10/7-30-91 JS ①

ornl

ORNL/TM-11849

OAK RIDGE NATIONAL LABORATORY

MARTIN MARIETTA

Cost Growth for Treatment Technologies at NPL Sites

C. B. Doty
A. G. Crotwell
C. C. Travis

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

ORNL/TM--11849

DE91 015800

COST GROWTH FOR TREATMENT TECHNOLOGIES AT NPL SITES

Carolyn B. Doty
Amelia G. Crotwell
Curtis C. Travis

Date Published - April 1991

Prepared by the
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831
managed by
Martin Marietta Energy Systems, Inc.
for the
U. S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

Risk Analysis Section
Health and Safety Research Division
Oak Ridge National Laboratory*
Oak Ridge, Tennessee 37831

*Managed by Martin Marietta Energy Systems, Inc. under Contract No. DE-AC05-840R21400 with the U. S. Department of Energy.

CONTENTS

TABLES

FIGURES

1. INTRODUCTION

The Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA or Superfund), as amended by the Superfund Amendments and Reauthorization Act of 1986 (SARA) provided the Environmental Protection Agency (EPA) with resources and direction for the identification, evaluation, and remediation of hazardous waste sites in the United States. Congress has authorized a total of $10.1 billion to be appropriated through fiscal year 1991 for this purpose. To date, more than 1200 sites have been added to the National Priority List (NPL) of hazardous waste sites that are eligible for CERCLA funding. At the end of fiscal year 1988, EPA had spent approximately $3.0 billion of the $4.4 billion that had been appropriated for cleanup (GAO 1990). At that time, although cleanup work had begun at 201 sites, only 27 sites had been completed.

EPA has estimated that approximately $30 billion will be needed to clean up the 1200 sites currently on the NPL. This figure, however, now appears to be underestimated (GAO 1990). This estimate was made before site work had begun on some of the more complex sites and before the effectiveness of treatment technologies was well established. More recent estimates range from $80 billion (CMA 1988) for sites currently on the NPL to $500 billion (OTA 1989), assuming the addition of 9,000 sites to the NPL over the next 10 years.

Legislative, policy, technical, and economic changes regarding the number of sites remediated, the types of remedies selected, and the cleanup goals established can directly affect the overall cost of hazardous waste cleanup. Since the passage of SARA, one of the key elements in estimating overall cleanup cost has been determining the cost of implementing treatment alternatives. SARA established more stringent requirements for the Superfund program, mandating that alternatives be permanent to the maximum extent practicable. During the past few years, an increased number of treatment technologies have been selected for implementation. As more sites are added to the NPL and more treatment technologies are implemented, an understanding of factors contributing to inaccuracies in cost estimation will become increasingly important for these technologies.

Cost growth associated with remedial alternative implementation has not been addressed extensively by researchers to date. One recent study analyzing cost growth at 40 sites indicates that significant positive cost growth is associated with all types of sites and remedial alternatives and suggests an overall average cost growth of 55% for all remedial activities as well as for treatment technology implementation (Schroeder and Shangraw 1990). Lack of project definition was cited as the primary factor contributing to cost growth. A study of remedial activities primarily involving soil and drum excavation has also been conducted (Richardson et al. 1990). This study suggests that a 26% cost growth exists between the Record of Decision (ROD) costs and completion costs for nonroutine construction activities. Construction cost growth, the deviation of final construction costs from the original contract amount, has also been studied. These cost increases result from changes in site conditions and problems associated with construction activities and are usually paid for as change orders. Construction cost growth for remedial activities ranges from an estimated 12% (GAO 1988) to 39.4% (Richardson et al. 1990).

1.1 PURPOSE

The purpose of the present study is to contribute to the base of knowledge needed to determine future resource requirements for hazardous waste cleanup programs. This objective was accomplished by conducting a cost growth analysis for treatment technology operable units and by developing a compendium of treatment technology costs based on recent vendor claims and field experience.

1.2 REMEDIAL ACTION COSTING

Two types of costs are considered when estimating expenditures for remedial action implementation: capital costs and operations and maintenance costs. The present worth of a remedial action is based on both capital costs and operations and maintenance costs. This costing component represents the amount of money required to complete the remediation if invested initially and disbursed over the period of remediation. Capital costs consist of direct and indirect costs. The primary direct capital cost components are construction costs such as expenditures for equipment, and the labor and materials used to install a remedial action. Other direct capital costs include additional major equipment expenditures and costs for land and site development, buildings and services, relocation of affected population, and disposal of contaminated media or residuals (EPA 1987b). Indirect capital costs, which are considered to be the markup portion of the capital costs, consist of engineering and design costs, contingency allowances, and legal and permitting fees. These costs vary from site to site, and in the past, feasibility study (FS) contractors have not been consistent in estimating these costs (OTA 1988). Capital costs for source remedies often include first-year operations costs.

Operations and maintenance costs consist of post-installation expenditures that are necessary to provide for the continued effectiveness of the remedial action. These costs consist of labor and materials costs, sampling and analytical fees, administrative costs, and contingencies. Yearly operations and maintenance costs are generally associated with remedial actions that operate over longer periods of time, such as pumping and treating ground water and in-situ treatment technologies for soils and groundwater.

1.3 APPROACH

The present analysis of treatment technology cost growth consists of: (1) an evaluation of cost growth for 18 source treatment operable units for NPL sites; (2) an estimate of a cost growth factor for operations and maintenance costs for groundwater restoration based on the effectiveness of operations to date; and (3) the development of a compendium of actual source treatment technology unit costs based on bench-scale, pilot-scale, and full-scale implementation. For the purpose of the analysis, cost growth is defined as the deviation of actual remediation costs from projected costs. Although the results are based on a limited set of data, the available data are sufficient to provide insights into trends associated with implementing treatment technologies.

Sites were selected for review based on the status of the cleanup and the availability of data. Interviews with regional EPA personnel were conducted and site contractors were contacted to identify sites for evaluation and obtain necessary data. The source treatment technology cost growth analysis is limited to NPL sites for which a ROD has been signed. Sites with post-ROD selection of an alternative remedy were eliminated from the cost growth analysis because few of these sites have bids for the alternative remedy. Both NPL and non-NPL sites were included in the cost compendium and groundwater analysis.

No remedial actions have been completed at NPL sites which involve both source and ground water treatment. Therefore, an operable unit approach was used for the cost growth analysis. The costs used in the analysis include the entire operable unit for which the specified treatment technology was selected. Different approaches were used to evaluate cost growth for source and groundwater operable units. For source operable units, the approach reflects the status of the cleanup at the sites, and provides a snapshot of capital cost growth to date. Capital costs are usually the only significant costs involved for source operable units, with the exception of in-situ treatment technologies. Capital costs for source operable units typically include site activities such as mobilization/demobilization costs, cleanup of debris, disposal of residuals, backfilling, post-remedial sampling, and other remedial components in addition to the treatment of the contaminated medium.

For groundwater restoration operable units, the approach provides an estimation of a cost growth factor based on projected modifications in remedial time frames. This evaluation is based on an analysis of the effectiveness of groundwater extraction (Doty and Travis 1991). The key cost component for groundwater is operation and maintenance costs. Monitoring and system modifications made after installation are included in these costs. Since pump and treat systems operate over long periods of time, the remedial time frame is the primary factor in determining overall cost growth for groundwater restoration operable units.

The present methodology for source technologies evaluates the degree to which the projected cost estimates reflect the actual costs of remediation both in terms of project definition and estimation of contingencies. Therefore, analyses of total capital cost growth, unit capital cost growth, and the adjustments in the volume of contaminated soil between the ROD and bid or completion phase are included in the study. Positive total cost growth generally reflects increases in costs resulting from a change in the definition of the project and those resulting from increased costs that are directly related to a particular technology. Unit capital cost growth consists of the cost growth per cubic yard of soil. This growth tends to reflect changes in cost that are specific to the technology and may be independent of changes in project definition. Since the objective of the study is not to estimate the true contingency associated with treatment operable units, contingencies contained in projected costs were not removed from consideration.

Approximately 50% of the source operable units reviewed are completed. The actual costs for the remaining sites are based on bid costs. The use of contractor bid information for some sites may result in an underestimation of overall capital cost growth. Recent studies have indicated that completion costs may increase by approximately 12% (GAO 1988) to 39.4% (Richardson et al. 1990) over the original construction price. Since only capital costs were analyzed for in-situ source technologies, aggregate cost growth for these technologies is not represented in the cost growth analysis. These operations typically operate over a period of several years and accrue operations and maintenance expenses that cannot be obtained because the remedial action is ongoing.

Careful attention was given to the verification and normalization of data to reflect the same remedial action cost components for both projected and actual costs; however, some inconsistencies existed in defining capital cost components. Inconsistencies also existed with respect to units used in costing. All unit costs were converted from dollars per ton to dollars per cubic yard, assuming a soil density of 100 lbs/cubic ft. Costs were not indexed to current dollars.

A compendium of source treatment technology costs was compiled using data from recent Superfund Innovative Technology Evaluation (SITE) demonstrations, vendor claim information, commercial proposals, and pilot studies. The costs listed in the compendium consist of both actual unit costs for full-scale implementation and unit cost estimations for full-scale implementation based on bench-scale or pilot-scale operations. These costs are for treatment only and do not include other remedial activities. A comparison of these projected and actual costs provides further insight into the accuracy of early cost projections for treatment technologies.

2. RESULTS OF ANALYSIS

2.1 COST GROWTH FOR SOURCE TREATMENT TECHNOLOGIES

Cost growth was evaluated for both total capital costs and unit capital costs for source operable units involving three types of treatment technologies: high intensity technologies, low intensity technologies, and in-situ technologies. High intensity technologies consist of high-temperature thermal technologies. Low intensity treatment technologies included in the study consist of low temperature thermal desorption, dechlorination, and solidification/stabilization. In-situ treatment technologies included are biodegradation and vacuum extraction.

Source operable unit cost growth data for the NPL sites reviewed are presented in Appendix A, and the results of the analysis are summarized in Tables 1 and 2 and Figures 1 and 2. Average unit costs based on vendor claims and recent bids for treatment only (from Appendix B) are presented in Figure 3.

2.1.1 High Intensity Treatment Costs

Two types of costs exist for incineration: fixed and variable. Fixed costs are those that are not dependent upon the size of the site and include such remedial components as site preparation, mobilization/demobilization, and permitting. Variable costs such as fuel costs, are a function of the system's throughput capacity, the types of wastes treated, and the size of the site. Inaccurate consideration of these factors is the most frequent contributor to positive unit cost growth.

Unit costs for incineration are very closely linked to the volume of soil to be treated, especially for mobile/transportable systems. Large systems are more expensive to mobilize and demobilize than are smaller systems. Variable costs per unit of soil, however, are lower for large systems because they have higher throughput capacities. Unit costs are lower at large sites because mobilization/demobilization costs are distributed over a large volume of contaminated soil. Small mobile systems have lower mobilization/demobilization costs, but the variable costs per unit of soil are higher because they have lower soil throughput capacities and are therefore, most cost-effective for small sites (Cudahy and Eicher, 1989).

All the sites reviewed involve on-site incineration except one. Cost growth for the site involving off-site incineration is 1,119% for unit costs and 330% for total capital costs (Table 1). The exorbitant cost growth for this site is probably attributable to both the gross underestimation of the volume of soil to be treated and the unrealistic cost projection in the ROD for incinerating such a small volume of soil. Cost growth for operable units involving on-site incineration ranged from

TABLE 1

COST GROWTH FOR SOURCE TREATMENT OPERABLE UNITS AT NPL SITES

HIGH INTENSITY TREATMENT

Site/Region	Technology	Projected Cost ($1000)	Projected Unit Cost ($/cy)	Actual Cost ($1000)	Actual Unit Cost ($/cy)	Capital Cost Growth (%)	Unit Cost Growth (%)	Actual Cost Basis
LaSalle Electrical, IL 5								
Phase I	incineration	26,400	920	11,699	427	-55.7	-53.6	completion costs
Phase II	incineration	34,059	989	17,262	323	-49.3	-67.3	contracted costs
Westline, PA 3	incineration	744	105	3,200	1,280	330.1	1119.0	completion costs
Motco, TX 6	incineration	36,300	371	28,300	399	-22.0	7.5	contracted costs
Sikes Disposal, TX 6	incineration	102,217	680	89,949	317	-12.0	-53.4	contracted costs
Bridgeport, NJ 2	incineration	57,672	961	52,457	590	-9.0	-38.6	contracted costs

LOW INTENSITY TREATMENT

Site/Region	Technology	Projected Cost ($1000)	Projected Unit Cost ($/cy)	Actual Cost ($1000)	Actual Unit Cost ($/cy)	Capital Cost Growth (%)	Unit Cost Growth (%)	Actual Cost Basis
McKin, ME 1	low temp. thermal	424	157	2,902	256	584.4	63.1	completion costs
Pepper's Steel, FL 4	solidification/ stabilization	5,212	109	7,000	58	34.3	-46.8	completion costs
Forest Waste, MI 5	solidification/ stabilization	1,295	323	2,400	397	85.3	22.9	completion costs
Mowbray Engineering, AL 4	solidification/ stabilization	750	156	778	---	3.7	---	completion costs
Independent Nail, SC 4	solidification/ stabilization	979	158	619	113	-36.8	-28.5	completion costs

LOW INTENSITY TREATMENT (continued)

Site/Region	Technology	Projected Cost ($1000)	Projected Unit Cost ($/cy)	Actual Cost ($1000)	Actual Unit Cost ($/cy)	Capital Cost Growth (%)	Unit Cost Growth (%)	Actual Cost Basis
Aladdin Plating, PA 3	stabilization	4,461	372	7,734	645	73.4	73.4	contracted costs
Davie Landfill, FL 4	stabilization	3,350	45	1,573	20	-53.0	-55.6	completion costs
Wide Beach, NY 2	dechlorination	8,800	351	15,317	733	74.1	109.0	contracted costs

IN-SITU TREATMENT

Site/Region	Technology	Projected Cost ($1000)	Projected Unit Cost ($/cy)	Actual Cost ($1000)	Actual Unit Cost ($/cy)	Capital Cost Growth (%)	Unit Cost Growth (%)	Actual Cost Basis
Groveland, MA 1	vacuum extraction	702	35	282	35	n.a.	0	SITE demonstration
Ponder's Corner, WA 10	vacuum extraction	38.5	12	61	19	58.4	58.3	contracted costs
Verona Well Field, MI 5	vacuum extraction	413	---	2,152	38	421.0	---	contracted costs
French Limited, TX 6	in-situ biodegradation	47,000	314	47,000	314	0	0	contracted costs

Table 2
Average Cost Growth and Increase
in Volume of Soil to Be Treated
Source Treatment Operable Units

Technology Category	Capital Cost Growth (%)	Unit Cost Growth (%)	Volume Increase (%)
High Intensity Treatment	-17.0*	-45.5*	66.5
Low Intensity Treatment	95.7	19.6	61.1
In-Situ Treatment	159.8	19.4	2.8
AVERAGE GROWTH	79.5	-2.3	43.5

* Median values

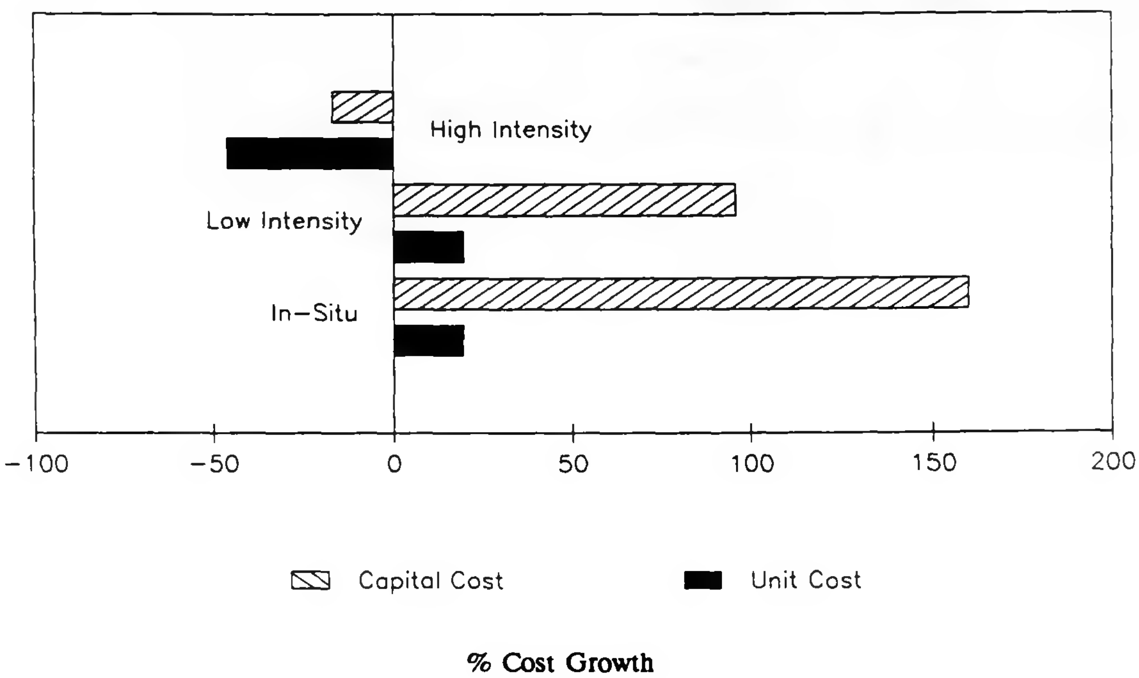


Figure 1. Summary of Cost Growth for Source Treatment Operable Units

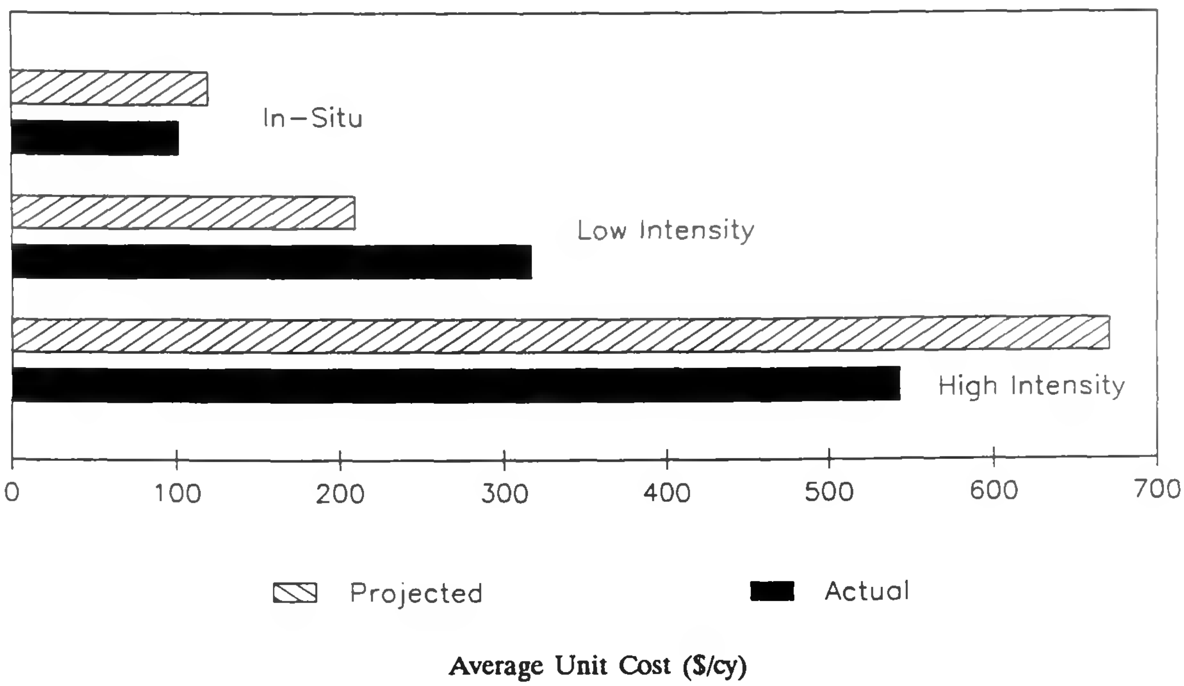
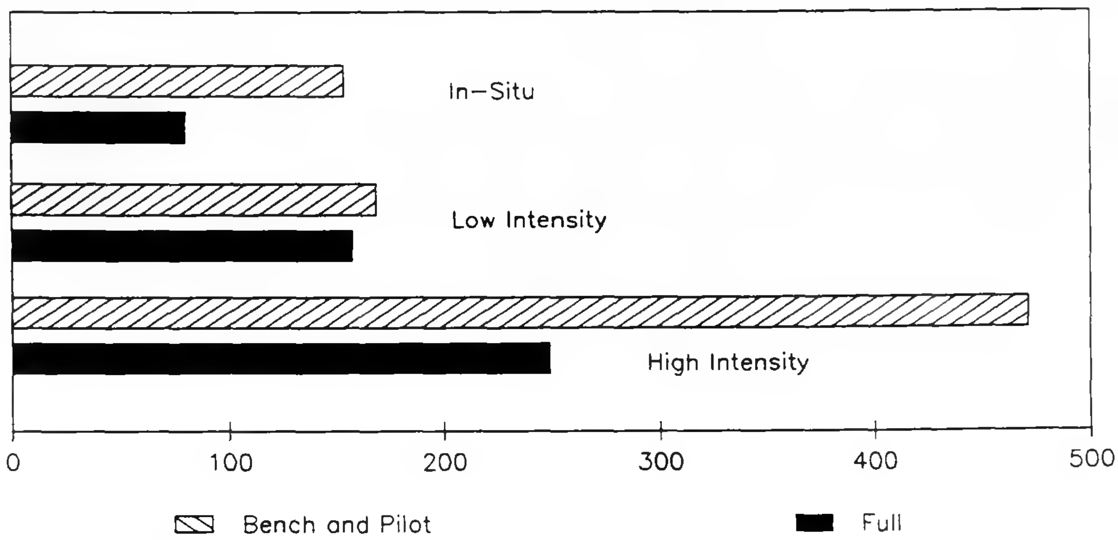


Figure 2. Average Projected and Actual Unit Costs for Source Treatment Operable Units



Average Unit Cost ($/cy)

Figure 3. Average Unit Costs for Source Treatment Technologies (from Appendix B)

-67% to 8%. The overall unit capital cost growth for incineration is -46%, and the capital cost growth is -17% (Table 2).

Table 3 Range of Current Costs for Incineration (Cudahy and Eicher, 1989)	
Volume	Unit Cost
less than 6,750 cy	$675-$2,025/cy
6,950 to 20,250 cy	$405-$1,215/cy
20,250 to 40,500 cy	$270-$810/cy
more than 40,500 cy	$135-$540/cy

The volume of contamination to be incinerated increased between the ROD and bid phases by an average of 66.5% at the sites reviewed. However, total capital cost growth was negative (Table 2). This phenomenon is either due to an overall decrease in the market price of incineration, EPA's general overestimation of the cost of incineration, or a failure to select the size of incineration system that is best suited for the volume of soil to be incinerated.

Current unit costs for incineration are considerably lower than the costs projected in the RODs (Figure 2) and those based on pilot studies (Figure 3). Tables 3 and 4 list unit costs for a range of soil volumes and types of incinerators based on vendor claims. Although the costs are for incineration only, the additional remedial activities included in the source operable units reviewed typically add no more than $200 to the unit costs for a site. Eighty-three percent of the actual operable unit costs at the sites reviewed fall within the ranges of current costs of incineration based on volume of soil that are estimated in Table 3; yet, 83% of the projected unit costs do not fall within the ranges given. All actual costs for onsite incineration at the sites reviewed fall within the ranges of unit costs listed in Table 4, suggesting a downward trend in incineration costs. Recently awarded

Table 4 Range of Current Costs for Commercially Available Mobile/Transportable Incineration Technologies (OTA, 1989)	
Technology	Unit Cost
Rotary kiln	$135-$675/cy
Infrared furnace	$202-$270/cy
Circulating bed	$135-$450/cy

contracts (see Appendix B and Figure 3) reflect a 47% decrease in unit costs from those based on pilot-scale operations. These recent contracts tend to reflect costs at the lower end of the ranges listed in Table 3.

2.1.2 Low Intensity Treatment Costs

Overall capital cost growth for low intensity treatment technologies was 95.7%, although unit cost growth was only 19.6%. The overall cost growth was primarily attributable to the underestimation of the volume of contaminated soil. A 61.1% underestimation of the volume of contaminated soils occurred at these sites (Table 2).

2.1.3 In-Situ Treatment Costs

Limited data were available for in-situ treatment technologies; however, high capital cost growth (160%) exists for this technology category. No significant unit cost growth or underestimation of the volume of soils occurred at these sites (Table 2). Therefore, the high cost growth appears to be primarily attributable to the underestimation of the mass of contaminants present in the soil. For example, the volume of contaminants in the soil at the Verona Wellfield site was originally estimated to be 1,700 pounds; yet more than 40,000 pounds had been extracted at the end of 1989.

In-situ source treatment technologies are generally in operation over longer periods of time than are low intensity and high intensity treatment technologies. Thus, they accrue operations and maintenance expenses. Since operations are not complete at the sites reviewed, no formal analysis of operations and maintenance cost growth could be conducted. The capital costs for the two sites with significant cost growth did, however, include some of the operations and maintenance costs, and thus, the capital cost growth for in-situ technologies reflects a portion of the expenses associated with the underestimation of the contaminants present.

At two major NPL sites where vacuum extraction is underway, performance records suggest that that increases in remedial time frames and materials required for the treatment systems will result in further overall cost growth. The extraction of VOCs at the Verona Wellfield site had required 250,000 pounds of carbon for the treatment system at the end of 1989 at a cost of $541,000, and at least another 150,000 pounds were estimated as needed to complete the remediation at a cost of $886,000 (Guerriero 1989). At the Tyson's site in Pennsylvania, the volume of contaminated soil is not known to be underestimated. Capital and operation and maintenance costs, however, have risen from the projected $5.7 million to $25 million with a total unit cost of $833 per cubic yard to date because of frequent clogging of the system by coal tar (Dennis 1990).

2.2 COST GROWTH FOR GROUNDWATER RESTORATION

For groundwater remediation, the costs of primary concern are operation and maintenance costs because pump and treat systems operate over long periods of time. Groundwater pumping and treating is ongoing at the sites evaluated, and the remediation is not likely to be completed in the near future; therefore, actual costs cannot be obtained. Trends in cost growth associated with pumping and treating groundwater were evaluated based on the effectiveness of the remedy to date at sites where aquifer restoration is the goal of remediation.

Costing for groundwater remedial action components is generally based on a 30-year period for operations and maintenance expenses. However, a recent analysis of groundwater pump and treat performance records (Doty and Travis 1991) indicates that remedial time frames for groundwater are grossly underestimated. Data suggest that aggregate operations and maintenance cost estimates for groundwater pumping and treating are underestimated by at least a factor of three. Mechanisms that control the extraction of immobilized contaminants in the subsurface are not fully understood and have not been adequately accounted for in groundwater models. Approximately 25% of hazardous waste sites where pumping and treating has been implemented for aquifer restoration

Table 5
Remedial Time Frames
Groundwater Operable Units

Site	Projected Time Frame	Cleanup Goal	Length of Operation[1]	Status of Operation
Amphenol Corp., NY	5-10 years	5 ppb TCE	3 years	VOCs leveled at 50 ppb
Des Moines TCE, IA	not projected	5 ppb TCE	2.5 years	Leveled at approx. 750 ppb
General Mills, MN	not projected	270 ppb TCE (shallow) 27 ppb (deep)	4 years	Leveled above 500 ppb
GenRad Corp., MA	>5 years	No goal specified	2 years	TCE reduced to approx. 100 ppb
Harris Corp., FL	not projected	500 ppb VOCs	6.5 years	Leveled at 1,000 ppb in three wells
IBM Dayton, NJ	6-11 years	100 ppb VOCs	13 years[2]	Leveled at 100 ppb; After pumps were shut off, conc. rose to 13,000 ppb; goal is no longer restoration.
IBM San Jose, CA	10 years	50 ppb TCA	8 years	Decreased to 50 ppb; however, shallow aquifer contamination is leaking to deeper aquifer.
Nichols Eng., NJ	2.25 years	10 ppb VOCs	2.5 years	80% to 90% red. in some wells; overall, leveled at 150 ppb
Ponders Corner, WA	10 years	5 ppb PCE	6 years	VOCs leveled at 50 ppb
Savannah River, SC	30 years	99% red. of cont. mass	5 years	Leveled after 25% reduction in mass
Sharpe Depot, CA	30 years	5 ppb TCE	2.5 years	Leveled at 100 ppb
Sylvester, NH	ACLs 2 years	1,500 ppb TCE	4 years	3,000 ppb
Twin Cities, MN	not projected	27 ppb TCE	2 years	Concentrations unchanged
United Chrome, OR	5 years	10 ppm chromium	2 years	600 ppm; increased conc. in some wells

Table 5 (continued)

Site	Projected Time Frame	Cleanup Goal	Length of Operation	Status of Operation
Verona Wellfield, MI	100 ppb in 3 years; not projected for complete restoration	MCLs VOCs	6.5 years	Leveled at 2,500 ppb; conc. increased in some wells
Wurtsmith AFB, MI	--	--	13 years	TCE concentrations remain at 70 ppb

[1] Performance records were not available for the entire duration of the operation for some sites.
[2] Operation ceased for four years during this period.

have already exceeded the projected remedial milestones by as much as a factor of two (Table 5). Projected remedial time frames at these sites range from 2 years to 30 years. However, time frames of 100 to 1,000 years have been suggested by leading groundwater scientists as more appropriate projections for complex sites, if aquifer restoration is achievable at all.

3. CONCLUSION

The average cost growth for all source treatment technologies is 79.5%, and groundwater remedial time frames are underestimated by at least a factor of three. The overall cost growth estimate for source technologies may be low because of the use of bid costs for some of the sites. This estimate, however, is consistent with the 55% cost growth observed by Shroeder and Shangraw (1990), whose projected costs did not include contingency allowances that are usually about 25%.

The following cost growth trends at the sites reviewed were identified as having implications for estimating future costs at NPL sites:

- The predicted exorbitant cost growth for groundwater restoration is primarily attributable to the gross undestimation of remedial time frames.
- The volume of contaminated soil was underestimated at 56% of the sites reviewed, with an overall increase in volume of 43.5%.
- Negative cost growth for incineration is a result of a recent decrease in the cost of incineration.
- Positive cost growth for low intensity source treatment technologies is primarily attributable to increases in the volume of contaminated soil.
- Positive cost growth for in-situ source treatment technologies is primarily attributable to the underestimation of contaminants in the soil.

4. REFERENCES

Alliance Technologies Corporation, 1986. Technical Resource Document: Treatment Technologies for Dioxin-Containing Wastes. EPA/600/2-86/096.

Alliance Technologies Corporation, 1989. Draft Case Summary, Ponders Corner (Lakewood) Site, Ground Water Extraction with Air Stripping, Soil Vacuum Extraction. Bedford, MA.

Army Corp of Engineers, U. S., 1990. Unpublished cost database.

Army Toxic and Hazardous Materials Agency, U. S. (USATHAMA), 1988. Installation Restoration and Hazardous Waste Control Technologies. AMXTH-TE-CR-88010.

BioTrol, Inc., 1990. Valine, et al., BioTrol Soil Washing System, presented at the U. S. Environmental Protection Agency Second Forum on Innovative Hazardous Waste Treat Technologies: Domestic and International, Philadelphia, PA, May 15-17.

CH2M-Hill, Inc., 1989. Final Remedial Design Analyses Report, Forest Waste Lagoons. Contract No. 68-01-7251

Chemical Manufacturers Association (CMA), 1988. Impact Analysis of RCRA Corrective Action and CERCLA Remediation Programs. Washington, DC.

Canonie Environmental, 1987. Soil Remediation and Site Closure, McKin Superfund Site. Gray, Maine.

Clark, Hoyt, 1990. Personal Communication, ENSR Corporation, Houston, TX.

Cudahy, J. and A. Eicher, 1989. Thermal Remediation Industry: Markets, Technologies, Companies. Pollution Engineering (November).

Dennis, Eugene, 1990. Personal Communication, Environmental Protection Agency, Region 3.

Dev, H. et al., 1987. In-Situ Radio Frequency Heating Process for Decontamination of Soil. ACS Symposium Series No. 338, Solving Hazardous Waste Problems: Learning From Dioxins.

Dole, Leslie, 1989. Successful PRP Remediation of the Pepper's Steel and Alloys Site, Proceedings of the Superfund '89 Conference, Hazardous Material Control Research Institute, Silver Springs, MD.

Doty, Carolyn B. and Curtis C. Travis, 1991. Effectiveness of Groundwater Pumping as a Restoration Technology. Office of Risk Analysis, Oak Ridge National Laboratory, Oak Ridge, TN.

Ecology and Environment Engineering, P. C., 1987. LaSalle Electric Utilities PCB Abatement, Community of LaSalle, Code B Cost Estimate. Buffalo, NY.

ECOVA Corporation, 1988. Statement of Qualifications. Dallas, TX.

Environmental Protection Agency, U. S., 1984a. Record of Decision, LaSalle Electrical, IL.

Environmental Protection Agency, U. S., 1984b. Record of Decision, Tyson's Dump, PA

Environmental Protection Agency, U. S., 1985a. Record of Decision, Bridgeport, NJ.

Environmental Protection Agency, U. S., 1985b. Record of Decision, Davie Landfill, FL.

Environmental Protection Agency, U. S., 1985c. Record of Decision, McKin, ME.

Environmental Protection Agency, U. S., 1985d. Record of Decision, Motco, TX.

Environmental Protection Agency, U. S., 1985e. Record of Decision, Verona Wellfield, MI.

Environmental Protection Agency, U. S., 1985f. Record of Decision, Wide Beach, NY.

Environmental Protection Agency, U. S., 1986a. Record of Decision, Forest Waste, MI.

Environmental Protection Agency, U. S., 1986b. Record of Decision, Mowbray Engineering, AL.

Environmental Protection Agency, U. S., 1986c. Record of Decision, Pepper's Steel, FL.

Environmental Protection Agency, U. S., 1986d. Record of Decision, Sikes Disposal, TX.

Environmental Protection Agency, U. S., 1986e. Record of Decision, Westline PA.

Environmental Protection Agency, U. S., 1987a. Record of Decision, Independent Nail, SC.

Environmental Protection Agency, U. S., 1987b. Remedial Action Costing Procedures Manual. EPA/600/8-87/049.

Environmental Protection Agency, U. S., 1988a. Assessment of International Technologies for Superfund Applications. EPA/540/2-88/003.

Environmental Protection Agency, U. S., 1988b. Record of Decision, Aladdin Plating, PA.

Environmental Protection Agency, U. S., 1988c. Record of Decision, French Limited, TX.

Environmental Protection Agency, U. S., 1988d. Record of Decision, Groveland, MA.

Environmental Protection Agency, U. S., 1988e. Record of Decision, Lasalle Electrical, IL.

Environmental Protection Agency, U. S., 1988f. Technology Evaluation Report: SITE Program Demonstration Test, Shirco Infrared Thermal Incineration System, Peak Oil, Brandon FL. EPA/540/5-88/0020.

Environmental Protection Agency, U. S., 1988g. Record of Decision, Tyson's Dump, PA.

Environmental Protection Agency, U. S., 1989a. Shirco Infrared Incineration System: Applications Analysis Report. EPA/540/A5-89/010.

Environmental Protection Agency, U. S., 1989b. SITE Program, HAZCON Solidification Process, Douglassville, PA, Applications Analysis Report. EPA/540/A5-89/001.

Environmental Protection Agency, U. S., 1989c. Technology Evaluation Report: SITE Program Demonstration Test, International Waste Technologies In-Situ Stabilization/Solidification, Hialeah, FL. EPA/540/5-89/004a.

Environmental Protection Agency, U. S., 1989d. Technology Evaluation Report: SITE Program Demonstration Test, Shirco Pilot-Scale Infrared Incineration System, Rose Township Demode Road Superfund Site. EPA/540/5-89/007a.

Environmental Protection Agency, U. S., 1989e. Technology Evaluation Report: SITE Program Demonstration Test, Terra Vac In-Situ Vacuum Extraction System, Groveland, Massachusetts. EPA/540/5-89/003a.

Environmental Protection Agency, U. S., 1990a. Emergency Response and Removal Branch Region 4.

Environmental Protection Agency, U. S., 1990b. Remedial Action, Treatment and Disposal of Hazardous Waste, Proceedings of the Fifteenth Annual Research Symposium. EPA/600/9-90/006.

ERT, Inc., 1987. In-Situ Biodegradation Demonstration Report, Volume I - Executive Summary, French Limited Site.

Farrier, Brian, 1990. Personal Communication, U. S. Environmental Protection Agency, Region 4.

Frigerio, Lorraine, 1990. Personal Communication, U. S. Environmental Protection Agency, Region 2.

General Accounting Office, U. S. (GAO), 1988. Superfund Cost Growth on Remedial Construction Activities. GAO/RCED-88-69. Washington , DC.

General Accounting Office, U. S. (GAO), 1990. Financial Audit: EPA's Financial Statements for Fiscal Years 1988 and 1987. GAO/AFMD-90-20. Washington, DC.

Geosafe Corporation, 1989. Application and Evaluation Considerations for In-Situ Vitrification Technology: A Treatment Process for Destruction and/or Permanent Immobilization of Hazardous Materials. GSA 1901. Kirkland, WA.

Geraghty and Miller, Inc., 1990. Revised Substantial Completion Report, Forest Waste Disposal Site, Lagoon Remedial Action, Otisville, MI.

Guerriero, Margaret M., 1989. In-Situ Soil Vacuum Extraction System, Verona Well Field Superfund Site, Battle Creek, Michigan. Draft Final Report for NATO/CCMS Pilot Study on Remedial Action Technologies for Contaminated Land and Groundwater.

Hazardous Waste Technology Services, 1987. Emergency Removal Cleanup Contract, Mowbray Engineering Co., AL

IT Corporation, 1990. Unpublished Bid Price Matrix for Incineration. Knoxville, TN.

Kopotic, J., 1991. Personal Communication, U. S. Environmental Protection Agency, Region 4.

La Bare, Marion, 1990. Personal Communication, U. S. Environmental Protection Agency, Region 6.

McCray, Jim, 1990. Personal Communication, IT Corporation, Port Allen, LA.

Metzer, N. et al., 1987. In-Situ Volatilization (ISV) Remedial Systems Cost Analysis, Technical Report. AMXTH-TE-CR-87123, USATHAMA.

Nielson, Roger K. and Craig A. Myler, 1990. Low Temperature Thermal Treatment of Soils Contaminated with Aviation Fuel and Chlorinated Solvents. Presented at the Second Forum on Innovative Hazardous Waste Treatment Technologies: Domestic and International, Philadelphia, PA.

Office of Technology Assessment (OTA), 1988. Are We Cleaning Up? 10 Superfund Case Studies, U. S. Congress, Washington, DC.

Office of Technology Assessment (OTA), 1989. Coming Clean: Superfund Problems Can Be Solved. U. S. Congress, Washington, DC.

Peterson, R. L., E. Milicic, and C. J. Rogers, 1985. Chemical Destruction/Detoxification of Chlorinated Dioxins in Soils. Proceedings of the 11th Annual Research Symposium, Cincinnati, OH. EPA/600/9-85/028.

Richardson, Thomas L., Paul Dappen, and Michael C. Ray, 1990. Estimated Versus Final Costs on Hazardous and Toxic Waste Remediation Projects. Proceedings of the Superfund '90 Conference, Hazardous Materials Control Research Institute, Silver Spring, MD.

Rollins, Frank, 1990. Personal Communication, U. S. Environmental Protection Agency, Region 5.

Ryan, J.R., R. Kabrick and R. Loehr, 1988. Biological Treatment of Hazardous Waste, reprint from Civil Engineering, February 1988.

Schrock, Roy, 1990. Personal Communication, U. S. Environmental Protection Agency, Region 3.

Schroeder, B. and R. Shangraw. 1990. Parametric Tools for Hazardous Waste Cleanup Projects. American Association of Cost Engineers Transactions J2.1-J2.5.

Sealy, David, 1990. Personal Communication, U. S. Environmental Protection Agency, Region 5.

Travis, Curtis C. and Carolyn B. Doty, 1990. Can Contaminated Aquifers at Superfund Sites Be Remediated? Environ. Sci. Technology 24(10):1464-66.

Westinghouse Electric Corporation. 1987. Commercial Proposal for the La Salle Electrical Utilities PCB Abatement. Community of La Salle. Westinghouse Environmental Technology Division, Madison, PA.

Wetzel, et al., 1987. In-Situ Biological Degradation Test at Kelly Air Force Base, Vol. 2: Field Test Results and Cost Model, Final Report. ESL-TR-85-52 Vol. 2, AFESC.

APPENDIX A

PROJECTED AND ACTUAL CAPITAL COSTS FOR SOURCE TREATMENT OPERABLE UNITS

TABLE A

HIGH INTENSITY TREATMENT TECHNOLOGIES

		Projected Costs				Actual Costs				
Site/Region	Technology	Volume (cy)[a]	Capital ($1000)	Basis Yr	Unit Cost ($/cy)	Volume (cy)[a]	Capital ($1000)	Basis Yr	Unit Cost ($/cy)	References
Lasalle Electrical, IL 5										
Phase I	incineration	28,690	26,400	1986	920	27,417	11,699	1987	427	EPA (1984a) Westinghouse Electric Corp. (1987) Ecology and Environment (1987)
Phase II	incineration	34,410	34,059	1988	989	53,352	17,254	1989	323	EPA (1988e) IT Corp. (1990) Sealy (1990)
Westline, PA 3	incineration (offsite)	710	744	1986	105	2,500	3,200	---	1280	EPA (1986e) Schrock (1990)
Motco, TX 6	incineration	97,658	36,300	1985	371	70,962	28,300	1989	399	EPA (1985d) IT Corp. (1990) LeBare (1990)
Sikes Disposal, TX 6	incineration	150,100	102,217	1986	680	230,413	89,949	1989	317	EPA (1986d) IT Corp. (1990)
Bridgeport, NJ 2	incineration	60,000	57,672	1985	961	102,000	52,457	1989	514	EPA (1985a) IT Corp (1990) Frigerio (1990)

[a] Medium is soil unless otherwise noted.
[b] Projected costs are for off-site incineration.

TABLE B

LOW INTENSITY TREATMENT TECHNOLOGIES

		Projected Costs				Actual Costs				
Site/Region	Technology	Volume (cy)[a]	Capital ($1000)	Basis Yr	Unit Cost ($/cy)	Volume (cy)[a]	Capital ($1000)	Basis Yr	Unit Cost ($/cy)	References
McKin, ME 1	low temp thermal[b]	2,700	424	1983	157	9,500	2,400	1985	252	EPA (1985c) Canonie Environmental (1987)
Pepper's Steel, FL 4	solidification/ stabilization	48,000	5,212	1986	109	120,000	7,000	1989	58	EPA (1986c) Dole (1989)
Independent Nail, SC 4	solidification/ stabilization	6,200	979	1987	158	5,500	619	1988	113	EPA (1987a) Kopotic (1991)
Forest Waste, MI 5	solidification/ stabilization[c]	4,000 110,000[d]	1,295	1986	323	6,044 56,922[d]	2,400	1990	397	EPA (1986a) CH2M-Hill (1989) Geraghty and Miller (1990) Rollins (1990)
Mowbray Engineering, AL 4	solidification/ stabilization	4,800	750	1986	156	---	778	1987	---	EPA (1986b) Hazardous Waste Technology Services (1987)
Aladdin Plating, PA 3	stabilization	12,000	4,461	1988	372	12,000	7,734	1989	645	EPA (1988b) Army Corp of Engineers (1990)
Davie Landfill, FL 4	stabilization/ capping	75,000[e]	3,000-3,700	1985	40-50	77,000[e]	1,573	1989	20	EPA (1985b) Army Corp of Engineers (1990)
Wide Beach, NY 2	dechlorination	25,079	8,800	1985	351	20,888	15,317	1989	733	EPA (1985f) Army Corp of Engineers (1990)

[a] Medium is soil unless otherwise noted.
[b] Costs do not include pilot study, site closure, waste disposal, or demobilization.
[c] Costs do not include remedial design.
[d] Gallons/liquid wastes.
[e] Medium is sludge.

TABLE C

IN-SITU TREATMENT TECHNOLOGIES

Site/Region	Technology	Projected Costs Volume (cy)[a]	Capital ($1000)	Basis Yr	Unit Cost ($/cy)	Actual Costs Volume (cy)[a]	Capital ($1000)	Basis Yr	Unit Cost ($/cy)	References
Groveland, MA 1	vapor extraction[b]	20,000	702	1988	35	8,100	282	1989	35	EPA (1988d) EPA (1989e)
Tyson's PA 3	vapor extraction[c]	30,000	10,200	1988	340	30,000	20,000-25,000	1990	660-833	EPA (1984b) EPA (1988g) (Dennis 1990)
Ponders Corner, WA 10	vapor extraction	3,047	38.5	1985	12	3,217	61	1987	19	Alliance Technologies (1989)
Verona Well Field, MI 5	vapor extraction	---	413	1985	---	56,246	2,152	1985	38	EPA (1985e) Guerriero (1989)
French Limited, TX 6	in-situ biodegradation	70,100[d] 79,500	47,000	1988	314	70,100[d] 79,500	47,000	---	314	EPA (1988c) ERT (1987) Clark (1990)

[a] Medium is soil unless otherwise noted.
[b] Actual costs based on remediation of a portion of the site.
[c] Present worth costs; site not included in capital cost growth analysis.
[d] Medium is sludge.

APPENDIX B

COMPENDIUM OF COSTS FOR SOURCE TREATMENT TECHNOLOGIES

COSTS FOR SELECTED SOIL TREATMENT TECHNOLOGIES

HIGH INTENSITY TREATMENT

Site/Company	Technology	Scale(a)	Contaminants	Results	Cost/cy(b)	Basis Yr	Reference
ECOVA Dallas TX [Vendor's claims]	Shirco Infrared Incineration	---	---	---	$220-350(c)	1989	ECOVA Corp. (1988)
Times Beach, MO	Shirco Infrared Incineration	Pilot	dioxin	> 99.9999%	$270-1600	1985	Alliance Technologies, Inc. (1986)
Peak Oil, FL	Shirco Infrared Incineration	Pilot	PCBs	> 99.999%	$270-560(d)	1987	EPA (1988f)
Rose Township Economic Analyses	Shirco Infrared Incineration	Pilot	PCBs, metals	> 99.99%	$250-325(d)	1989	EPA (1989d)
Brio Refining, TX	Infrared Incineration	Pilot	CCl_4	> 99.9997%	$160-193(c)	1989	ECOVA Corp. (1988)
Naval Combustion Research Facility	UV Photolysis	Pilot	dioxin	> 98.7%	$340-1600	1986	Alliance Technologies, Inc. (1986)
Denny Farm, MO	Circulating Bed Combustion	Pilot	PCBs	> 99.9999%	$36-430	1986	Alliance Technologies, Inc. (1986)
Florida Steel, FL	Shirco Infrared Incineration	Full	PCBs	99.998-99.999%	$400(e)	1988	EPA (1989a)

Site/Company	Technology	Scale(a)	Contaminants	Results	Cost/cy(b)	Basis Yr	Reference
LaSalle Elect., IL	Incineration	Full	PCBs	> 99.9%			Westinghouse (1987)
Phase I					$297(c)	1987	
Phase II					$140(c)	1990	
Prentiss Creosote, MS	Incineration	Full	PCP creosote	<2 ppm	$148	1987	EPA (1990a) Farrier (1990)
Cornhusker, NE	Incineration	Full	TNT	<1.3 ppm	$175	---	IT Corp. (1990) McCray (1990)
So. Crop Services, FL	Incineration	Full	PCP DDT	0.003 ppm <0.2 ppm	$237	1988	EPA (1990a)
Paxton Avenue, IL	Incineration	Full	RCRA constituents	contracted	$506	---	IT Corp. (1990)
S&S Flying Service, FL	Incineration	Full	toxaphene DDT chlordane	---	$118	1990	EPA (1990a)
Malone Air Service, FL	Incineration	Full	toxaphene DDT DDD chlordane	ongoing	$220	1990	EPA (1990a)

LOW INTENSITY TREATMENT

Site/Company	Technology	Scale(a)	Contaminants	Results	Cost/cy(b)	Basis Yr	Reference
Air Force Lab	Dechlorination	Bench	PCBs, dioxins	>99.9%	$300	1985	Peterson, et al. (1985)
BioTrol [Vendor's Claims]	Soil Washing	Bench	VOCs	99%	$145	1990	BioTrol, Inc. (1990)
Letterkenny Army	Low Temp Thermal	Pilot	VOCs	55-93%	$100-250(g)	1986	USATHAMA (1988)
Tinker AFB	Low Temp Thermal	Pilot	jet fuel TCE	met cleanup goals	$121-135	1990	Nielson and Myler (1990)
Air Force Site	Radio Freq. (RF) Thermal	Pilot	VOCs	90%	$60(h)	1987	Dev, et al. (1987)
US Navy, Guam	Dechlorination	Pilot	PCBs	99.58 to < 99.9%	$270-400	1990	EPA (1990b)
TNO-Deptartment Process Technology, Apeldoorn, the Neths.	Bioremediation	Pilot	non-chlorinated hydrocarbons	78% for dry 82-95% for wet	$60	1988	EPA (1988a)
Untitled CERCLA Site	Bioremediation Land Treatment	Pilot	hydrocarbons	not available	$50-80	1987	Ryan, et al. (1988)

LOW INTENSITY TREATMENT (Continued)

Site/Company	Technology	Scale(a)	Contaminants	Results	Cost/cy(b)	Basis Yr	Reference
Heijmans Milieutechniek BV Rosmalen the Neths.	Soil Washing	Pilot	cyanides, PCA's metals	cyanides 93%, PCA's 97.5-99.8% metals 80-95.2%	$100-275	1988	EPA (1988a)
Heidemij Uitvoering BV the Neths.	Soil Washing	Pilot	oil products, heavy metals HCH's	85.9-99.07% 88-99% 97.78%	$120-250	1988	EPA (1988a)
Douglasville, PA	Solidification/ Stabilization	Pilot	metals VOC's	immobolized metals	$130-275	1989	EPA (1989b)
Kelly AFB, TX	Bioremediation	Full	hydrocarbons	< 1ppm	$135-270	1987	Wetzel, et al., (1987)
Umweltschutz Nord Gmbh Ganderkesee, FRG	Bioremediation	Full	non-chlorinated hydrocarbons	98%	$120	1988	EPA (1988a)
TBSG Industrievertretungen GmbH, FRG	Soil washing, Oil CREP	Full	PCBs, PAHs hydrocarbons	86.6-98.9% 74-99.04% 82.2-98.4%	$110-150	1988	EPA (1988a)

IN-SITU TREATMENT

Site/Company	Technology	Scale(a)	Contaminants	Results	Cost/cy(b)	Basis Yr	Reference
Terra Vac [Vendor Claims]	Vapor Extraction	---	VOCs, semi-, VOCs hydrocarbons	non-detect levels	$10-50/cy $10-35/gal	1988	EPA (1989e)
Geo-Safe [Vendor claims]	Vitrification	Pilot	non-radioactive	>99%	$400-540(f)	1990	Geo-Safe, Inc. (1990)
Hialeah, FL	Solidification (in-situ)	Pilot	PCBs	---	$260	1989	EPA (1989c)
Twin Cities Army Ammunitions Plant, MN	Vapor Extraction	Pilot	VOCs	---	$15-20/cy(i)	1987	Metzner, et al. (1987)
Bellview, FL Union 76	Vapor Extraction	Pilot	hydrocarbons	<0.2 to 0.3 (ppmv)	$20-60	1987	EPA (1989e)
RIVM-Bilthoven, the Neths.	Bioremediation	Full	gasoline	not available	$171	1988	EPA (1988a)
TAUW Infra Consult BV the Neths.	Ion Exchange	Full	cadmium	not available	$63	1987	EPA (1988a)
Hannover Umweltechnik GmbH Waldorf, FRG	Vapor Extraction	Full	VOCs	not available	<$7	1988	EPA (1988a)

(a) pilot scale and bench scale costs are estimated costs for full scale operations based on the results of the studies listed
(b) cost/ton converted assuming soil density of 100 lbs./cubic foot
(c) cost includes vendor profit, and excludes waste excavation, feed prep and ash disposal
(d) cost excludes vendor profit, waste excavation, and feed prep. and ash disposal
(e) cost includes vendor profit, waste excavation and feed prep. and excludes ash disposal
(f) excludes pilot treatability study, mobilization/demobilization costs, analytical costs
(g) fully loaded costs for sites with 15,000-80,000 tons of soil to be processed
(h) 3-acre site to a depth of 8-feet containing 12% moisture raised to a temperature of 170 degrees C would cost $42/ton
(i) cost includes soil vapor extraction system hardware, extraction air carbon adsorption system, and soil sampling

ORNL/TM-11849

INTERNAL DISTRIBUTION

1-25. C. B. Doty
26. S. V. Kaye
27. C. C. Travis
28. Central Research Library
29. Document Reference Station
30. Laboratory Records - RC
31. Laboratory Records Department
32. ORNL Patent Office

EXTERNAL DISTRIBUTION

33. Office of the Assistant Manager, Energy Research and Development, U. S. Department of Energy, Oak Ridge Operations Office, Oak Ridge, TN 37831
34-35. Office of Scientific and Technical Information, P. O. Box 62, Oak Ridge, TN 37831