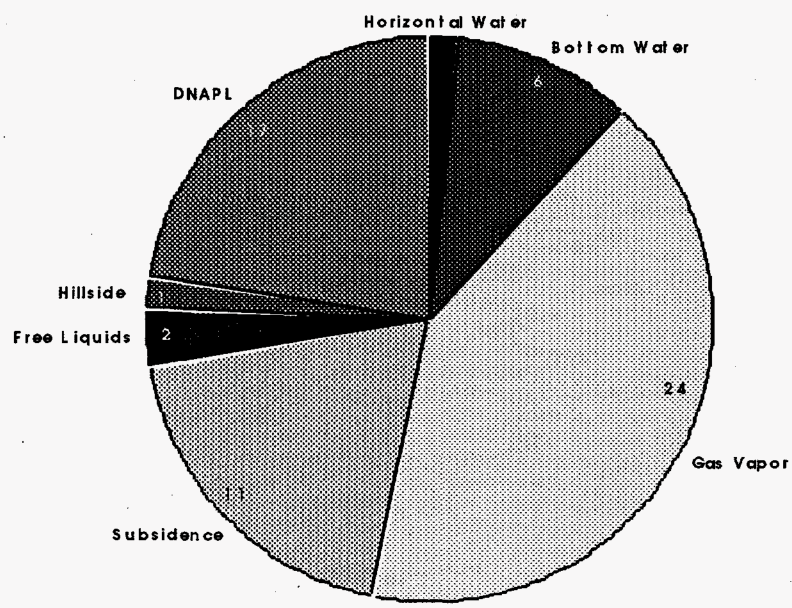

Figure 14. Within the 50 landfill candidate containment sites, this is a graphic depiction of the number of sites reporting potential problems in specific areas.

Burrowing and tunneling animals can mobilize contaminants by displacement of waste or by altering erosion, water balance, and gas release processes. Displacement results as animals excavate burrows and ingest or transport contaminants on skin and fur. Loose soil cast to the surface is susceptible to wind and water erosion.

Requirement: 6. Prevent exposure of buried waste that would contribute to migration of the waste, e.g., erosion (sheet flow, rilling, gullying, and wind deflation).

Discussion: Table 1 lists the arid and humid field offices with average annual precipitation. A reference that may be helpful when considering the impacts of erosion is, Ligotke, M. W., and D. C. Klopfer, 1990, *Soil Erosion Rates from Mixed Soil and Gravel Surfaces in a Wind Tunnel*, PNL-7435, Pacific Northwest Laboratory, Richland, Washington. Exposure could also result from subsidence. Currently 11 sites have reported a potential problem with subsidence, see Figure 14.

Desirable: The structure will support vehicular traffic for a loaded 2-ton truck on the ground surface without causing damage to the containment system.

Discussion: Supporting vehicular traffic enables transportation of personnel and equipment over the surface for inspection, maintenance (of monitors, barriers, or cover), and repair.

Trade Study: Consider repairability and maintenance in the life-cycle cost.

Requirement: 7. Maintain integrity of the remedial solution (no holes or breaches, no mixing of layers). This requirement is derived from all of the above requirements.

Requirement: 8. Be continuous (for example, no separations at seams if seams are used; positive placement). This requirement is derived from all of the above requirements.

Requirement: 9. Meet the set of requirements as stated in Department of Energy (DOE) Order 5480.31 prior to start of operations (Operational Readiness Review).

Requirement: 10. Meet the remediation schedules.

Discussion: Site remediation schedules for plume sites are depicted in Figures 15 through 19. The remediation schedules are for plume sites but give a good representation of the schedules to meet for the entire SCFA. The graph will be updated to include the landfill site data when the data are collected. Technology development demonstration results must be available to support the alternatives analysis. After alternative selection, other technologies can be infused as replacement technologies when they show a clear cost, schedule, and/or performance advantage for the SCFA.

Requirement: 11. Decontaminate or dispose of all equipment, structures, and material used during remediation per DOE Orders 5400.5 and 5480.11.

Characterization Schedules

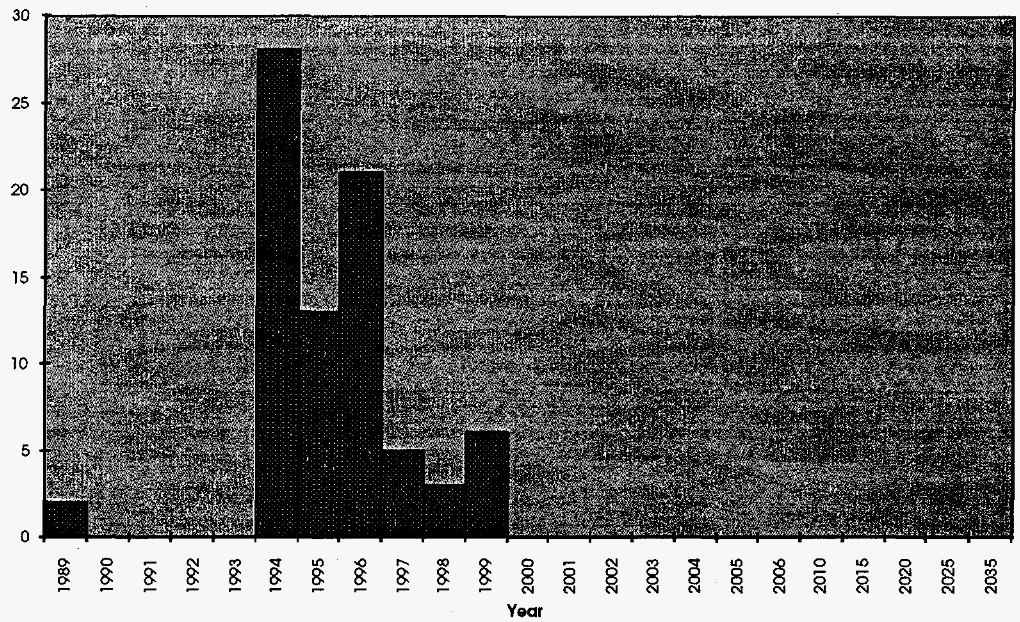

Figure 15. Summary of schedules for plume site characterization.

Alternatives Analysis

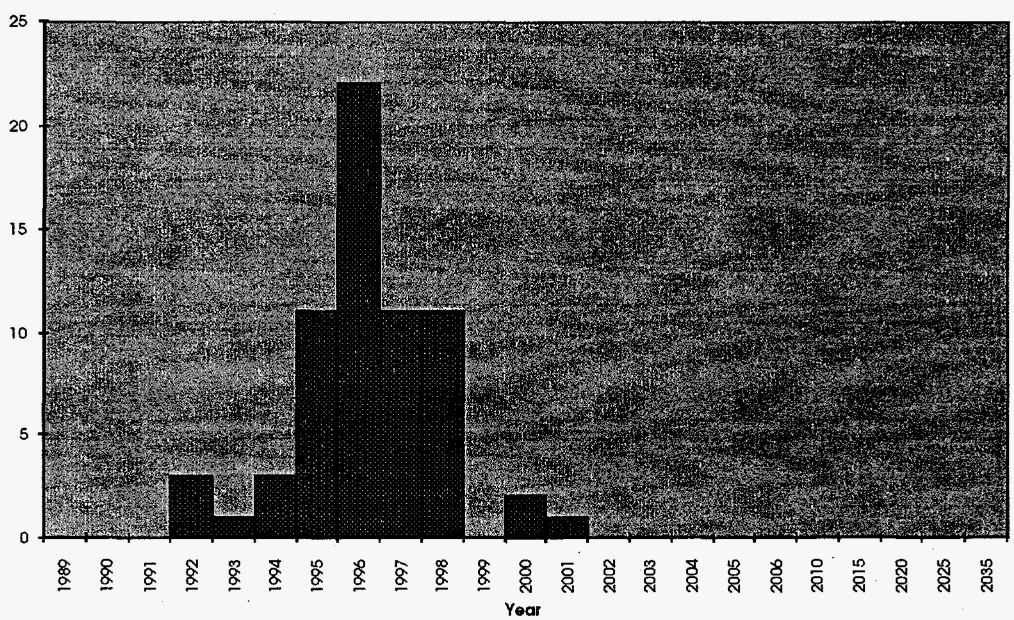

Figure 16. Summary of schedules for plume alternatives analysis.

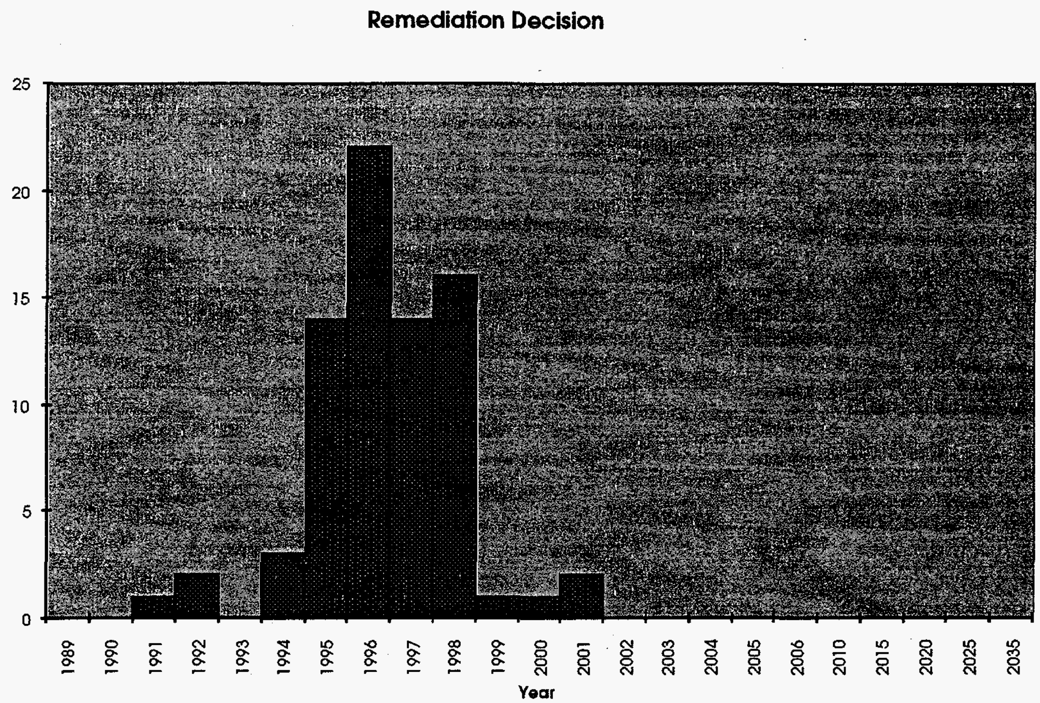

Figure 17. Summary of schedules for plume site remediation decision.

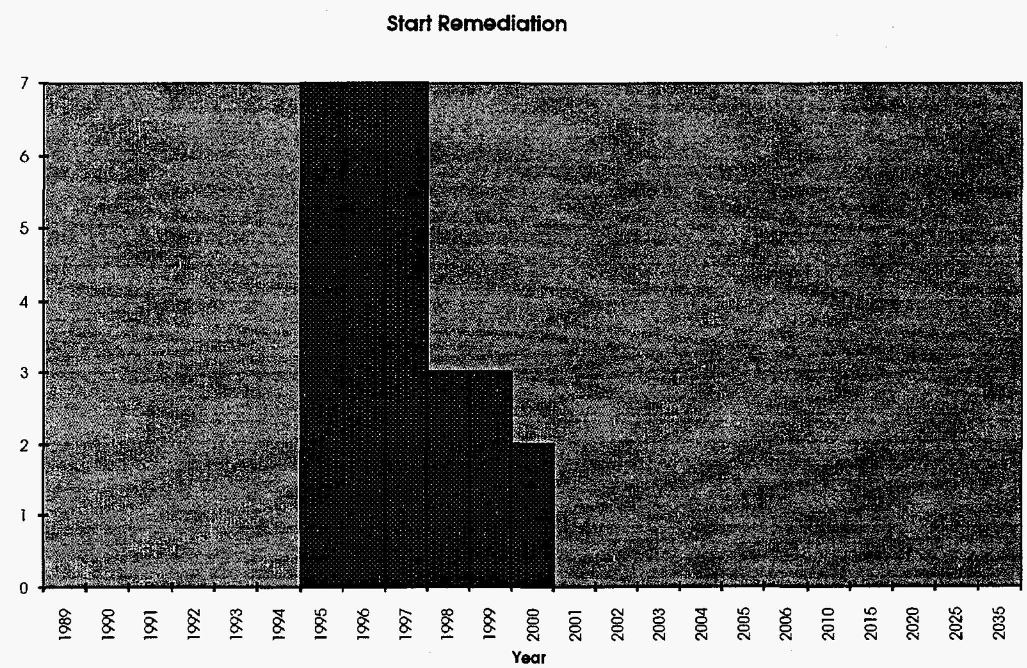

Figure 18. Summary of schedules for plume site start remediation.

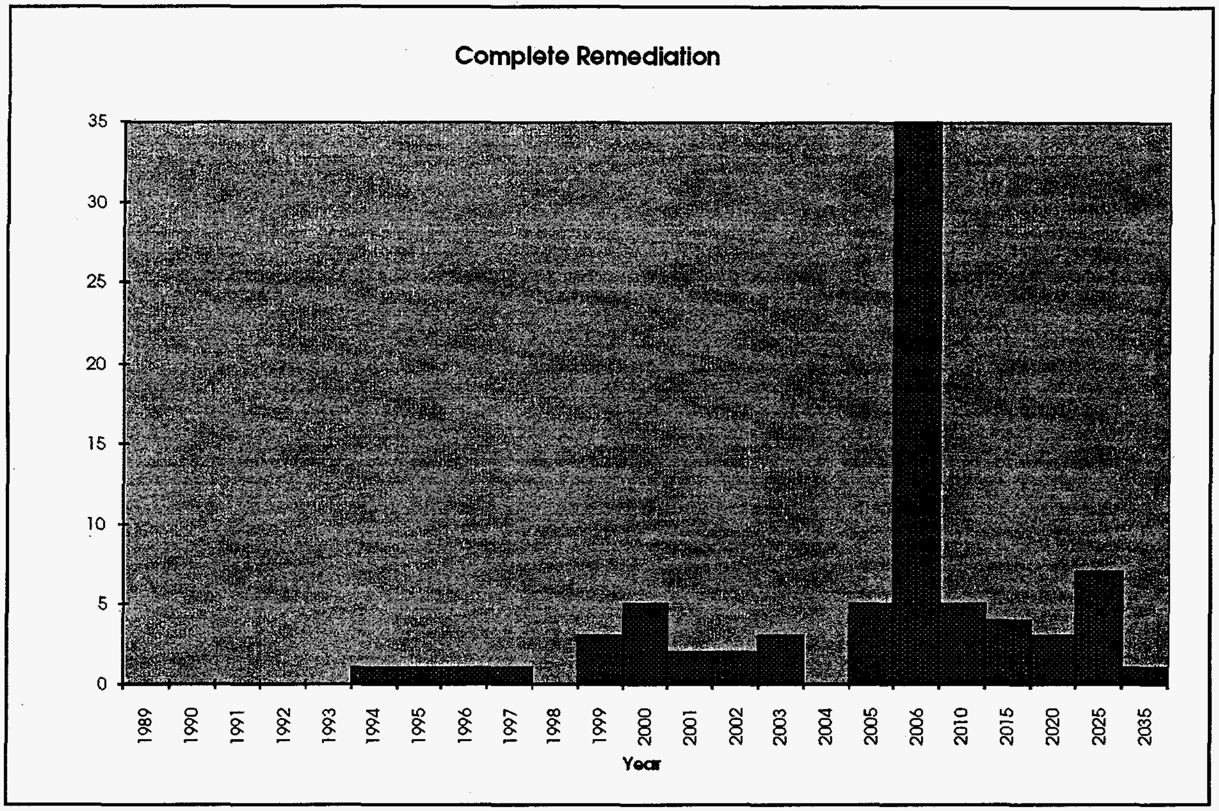

Figure 19. Summary of schedules for plume site complete remediation.

Desirable: The design features will:

a. Eliminate current and prevent (do not create) pathways for water infiltration into the waste material due to cracks, crevices, roots that have rotted over time, holes due to insects and animals, or subsidence that might funnel water into the waste.

b. Be a systems versus a compartmentalized approach, i.e., consider the design as a whole rather than independent components to be combined at a later date.

2.2 Requirements That Are Function Specific

2.2.1 Characterize for Containment Planning

Requirement: 1. Map the boundaries (landfill or plume).

Discussion: Area is known for 31 of the 50 landfill candidate sites for containment. These areas, in acres, are plotted in Figure 20. For scale, this figure excludes three large sites with areas of 200, 194, and 97 acres. The depth of waste (Figures 11 and 12), depth to the groundwater (Figure 13), and potential

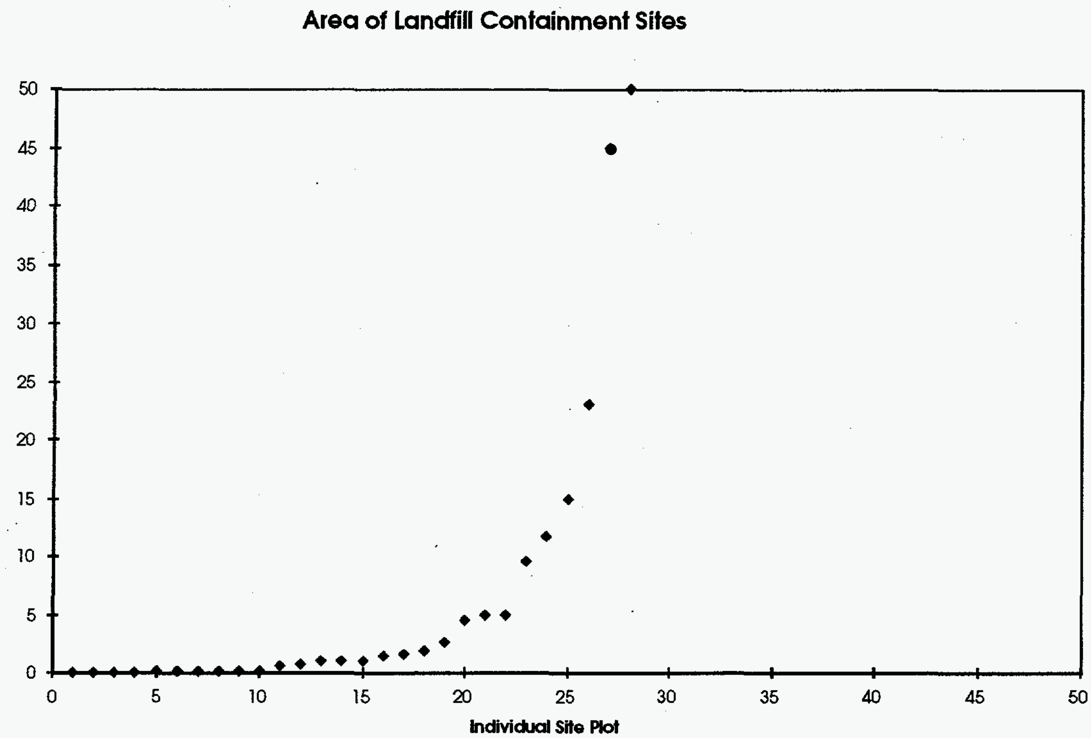

Figure 20. The area, in acres, of the landfill site candidates for containment.

problems (Figure 14) will help in the mapping strategy for the landfill boundaries. The area information for plumes is not currently meaningful; plume area information will be added as soon as it is available.

Trade Study: Measurement accuracy and resolution for length, width, and depth affect size and cost of equipment and materials.

Requirement: 2. Determine the mass or radioactivity and concentration of the constituents of concern above EPA limits.

Discussion: References for EPA guidelines are contained in paragraph 2, requirement number 4. This information yields the physical distribution of contaminants. For this requirement, we assume that we know the contaminate(s) of concern from site characterization.

Trade Study: Mass or radioactivity and concentration of constituents impact the problem definition and the treatment options relative to type of treatment, compatibility, etc. However, there is a tradeoff between characterization and treatment, i.e., better characterization may lead to less treatment, or treatment may be less expensive than characterization.

Requirement: 3. Data gathering shall determine the soil permeability, conductivity, and pH.

Discussion: This information impacts the technical solution. Ranges for these parameters will be included in this requirements document as soon as data become available.

2.2.2 Prevent Infiltration

Requirement: A surface structure (could be a cap or a building) shall maintain the water balance (for a period established by general requirement number 3, durability), if water infiltration from the top is the problem or a potential problem. Water balance shall be determined by the equation $P = ET + S + D + RO$ where:

P	=	precipitation
ET	=	evapotranspiration
S	=	soil water storage change
D	=	drainage
RO	=	water runoff

Reference: Equation is from BHI-00007, *Prototype Hanford Surface Barrier: Design Basis Document,* Bechtel Hanford, Inc., Richland, Washington, November 1994, pages 7-11.

2.2.3 Stop Migration of Contaminants

2.2.3.1 Install Vertical Barriers.

Requirement: Vertical barriers shall extend from the top of the waste and shall be keyed into the bottom barrier (natural or manmade) such that no contaminants will migrate around or under the barrier.

2.2.3.2 Install Bottom Barriers.

No additional requirements were identified.

2.2.3.3 Stabilize In Situ.

Performance criteria were extracted from INEL-96/0069, *Laboratory-Performance Criteria for In Situ Waste-Stabilization Materials,* Peter Shaw and Jerry Weidner, March 1996.

Requirement: 1. Stabilization materials shall produce temperatures less than 100°C during and after the application process.

Requirement: 2. Chemical reactions between waste-stabilization material and waste shall not produce unacceptable results such as a steam or chemical explosion, separation of phases, production of hazardous compounds, or degradation of the waste form properties.

Requirement: 3. The final waste-stabilization material after setting cannot itself pose a threat to human health and the environment.

Discussion: This does not preclude the possible present hazardous components. In other words, the final waste form material cannot exhibit any EPA characteristic hazards such as being ignitable, reactive, or corrosive. See paragraph 2.1, requirement number 4.

Requirement: 4. For pressure grouting, the uncured materials must be appropriate.

Requirement: 4a. The material must have hydraulic properties, i.e., be a pumpable liquid-like material with a viscosity of less than 30 cP.

Requirement: 4b. The size of the particles must be less than 3 mm to prevent nozzle plugging.

Requirement: 4c. The material must be suspended in a hydraulic state for and have a set time greater than 120 minutes.

Requirement: 5. The hydraulic conductivity shall be less than 10^{-6} cm/s.

Discussion: The goal for hydraulic conductivity is 10^{-7} cm/s. This value is about the rate of ionic diffusion in water.

Requirement: 6. Applicability of a waste form for the mechanical stabilization of a waste site to prevent subsidence shall have a compressive strength comparable to the undisturbed soils already existing at that site.

Requirement: 7. Stabilized waste shall resist the normal thermal and moisture changes found in the environment at the site.

Discussion: Site-specific values shall be generated for (a) wet-dry conditions, (b) high-low temperature range, (c) thermal degradation, and (d) variable waste loading. For the Idaho National Engineering Laboratory (INEL), suggested ranges for compressive strength measurement are wet-dry, 5-100% relative humidity, high-low temperature 80 to -20°F, and waste loading 0-50% waste, 0-67% soil. Use the American Society for Testing and Materials procedure for hydraulic cement, bitumen, and plastics for measuring compressive strength.

Requirement: 8. Stabilization materials shall prevent contaminant migration to less than the EPA limit, i.e., retard the dissolution of itself and the contained waste.

Discussion: It is recognized that chemical durability, i.e., the ability of the waste form to resist chemical attack in a specific waste site is a function of the geochemistry of that site.

Requirement: 9. To comply with the general Nuclear Regulatory Commission rule, there shall be less than 0.5% free liquids after solidification.

Requirement: 10. Final waste form shall resist biodegradation by both fungi and bacteria that may be common in the repository environment.

Discussion: This is more of an issue with organic polymers than inorganic substances containing no carbon.

Requirement: 11. Chemical and radiological reactions of both the waste-stabilization material and waste shall not generate radioactive and nonradioactive gases unless the system being employed eliminates the hazard associated with the gases.

Requirement: 12. The long-term stability of the waste form shall not degrade from damage to the solidification agent from gamma, beta, alpha, or neutron fields.

Discussion: Testing in a 108-rad field is necessary if the waste site contains high field contaminants such as reactor parts or high-level waste processing by-products.

2.2.3.4 Treat In Situ—Biological and Chemical.

Requirement: Biological and chemical treatment shall change the form of the element such that the element and the change are not an EPA-listed or characteristic waste.

2.2.4 Monitor Effectiveness of the Containment/Stabilization

Desirable: 1. Monitoring equipment will verify properly functioning structures and identify failed structures.

Discussion: The accuracy of verification, types of monitors, and placement of monitors are dependent upon verifying that requirements are satisfied. Accuracy of verification is dependent upon the EPA limits or background that establishes remediation standards.

Desirable: 2. Equipment will measure the effect (benefit) of the remediation solution on the contaminated and surrounding area.

Trade study: The number, location, and type (physical or nonphysical, manual or automatic) of monitoring instruments depend on the type of data, range, and accuracy of the instruments. Once the trade study is complete, the result may generate specific requirements for the monitoring instruments, e.g., electronics, controls, control room, alarms (how often), etc.

3. SOURCE TERM AND PLUME RETRIEVAL

Section 3 summarizes requirements for source term and plume retrieval. Source term retrieval is the removal of contaminants by excavation from a designated source term such as a landfill. This includes waste, interstitial material, and surrounding matrix that lies within the physical boundaries of the source term. Contamination that has migrated from the source term is considered a plume. Plume retrieval is the physical removal of contaminants from a groundwater or contaminated soil plume. Retrieval is classified as full or selective. Selective retrieval is the removal by excavation of selected contaminants of concern from a source term or plume. This removal may be complete or partial depending on the requirements of the specific site. Examples include containers or high concentrations of major risk drivers such as contaminated soil near the source of a spill.

The requirements presented here include source term and plume characterization that directly supports excavation, the excavation itself and associated support functions, and the identification and placement of the retrieved material. They do not include general site characterization that is not associated with a preferred option. Also not included are ex situ treatment, long-term storage, and final disposal.

Source term and plume retrieval consists of three activities: mapping boundaries, excavating or removing the waste or contaminant, and placing the waste prior to disposal or treatment. Within these activities are 14 specific functions. These functions and their associated requirements are illustrated as a summary configuration option in Figure 21. Each of these requirements and desired attributes is presented and discussed in the following sections.

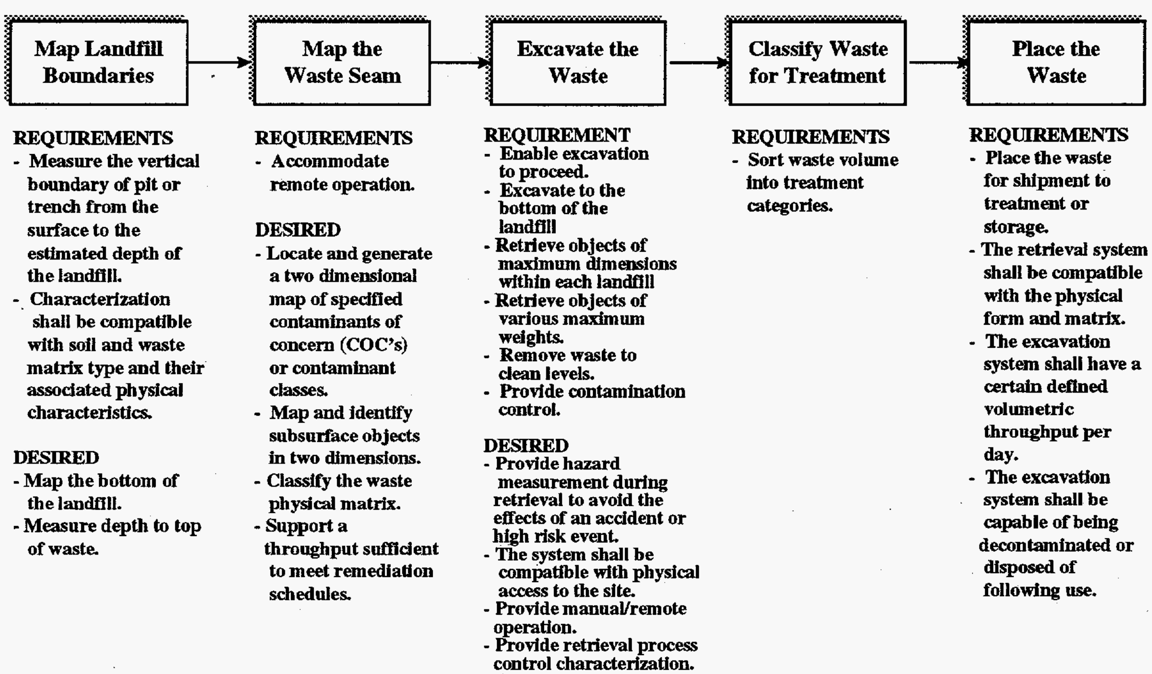

Figure 21. Retrieval/Removal functions, Requirements, and Desirables

Figure 21. Retrieval/removal functions, requirements, and desirables.

3.1 Characterization for Excavation Planning

The purpose of characterization for excavation planning is to gather information directly relating to subsequent excavation activity. Included are the functions of mapping the source term boundaries and locating and mapping the waste seam itself.

Function 1: Map the source term boundaries.

Requirement: 1. Measure the vertical boundaries of pit or trench from the surface to the estimated depth of the source term.

Discussion: There is a requirement to provide both spatial and vertical profile of the external boundaries of a pit or trench source term for remediation planning and control. To select or design a technology or system that will meet this requirement, estimated depths of the source term sites must be known. There is some information available from preremediation site characterization and historical records. Because each site has unique requirements, depth is expressed as a graph showing estimated depth for each site across the complex problem set. Figure 22 displays depth as a function of facility sequence. Facilities were listed in ascending order from the least to the greatest depth. Known data on landfill source term depth are illustrated in Figures 23 and 24.

Below is a scatter plot showing depths at facilities with corresponding facility volumes. This relates the volume of individual sites with certain estimated depths. Note that multiple facilities overlap on this type of chart.

It is useful to know how much of the total source term retrieval volume is at or less than a certain depth because most characterization technologies are limited by depth due to effects such as dispersion or attenuation. Below is a plot relating depth to total complex volume. A certain volume on the abscissa represents the total retrieval volume at a depth that is equal to or more shallow than the corresponding depth on the ordinate.

Plume depths also have to be known to physically remove contaminants. Figure 25 illustrates the estimated depths of plumes where the preferred option is known to be excavation.

Figure 26 illustrates depths of plumes that are anticipated by the sites to be remediated by pump-and-treat removal technology.

Trade Study: There are trade issues associated with mapping the source term and plume boundaries. Depth and spatial accuracy will vary among technologies. Lower accuracy will require a wider safety margin, thus increasing the volume of matrix excavated. This may reduce net volume or drive additional sorting requirements. Both of these add additional cost to the overall remediation. Resulting volumetric increases can be first order modeled as being proportional to the square of the inaccuracy for 3D errors, and is linearly proportional to the inaccuracy for spatial 2D mapping errors.

Desirable: Map the bottom of the source term.

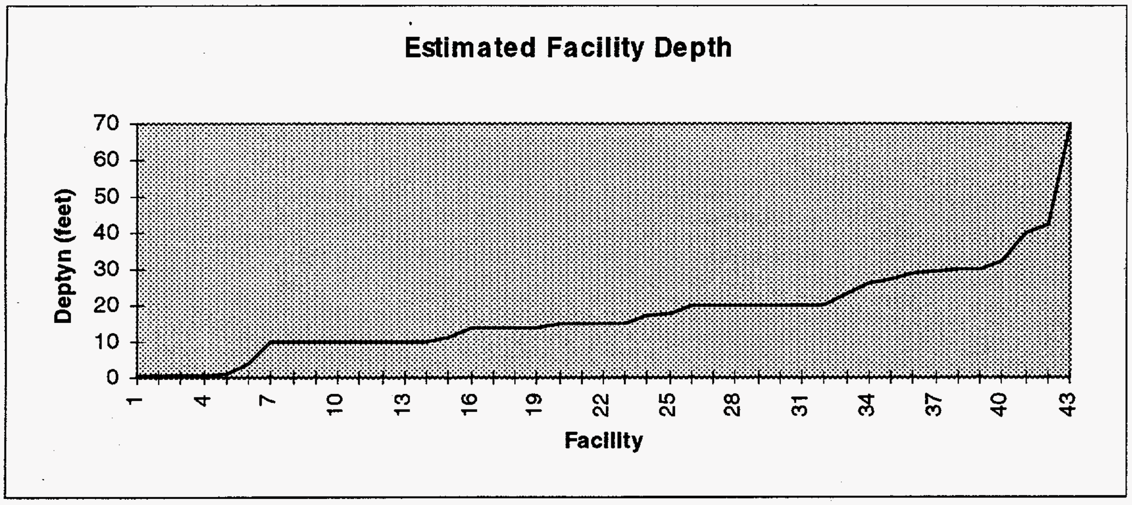

Figure 22. Landfill estimated facility depths.

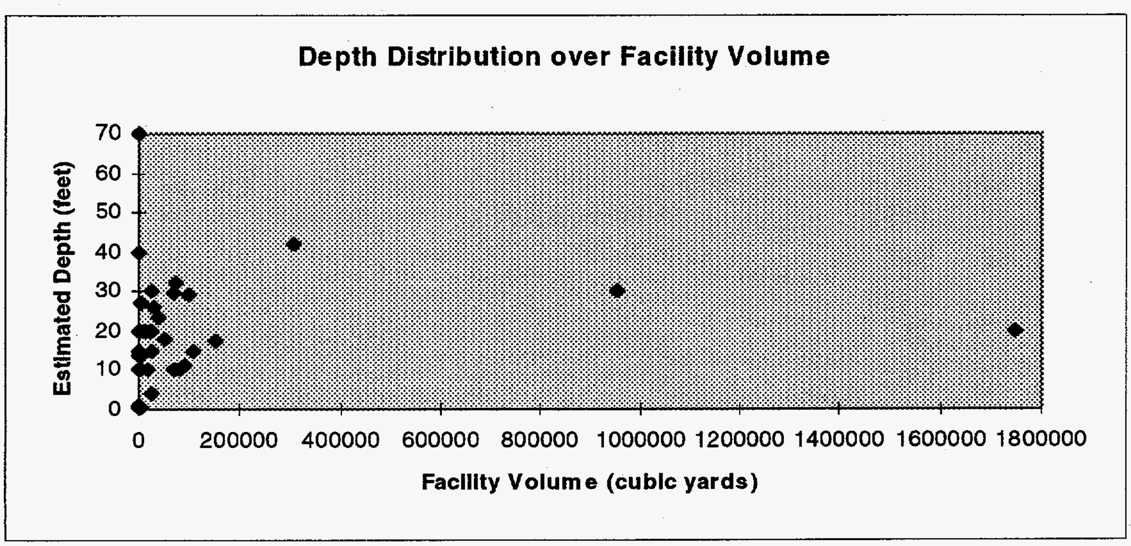

Figure 23. Estimated landfill depths and volumes.

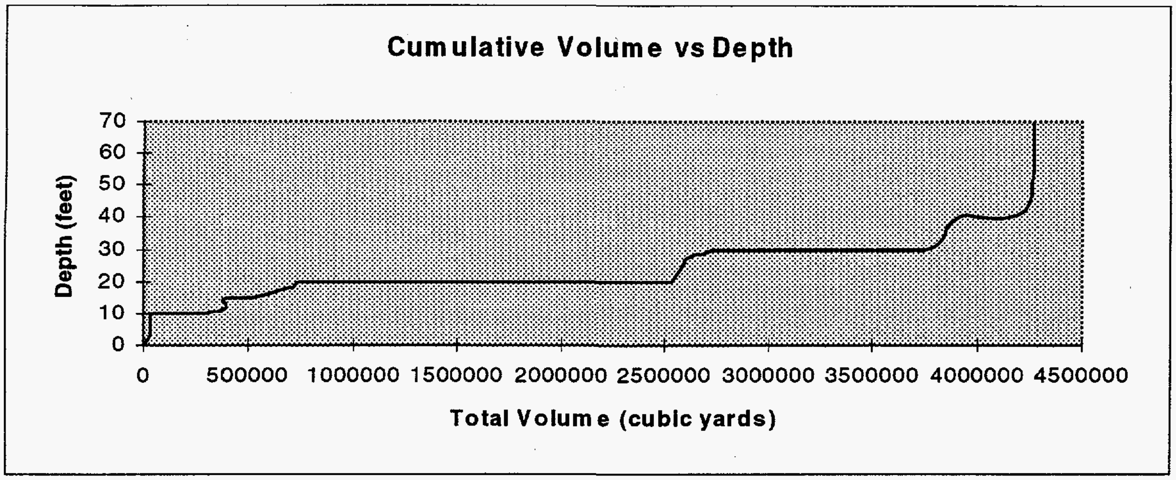

Figure 24. Landfill cumulative volume versus estimated depth.

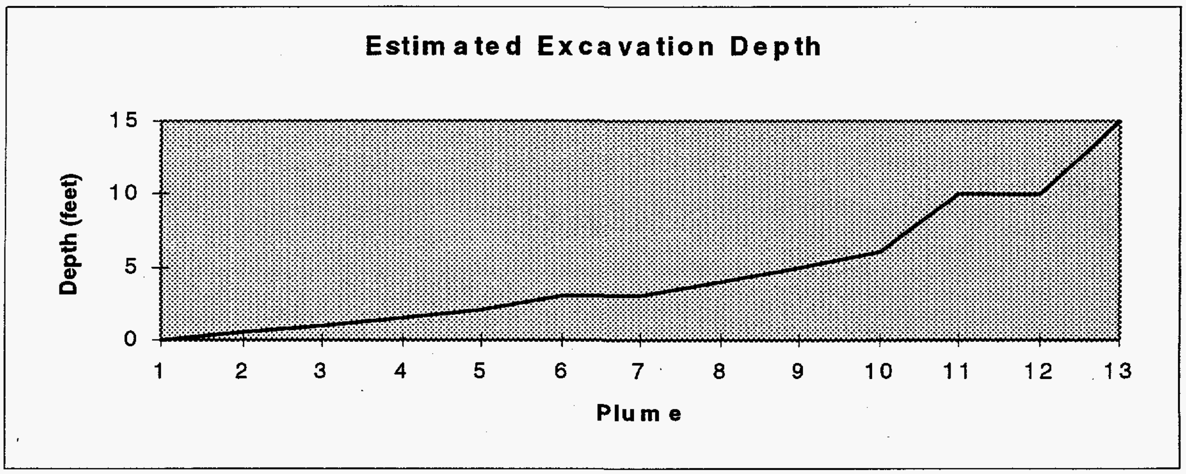

Figure 25. Estimated depths of plume excavation options.

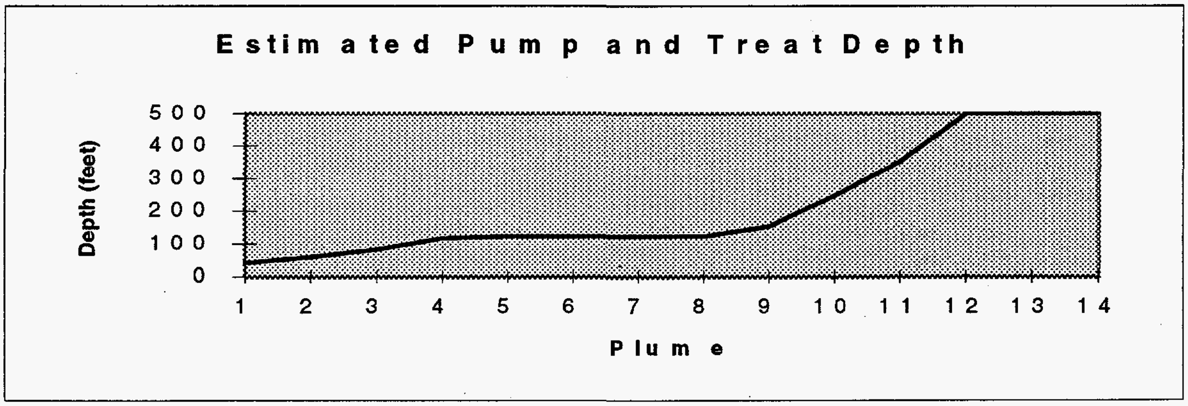

Figure 26. Estimated depths of plume pump-and-treat options.

Discussion: Determine the depth to the bottom of a source term and create a spatial map from this information. This is necessary to plan the excavation, particularly if the bottom depth varies greatly with location. If this is not known beforehand, it must be measured. To fulfill this requirement, the measurement
and mapping technology must be able to measure the bottom of the waste at least to the predicted depth of the source term. Known data on landfill source term depth are illustrated in Figures 22, 23, and 24. Known data on plume depth are illustrated in Figures 25 and 26.

Requirement: 2. Characterization shall be compatible with soil and waste matrix type and their associated physical characteristics.

Discussion: Various characteristics of waste matrix and the surrounding geology affect the performance of source term characterization technologies. Known information about landfill source term retrieval site characteristics includes the physical matrix classification by volume (Figure 28) and by waste stream (Figure 30), calculated matrix density (Figure 35), and known landfill retrieval object dimensions (Figure 31). Figures 30 and 35 are illustrated in Section 3.2, Retrieval.

Desirable: Measure depth to top of waste.

Discussion: Accurately knowing the overburden thickness facilitates clean overburden removal prior to remediation of the waste seam. This may be done at some cost of characterization and will net a cost savings by not treating the clean overburden as waste. Known overburden thickness for 25 landfill locations is illustrated below as Figure 27.

Function 2: Map the landfill waste seam.

Desirable: Locate and generate a two-dimensional map of specified contaminants of concern or contaminant classes.

Discussion: Spatial location (X-Y location) of the waste location is necessary to minimize retrieval volume. Further volume reduction can be attained if depth information is known.

Desirable: Map and identify subsurface objects in two dimensions.

Discussion: Locating subsurface objects spatially is desired for remediation activity. These can be located through characterization, or determined as a by-product of the excavation activity itself. Subsurface objects can be classified as waste objects such as barrels, boxes, or casks, or may be geological features. Knowing this information prior to remediation allows excavation activity to be tailored to the actual spatial distribution of the waste itself, thus avoiding some or all excavation of the uncontaminated matrix. This will reduce the effective throughput requirement and thus can reduce cost. Also, work can be planned so that the approach can be tailored to the detected problem. Different parts of the remediation system can be scheduled to perform when needed.

Figure 31 illustrates known landfill subsurface object maximum linear dimensions.

Desirable: Classify the waste physical matrix.

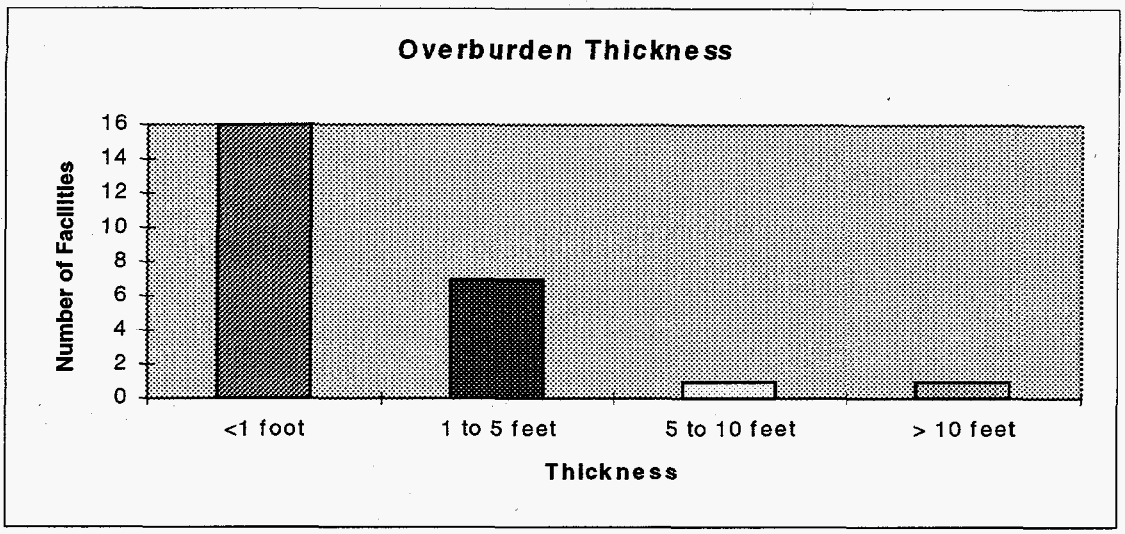

Figure 27. Landfill overburden thickness summary.

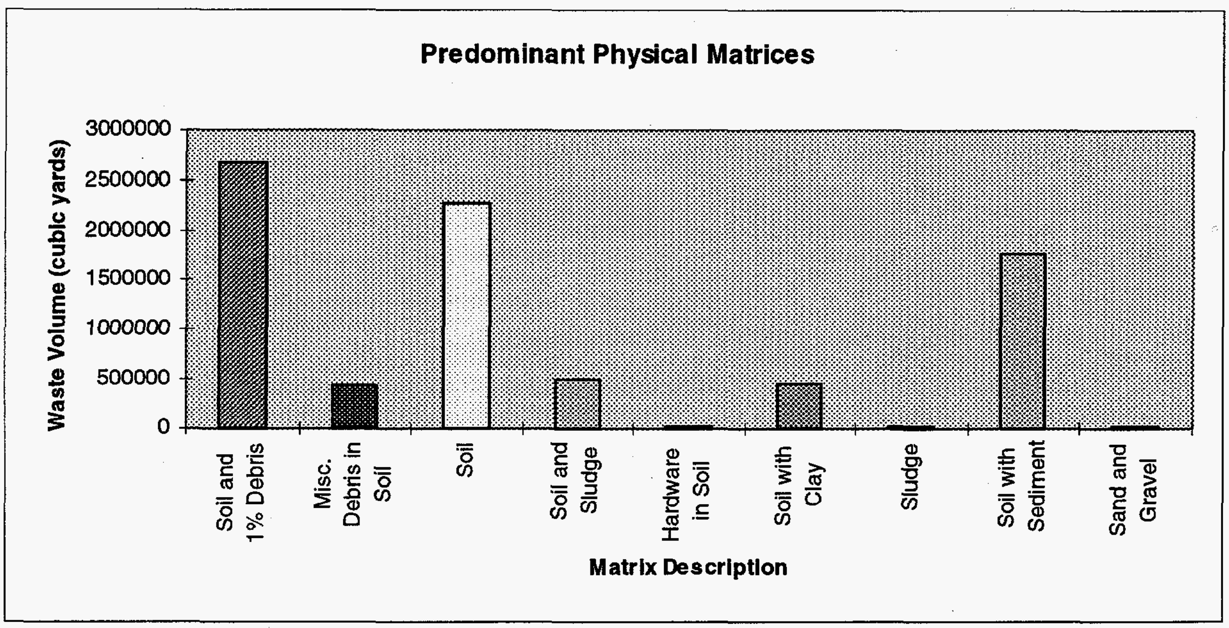

Figure 28. Predominant physical matrices of the landfill retrieval sites.

Discussion: Once the physical matrix is known, the remediator can properly assign retrieval system components that are compatible with sizes, shapes, and other physical characteristics of the waste matrix being retrieved.

Figure 28 summarizes known physical matrix information among the source term sites where retrieval is the preferred or assigned option. There are 12 categories, and each known total volume is presented. At some sites, several matrix categories are represented within the same facility. Note that soil is the single largest volume of any of the matrices presented for the landfill sites.

Non Function-Specific Requirements

Requirement: 3. Accommodate remote operation.

Discussion: Remote operation is necessary at sites where the waste matrix or objects classified as unexploded ordinance, pyrophoric, or high-level radiological waste are known to be in the source term. Figure 29 illustrates the number of sites that have known unexploded ordinance or high explosives, pyrophorics, high-level radiological waste, or remote-handled waste. Sites containing alpha emitters (as defined by low surface count rates per 10 CFR 835) are also included in the figure because it is likely that remediation of these sites will be performed using full or partial remote-handling technology.

Desirable: Support a throughput sufficient to meet remediation schedules.

Discussion: Many remedial decisions have not been made for the source term sites. It is useful, therefore, to examine throughput requirements against a common baseline. Figure 43 illustrates the remediation throughput requirement as a function of occurrences for an assumed 10-year lifetime. This graphic does not break out time required for excavation planning characterization or the excavation and placement of the waste itself. Time savings in characterization will reduce system excavation and placement throughput.

3.2 Retrieval

The purpose of retrieval is to physically remove waste from the source term. Included activities are excavation, waste classification (as necessary), and placement of the waste and associated contaminated matrix material.

Function 1: Excavate waste.

Requirement: 1. Enable excavation to proceed.

Discussion: Treat or modify the waste seam and/or overburden as necessary to make the physical form compatible with the retrieval function. This might include physical modification of the waste form so that it can be efficiently removed. Examples include solidifying sludge or creating an aggregate. Another activity is actively preventing subsidence through the use of things such as physical barriers or stabilization technologies. Figure 28 is a summary by volume of nine predominant physical matrix categories. Note that contaminated soil is the predominant matrix.

Figure 30 illustrates the eight predominant matrices' occurrence by waste stream. Like the volumetric chart, soil composes the majority of data entries.

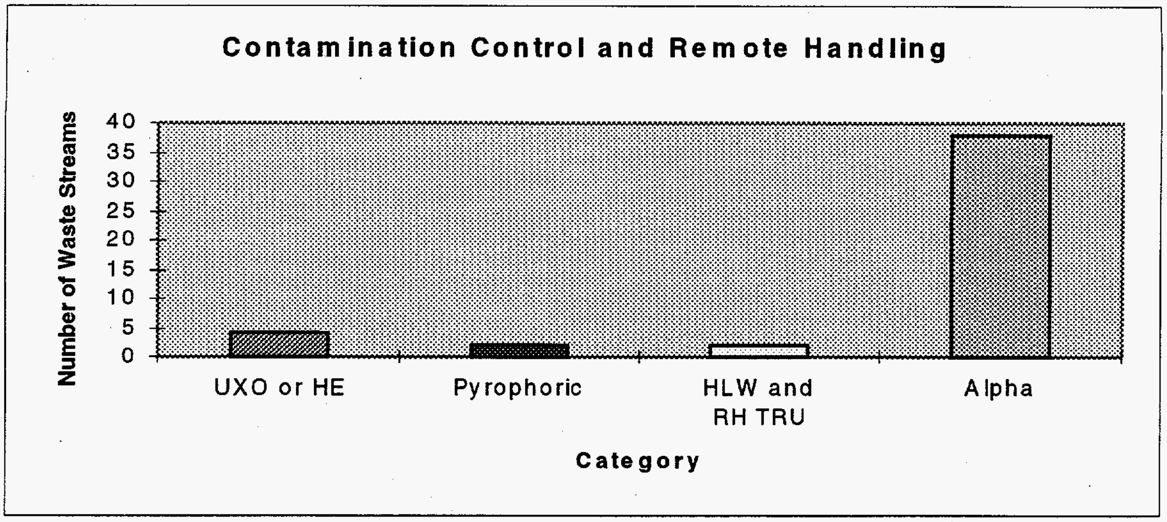

Figure 29. Contamination control and remote handling for landfill sites.

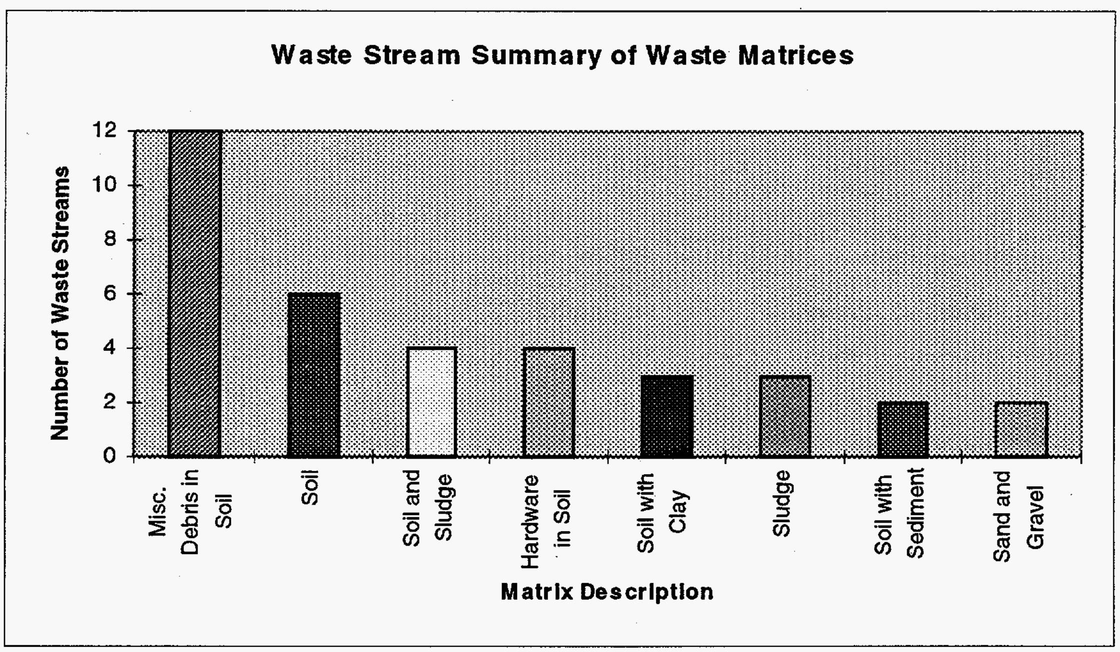

Figure 30. Landfill waste stream matrices.

Requirement: 2. Excavate to the bottom of the source term.

Discussion: Complete removal of the source term contents can only be accomplished if excavation can proceed at least to the physical boundaries including the bottom. This requirement does not specify above grade or below grade placement of excavation equipment, but implies a "reach distance" that must be met by the excavation system. It is the distance that the chosen technology must be able to operate at from an above or below grade reference point. Reach distance is maximum of depth, whether retrieving from the top (down to bottom) or in trench (up to top). The effect of spatial extent is not considered here because it is likely that excavations can be staged to avoid arbitrary horizontal reach distances.

Figure 22 illustrates the distribution of depth information for source term retrieval sites.

Requirement: 3. Retrieve objects of maximum dimensions within each source term.

Discussion: Maximum linear dimensions of buried objects are site specific. Typical objects are barrels (either intact, degraded, or unknown state), vaults and casks, steel beams, and construction debris. Note that most sites are contaminated soil, however. See Figure 30.

Known object dimensions for objects in 23 facilities are illustrated in Figure 31, and may be representative of the remaining retrieval sites.

Trade study: One tradeoff issue associated with retrieval object size and weight is in situ size reduction. The cost to implement this technology needs to be weighed against the savings in retrieval, placement, and downstream treatment costs that might result.

Requirement: 4. Retrieve objects of various maximum weights.

Discussion: Like linear dimension, object weight and matrix density are both site specific, and a necessary input to the design of an excavation system. Known information about lift weight requirements is illustrated in Figure 32. Object lift weights were calculated using estimated weights of known objects in source terms.

Figure 33 illustrates known relationships from the site data between object weights and object dimensions. For scaling purposes, car bodies known to be buried at American Auto Salvage (Grand Junction Office) and in underground storage tanks buried at the Chicago E-800 Area site are not included.

Figure 34 is an additional graph illustrating lift weight distribution across the complex. Lift weight is based on an assumed 1 cubic yard bucket, with different weight being due to different waste matrix densities. The abscissa is summed volume across the complex.

Densities of dominant waste matrices are illustrated in Figure 35. The basis for these values and densities of additional matrices that occur infrequently is contained in Volume II. These densities may be used to develop specific design requirements for selected retrieval systems.

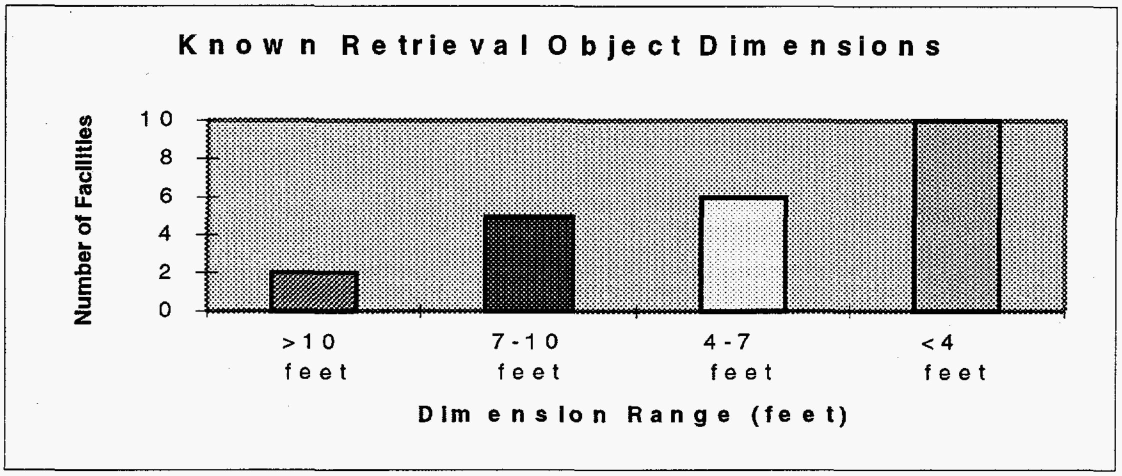

Figure 31. Landfill retrieval object dimensions.

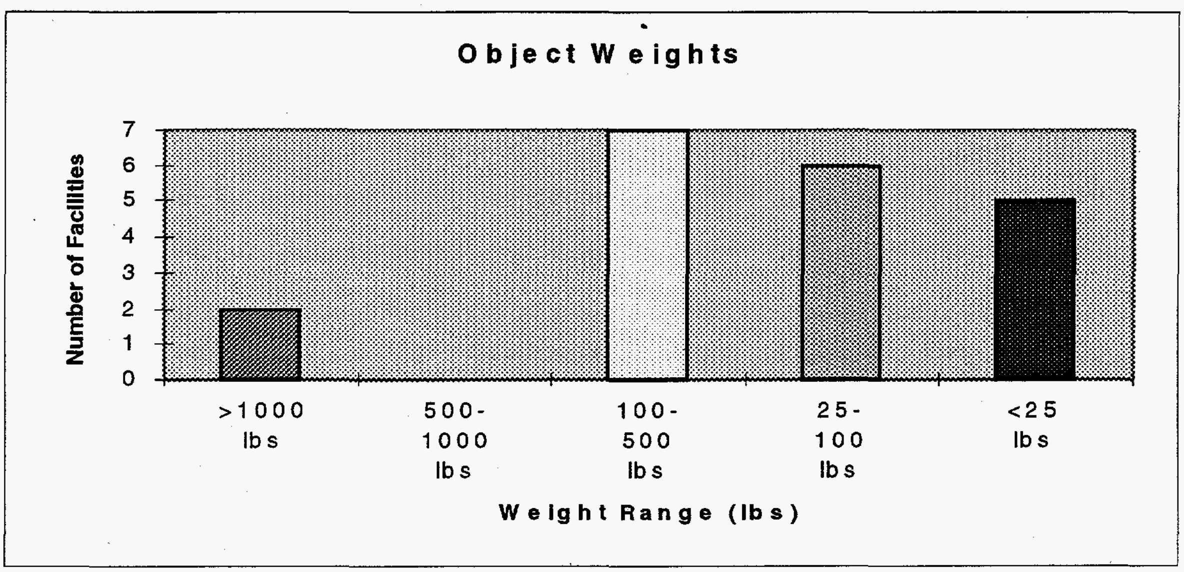

Figure 32. Landfill retrieval object weights.

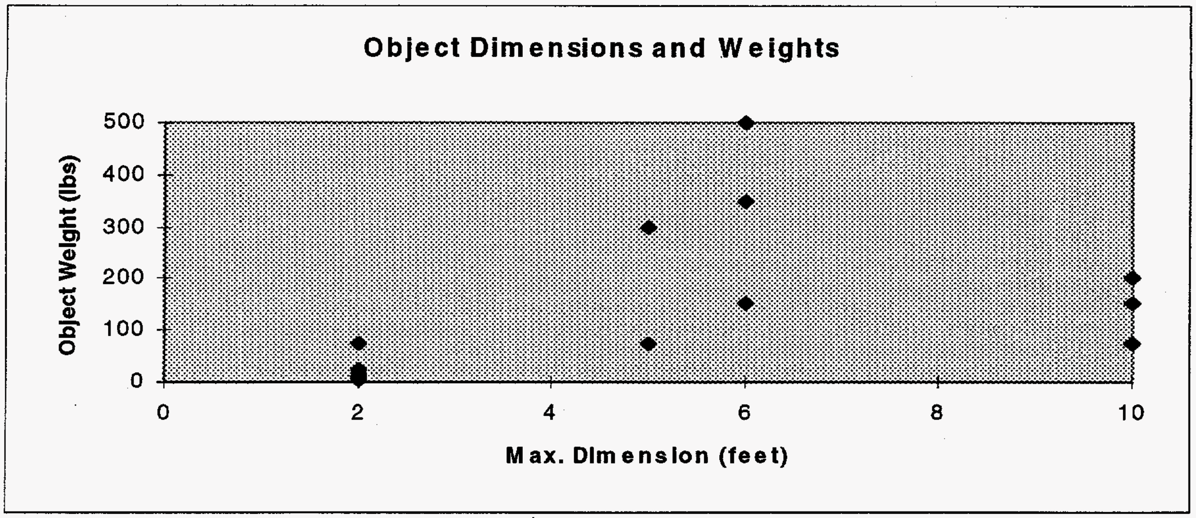

Figure 33. Landfill retrieval object dimensions and weights.

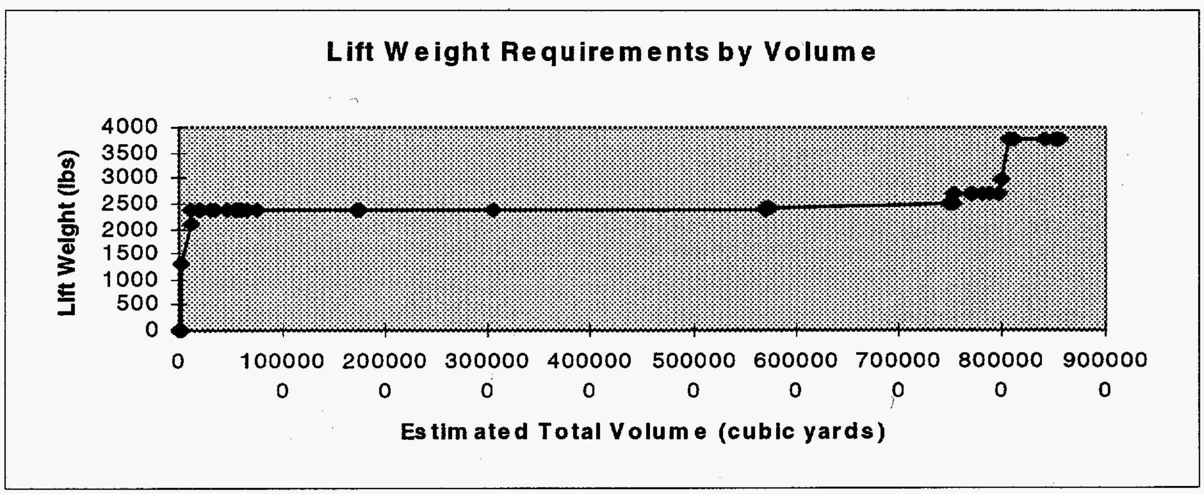

Figure 34. Lift requirements by volume.

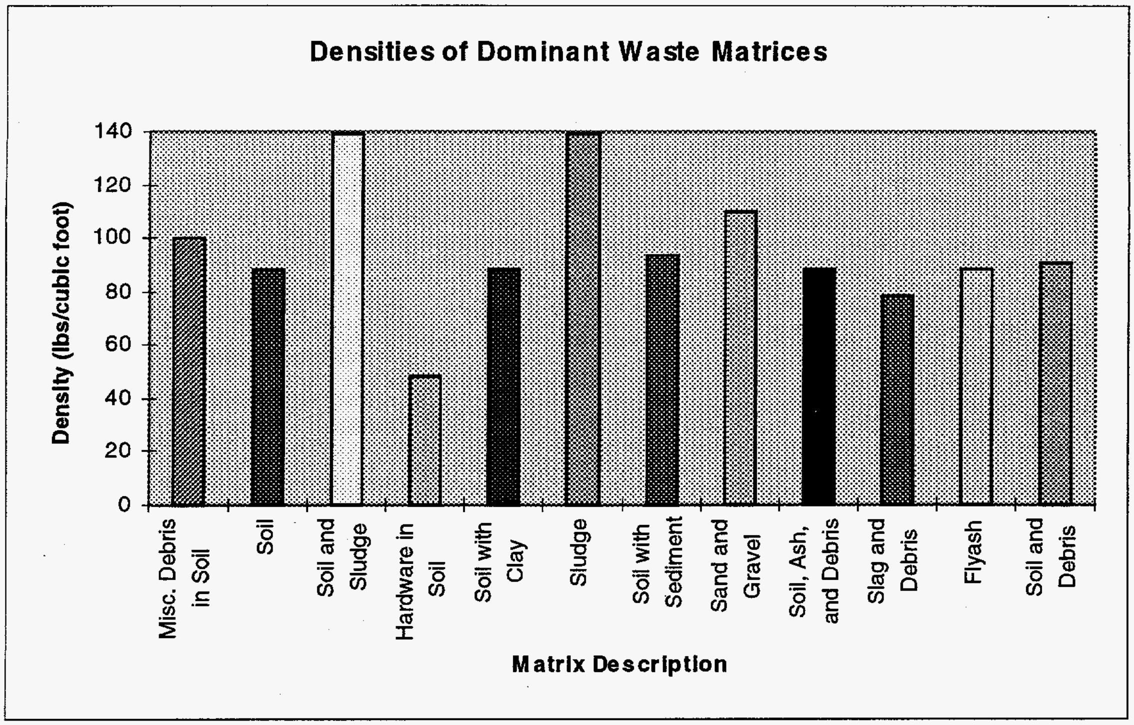

Figure 35. Densities of dominant waste matrices in landfills.

Object weights, like object sizes, can be changed by intervention prior to retrieval. The cost of weight reduction, like that of size reduction, needs to be traded against the resulting savings in implementing excavation and handling equipment.

Requirement: 5. Remove waste to clean levels.

Discussion: For some sites, these levels will be negotiated levels. For others, assume natural background (rad) or regulatory levels outlined in 40 CFR 261 (identification and listing of hazardous waste) and 268 (land disposal restriction treatment standards).

Requirement: 6. Provide contamination control.

Discussion: 10 CFR 835 codifies requirements contained in various DOE directives referring to contamination control requirements. There are two issues: alpha contamination and other contamination. For alpha, assume any alpha emitter in contaminants will necessitate contamination control (this is common practice but is not in 835; it is also based on the extremely high-quality factor for alpha particles). 10 CFR 835 specifies allowable surface radioactivity (disintegration per minute) values for mixed fission products and beta/gamma emitters at allowable levels of 10–50 times the allowable activity of the transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, and I-129. For further details, see Volume II of this report. This could include pretreatment or surfactant, static curtain, confinement. Part of this is actually a cost/safety issue and part is a regulatory requirement.

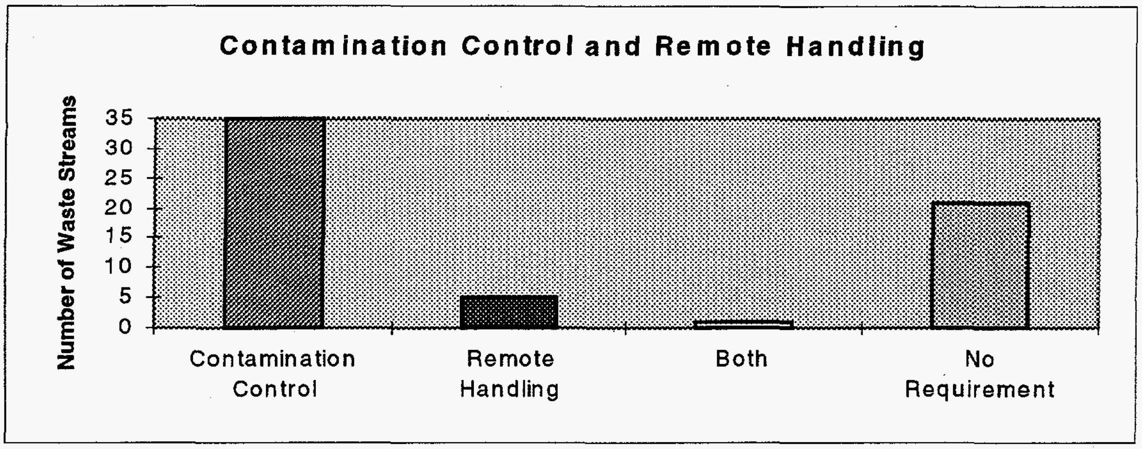

Figure 36. Contamination control and remote handling for landfill sites.

Contamination control is also a requirement at plume sites. Among the 42 sites whose preferred option is excavation, 20 have alpha contaminants and 18 have beta-gamma contaminants. Of the 31 plumes sites where pump and treat is the preferred option, 7 have reported alpha contamination and 12 have reported beta-gamma contamination.

Desirable: Provide hazard measurement during retrieval to avoid the effects of an accident or high-risk event.

Requirement: 7. The excavation/removal system shall be compatible with waste/contamination chemical constituents.

Discussion: The constituent makeup that will be excavated or otherwise removed presents challenges in several areas to the excavation system design. These challenges include chemical reaction and corrosion, radiation damage, constraints on maintainability, flammability and explosive hazards, and other effects.

Known constituents for each of the sites have been classified into 12? contaminant categories. A summary of these categories by landfill waste stream is presented in Figure 37. These categories represent the number of single occurrences within the suite of facilities. Thus, the totals add up to a number greater than the number of facilities.

Plumes removal options have been categorized into excavation (31 sites), pump and treat (42 sites), and vapor extraction (9 sites) as reported by the sites. Figure 38, Figure 39, and Figure 40 illustrate contaminant category distributions among these three removal options.

Trade study: Various options exist to ensure compatibility of the excavation system with waste constituents. These options include design for long-term compatibility, frequent scheduled replacement of critical parts, and remote or intermittent remote operation.

Desirable: The system shall be compatible with physical access to the site.

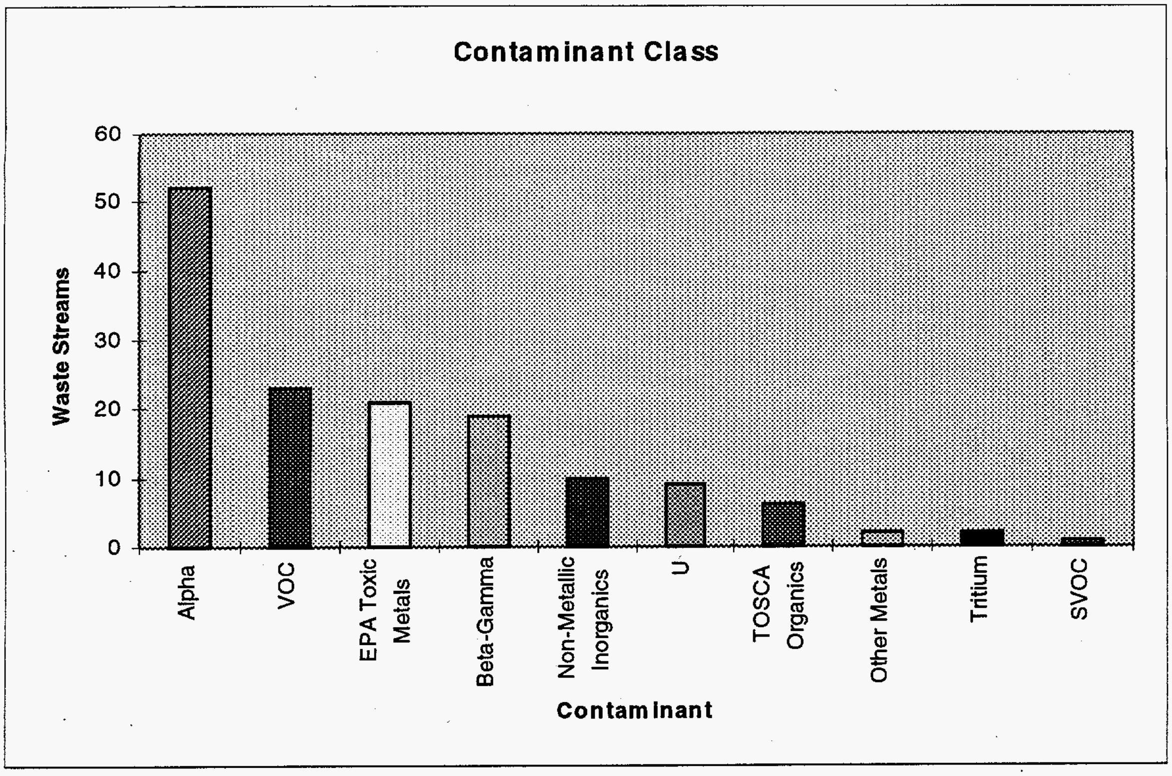

Figure 37. Contaminant class distribution for landfill excavation.

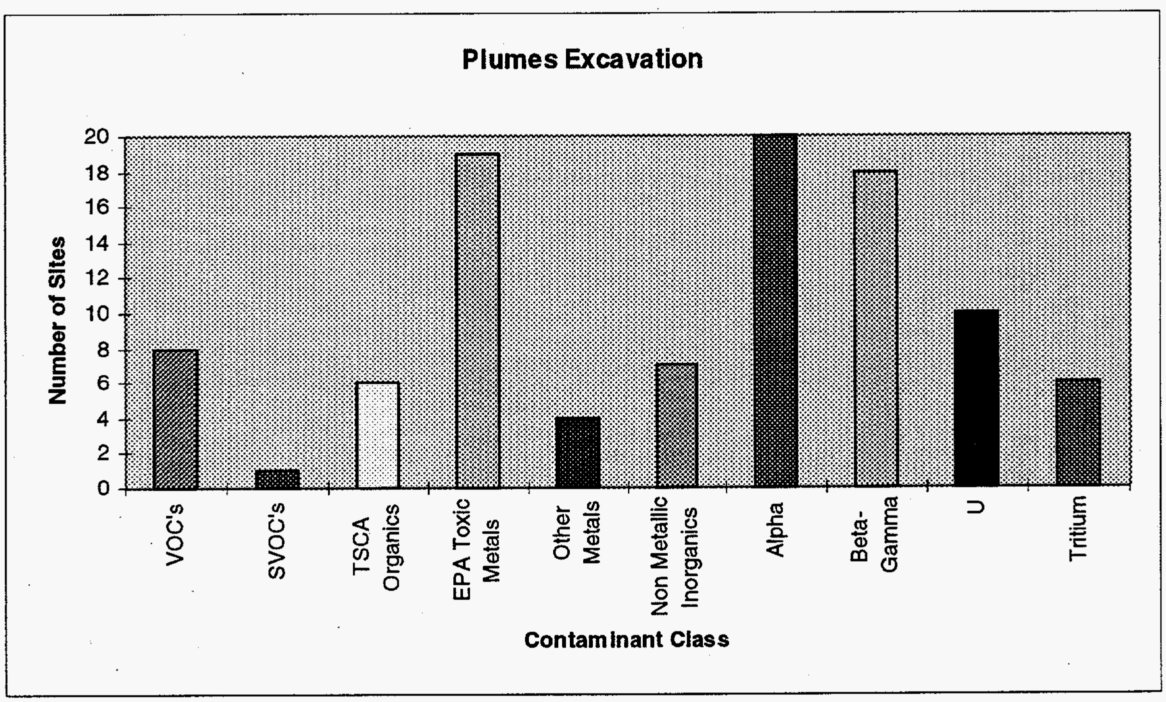

Figure 38. Contaminant class distribution for plume excavation.

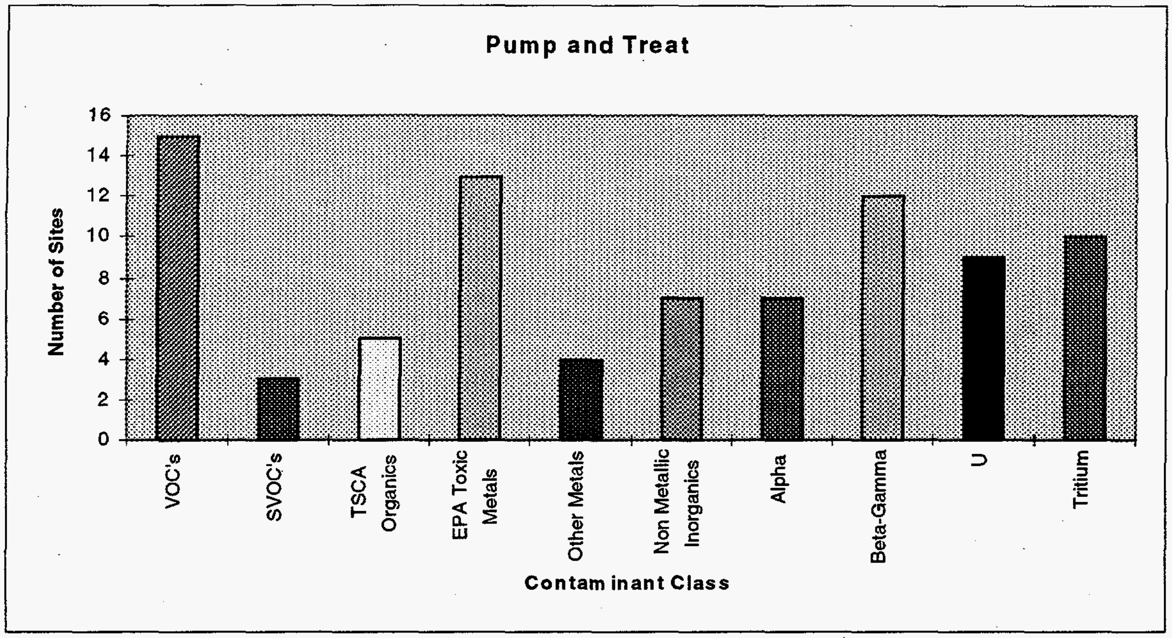

Figure 39. Contaminant class distribution for pump-and-treat plume removal.

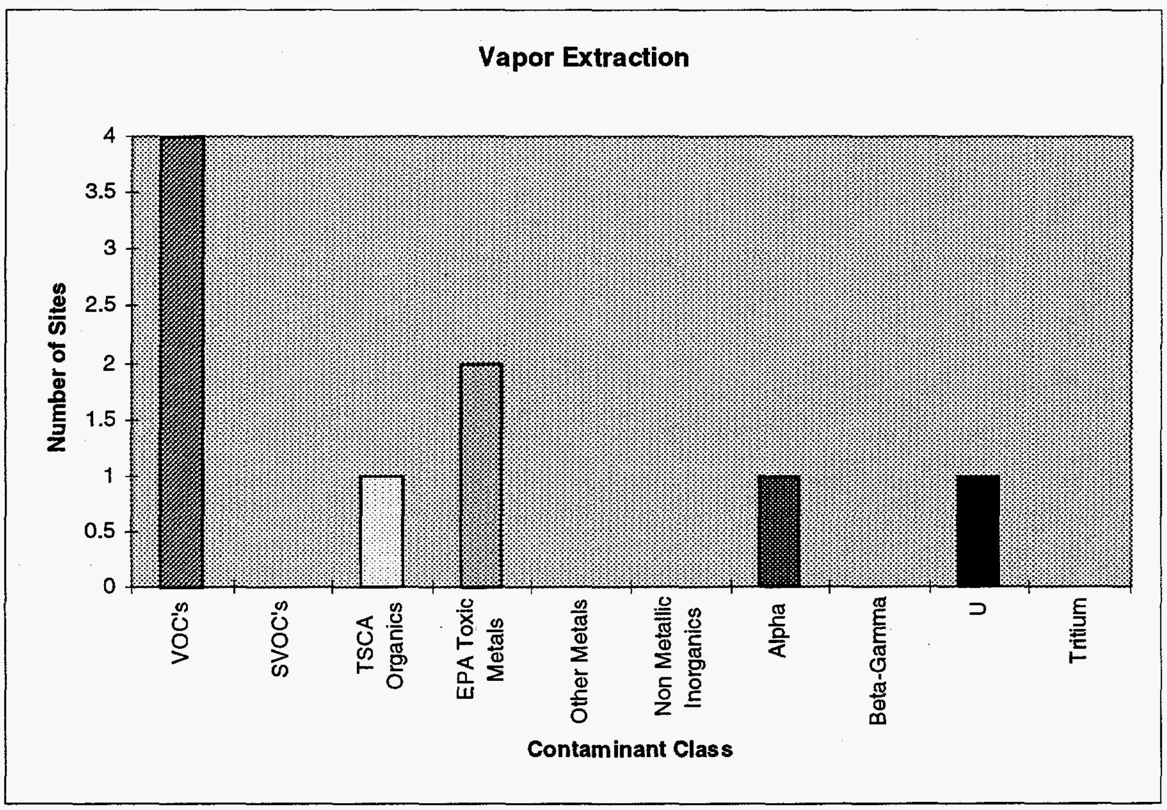

Figure 40. Contaminant class distribution for plume removal by vapor extraction.

Discussion: It is generally undesirable to make major site access modifications if a technology can be identified that is inherently compatible with the current physical state of the site. The cost of necessary site access modifications may be less than that of customizing a technology, however.

Desirable: Provide manual/remote operation.

Discussion: The system design can ensure personnel safety by providing for remote operation. This is a technology application that is often stated as a requirement. Tradeoff issues include such things as the relative costs of options such as telerobotics, shielded cabs, short working times in unshielded environment, and the probability of unexploded ordinance, pyrophorics, alpha emitters, or high-level contaminant in waste seam. Known actual requirements for remote handling only exist at five sites where explosive hazards exist.

Desirable: Provide retrieval process control characterization.

Discussion: Characterization conducted during a retrieval activity can often provide information that is difficult or impossible to obtain otherwise, and can be used directly to control or direct the process of excavation and removal of material. This can result in cost savings. The overburden or waste will be partially and fully exposed, with direct physical access possible. Although much of the data may be too late to use for remedial planning, real-time hazard detection and nonsafety related measurements can be taken. Examples include identification of unbreached containers and sources, high concentrations of hazardous material or high activity levels of radiological contaminants, special-case objects or objects that require customized retrieval strategies, and other general matrix information.

Function 2: Classify the waste for treatment.

Requirement: 8. Sort waste volume into treatment categories.

Discussion: Waste classification is necessary to properly assign treatment processes. Based on a priori information, all retrieved waste streams are technically compatible with treatment trains identified by the Mixed Waste Focus Area. Relationships between these waste streams and the treatment trains are illustrated in Figures 41 and 42. This assignment can be verified by classifying each waste stream to a Matrix Parameter Code as more waste data become available.

Function 3: Place the waste.

Requirement: 9. Place the waste for shipment to treatment or storage.

Constraints and Other Requirements

Requirement: 10. The retrieval system shall be compatible with the physical waste form and matrix.

Discussion: Examples of physical waste form are barrels, boxes, and sludge. Known waste matrix information is summarized in Figures 29 and 30.

Requirement: 11. The excavation system shall have a certain defined volumetric throughput per day.

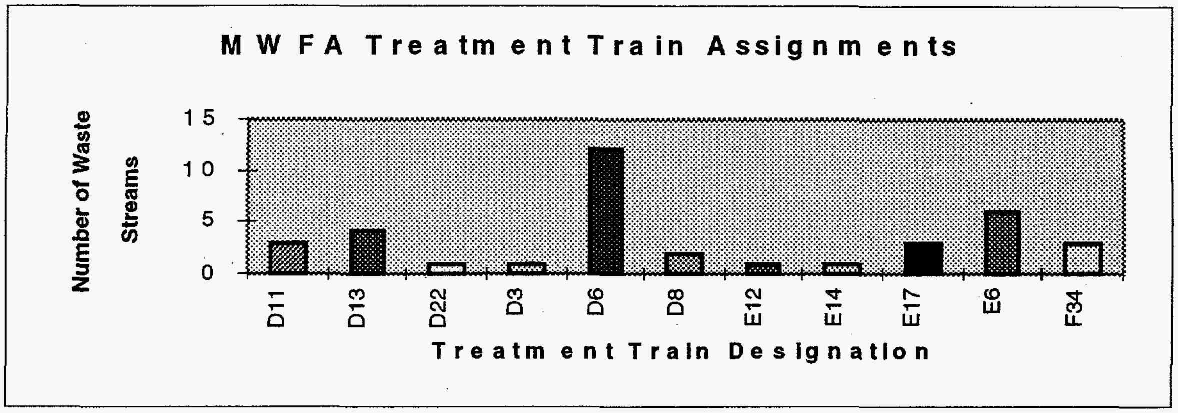

Figure 41. Mixed waste treatment train assignments to SCFA landfill retrieval waste streams.

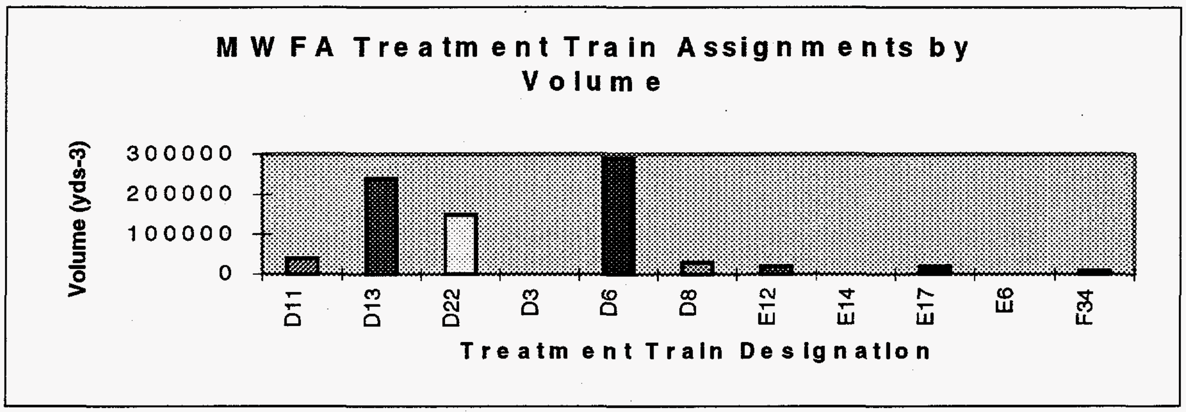

Figure 42. Treatment train assignments by volume.

Discussion: Environmental remediation schedules and estimated waste volumes set a lower limit on facility throughput requirements. Excavation system throughput is defined as the throughput of waste. These numbers are based on site estimates of waste volume and do not include overburden or side burden which are contaminated during excavation.

Trade study: Unneeded excavation and contamination will increase these volumes and represent a trade issue. For example, retrieving overburden if the cost of retrieving it with the waste is cheaper than attempting to segregate and retrieve it separately. In such an example, the excavation system would have to exhibit a higher throughput than the required waste throughput to remediate the site on schedule.

Throughput is also dependent on schedule assumptions. Figure 43 illustrates throughput requirements over the number of facilities. A remediation schedule of 10 years is assumed, reflecting the 10-Year Plan initiative of the DOE Assistant Secretary for Environmental Management to complete cleanup at most sites. This is also reflected in the site schedule information provided for plume remediation, which is presented in Figures 16 and 17.

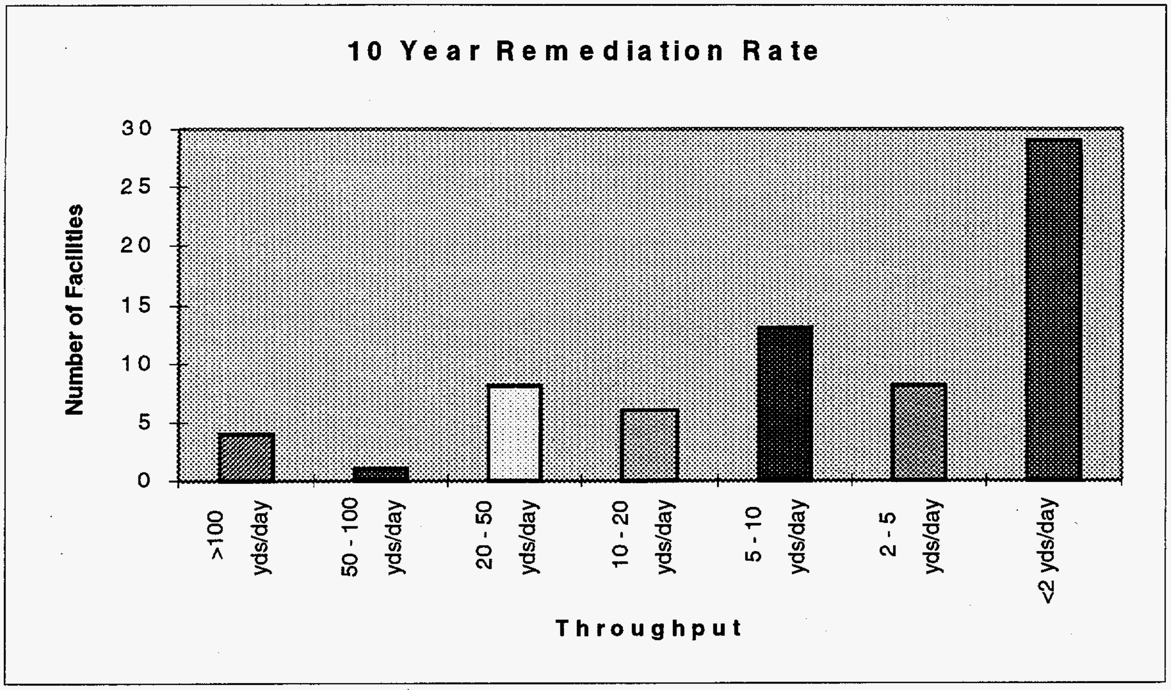

Figure 43. Throughput rates for 10-year remediation.

Trade study: Figure 43 represents lower bounds on throughput requirements because the numbers represented reflect only estimated waste volume and a 10-year time window. Any characterization activity will reduce excavation time, thus increasing actual throughput rates. However, benefits include reduced cost, risk, and reduced nonwaste volume retrieved. The latter will reduce throughput requirements.

Requirement: 12. The excavation system shall be capable of being decontaminated or disposed of following use.

Discussion: While typically viewed as a radiological requirement, decontamination also may apply to hazardous constituents. Figure 37 illustrates the distribution of source term retrieval contaminant classes. The four dominant classes are alpha, VOC, EPA toxic metals (heavy metals), and beta-gamma.

Trade study: One cost-related trade issue is that of comparing the costs of decontamination (both design and operations) versus wholesale or selective replacement of equipment following failures or end of service life.

Requirement: 13. Meet the remediation schedules.

Discussion: Site remediation schedules for plume sites are depicted in Figures 13 through 17. The remediation schedules are for plume sites but give a good representation of the schedules to meet for the entire SCFA. The graph will be updated to include the landfill site data when the data are collected. Technology development demonstration results must be available to support the alternatives analysis. After alternative selection, other technologies can be infused as replacement technologies when they show a clear cost, schedule, and/or performance advantage for the SCFA.

3.3 Source Term Selective Retrieval

Selective retrieval is the full or partial removal of selected contaminants of concern or partial removal of the site volume. This activity may be followed by subsequent stabilization and further removal, or a containment and monitoring activity. Selective retrieval may also be followed by monitoring only. There are 14 facilities within the source term retrieval data set where selective retrieval was preferred by the sites or assigned. These sites form the basis for special selective retrieval requirements. There are incomplete data. The data reflect information from a limited number of the selective retrieval sites. It is likely that additional selective retrieval sites will be defined as more information becomes known about site contents and the relatively high cost of full retrieval activities.

Below are text and a series of graphics illustrating requirements-related information about the selective retrieval facilities. The source term retrieval discussion relates the information in these graphics to technology development requirements and some of the trade issues that can be considered. The same general requirements must be met for selective retrieval as those presented for full retrieval. Supporting data are different as noted here.

Figure 44 illustrates the distribution of depth by selective retrieval facility. Bottom depths vary from 6 inches to 20 feet. Volumes vary from 2 cubic yards (remote-handled transuranic waste) to 12,000 cubic yards of debris. Figure 45 presents depth distribution over facility volume. Depth information is necessary to specify characterization and retrieval systems.

Physical matrix information is necessary to specify and design retrieval systems, and serves as a constraint on the design and operation of characterization technologies. Figure 46 illustrates the volumes of the five known physical matrices that will be selectively retrieved.

There are a number of special-case objects that are known to exist within the selective retrieval facilities. These include drums, glove boxes, 4 x 4 x 6-foot wooden boxes, 5-gallon drums, culverts, small tanks, and auto bodies. Other objects include cobble and miscellaneous debris. Of the 14 selective retrieval sites, nine contain alpha-emitting constituents, one contains remote-handled waste, and two contain pyrophorics. Other nonradiological contaminants include PCBs (one site), inorganic solids, and EPA toxic metals (two sites).

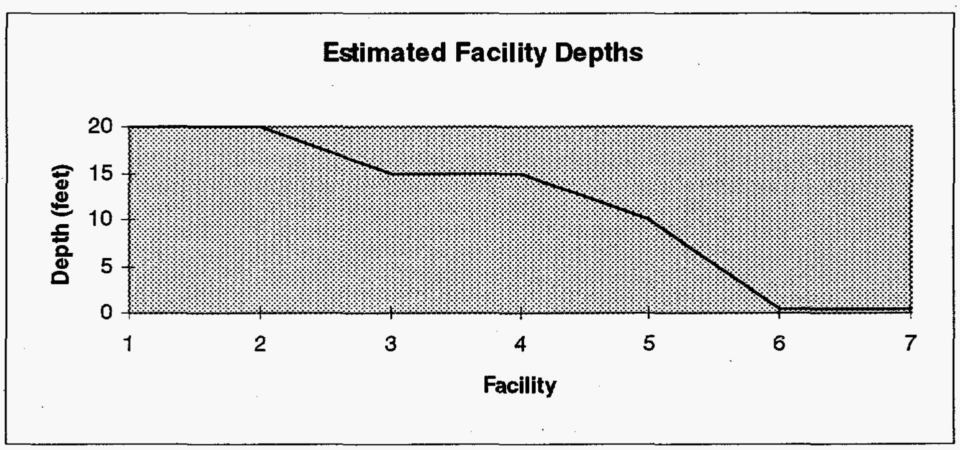

Figure 44. Selective retrieval estimated facility depths.

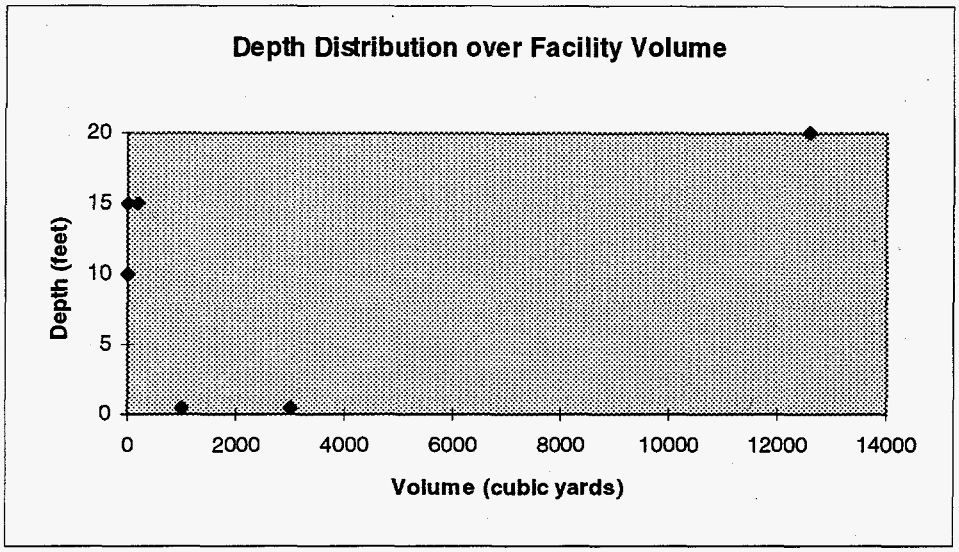

Figure 45. Selective retrieval depth distribution over volume.

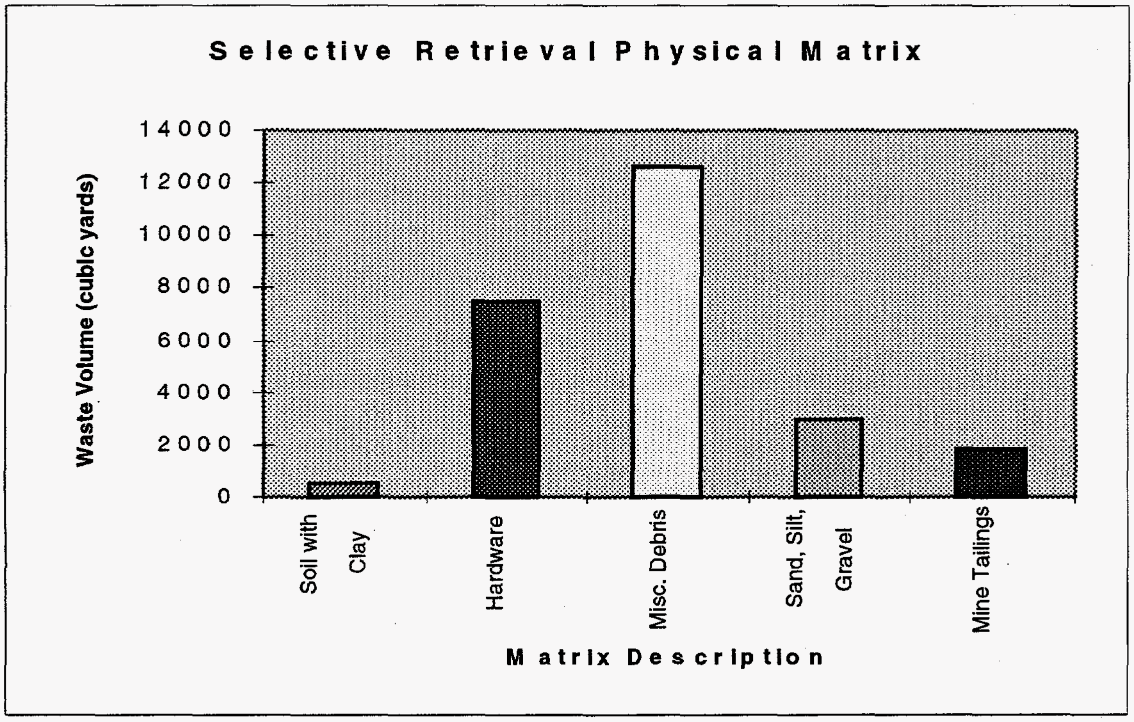

Figure 46. Selective retrieval physical matrix.

4. VERIFICATION

Each requirement must be verified by one or more of the verification methods as follows: inspection, analysis, demonstration, monitoring, or test. Table 5 is called a verification matrix. The table contains a summary of the technical requirements applicable to technology development and the requirements' associated verification method.

Table 5. Requirements verification matrix.

Requirement	Verification Method				
	Inspection	Analysis	Demonstration	Monitor	Test
Containment and Stabilization					
1. Accommodate expected extremes in freeze, thaw, and precipitation.		X			
2. Be compatible with waste materials.		X			
3. Design life based upon the half-life of contaminants at a specific site.		X		X	
4. Control advective and diffusive flow of contaminants, exceeding EPA guidelines, away from their place of disposal.		X		X	X
4a. Control advective and diffusive flow of contaminants from 1 to 250 feet below the surface.		X		X	
4b. Prevent contaminants from reaching the groundwater; depths are from 1 to 850 feet.		X		X	
5. Prevent biological transport of contaminated waste to the surface.				X	
6. Prevent exposure of buried waste that would contribute to migration of the waste.	X	X		X	
7. Maintain integrity of the remedial solution.			X	X	X
8. The remedial solution be continuous.			X	X	X
9. Meet requirements of DOE Order 5480.31 (Ops readiness review).	X	X	X		
10. Meet the remediation schedules.		X	X		
11. Decontaminate or dispose of all equipment, structures, and materials used during remediation.			X		X
Characterization for Containment Plan					
1. Map the landfill boundaries.	X			X	X
2. Determine the mass or radioactivity and concentration of contaminants of concern.	X				X
3. Determine the soil permeability, conductivity, and pH.		X			X

Table 5. (continued).

Requirement	Verification Method				
	Inspection	Analysis	Demonstration	Monitor	Test
Barriers					
1. A cap shall maintain the water balance if water infiltration from the top is a problem.		X		X	
2. Vertical barriers shall extend from the top of the waste and shall be keyed into the bottom barrier such that no contaminants will migrate around or under the barrier.	X			X	
In Situ Stabilization					
1. Stabilization materials shall produce temperatures less than 100°C during and after the application process.		X	X		X
2. Chemical reactions between waste stabilization material and waste shall not produce unacceptable products, e.g., steam, chemical explosion, etc.		X		X	
3. The final waste stabilization material after setting cannot itself pose a threat to human health or the environment.		X	X		X
4. For pressure grouting, the uncured materials shall be appropriate. (a,b,c)		X	X		X
5. The hydraulic conductivity shall be less than 10^{-6} cm/s.		X			
6. Waste form for mechanical stabilization of a waste site to prevent subsidence shall have a compressive strength comparable to the undisturbed soils already existing at that site.		X	X		
7. Stabilized waste shall resist the normal thermal and moisture changes found in the environment at the site.		X		X	
8. Stabilization materials shall prevent contaminant migration to less than the EPA limit, i.e., retard the dissolution of itself and the contaminated waste.		X		X	

Table 5. (continued).

Requirement	Verification Method				
	Inspection	Analysis	Demonstration	Monitor	Test
In Situ Stabilization (continued)					
9. There shall be less than 0.5% free liquids after solidification.		X	X		
10. Final waste form shall resist biodegradation by both fungi and bacteria.		X			
11. Chemical and radiological reactions of both the waste-stabilization material and waste shall not generate radioactive and nonradioactive gases without elimination of the gases.		X		X	
12. Long-term stability shall not degrade from damage due to radioactivity.		X	X	X	
In Situ Treatment - Bio and Chem					
1. Bio and chem treatment shall change the form of the element such that the element and change are not an EPA-listed or characteristic waste.		X			

Table 5. (continued).

Requirement	Verification Method				
	Inspection	Analysis	Demonstration	Monitor	Test
Retrieval Requirements					
Characterization - Excavation Planning					
1. Measure the vertical boundaries of pit or trench from the surface to the estimated depth of the landfill.	X		X		
2. Characterization shall be compatible with soil and waste matrix type and their associated physical characteristics.		X	X		X
Non Function Specific					
1. Accommodate remote operation.	X	X	X		
Retrieval					
1. Enable excavation to proceed.		X			X
2. Excavate to the bottom of the landfill.	X				X
2. Retrieve objects of maximum dimensions within each landfill.		X	X		X
3. Retrieve objects of various weights.		X	X		X
4. Remove waste to clean levels.		X		X	X
5. Provide contamination control.			X		X
6. The excavation system shall be compatible with waste/contamination chemical constituents.		X	X		X
7. The retrieval system shall be compatible with the physical waste form and matrix.		X	X		X
8. The excavation system shall have a defined volumetric throughput per day.		X	X		X
9. The excavation system shall be capable of being decontaminated or disposed of following use.		X	X		
Place the Waste					
1. Place the waste for shipment to treatment or storage.	X				X