EPA 542-B-98-007
October 1998

Guide to Documenting and Managing Cost and Performance Information for Remediation Projects

Revised Version

Federal
Remediation
Technologies
Roundtable
<www.frtr.gov>

Prepared by the

Member Agencies of the
Federal Remediation Technologies Roundtable

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Environmental Protection Agency
Department of Defense
U.S. Air Force
U.S. Army
U.S. Navy
Department of Energy
Department of Interior
National Aeronautics and Space Administration
Tennessee Valley Authority
Coast Guard

October 1998

NOTICE

This document has been subjected to administrative review by all Agencies participating in the Federal Remediation Technologies Roundtable, and has been approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Preparation of this document has been funded wholly or in part by the U.S. Environmental Protection Agency under EPA Contract No. 68-W5-0055.

FOREWORD

A key objective of the Guide to Documenting and Managing Cost and Performance Information for Remediation Projects (the guide) is to provide a tool for improving the collection, documentation, and management of data by describing a standard set of parameters for reporting cost and performance information about treatment technologies. Since the first version of the guide was published in 1995, federal agencies have made significant progress in coordinating efforts to document projects and to share the results of those efforts. To date, members of the Federal Remediation Technologies Roundtable (Roundtable) have completed approximately 130 case study reports.

The success of the guide is tied directly to the efforts of the Roundtable agencies. The Roundtable is an interagency working group that was created to build a more collaborative atmosphere among the federal agencies involved in remediation of hazardous waste sites. The Roundtable seeks to promote the exchange of information about the development and use of technologies and works to identify and publicize more efficient, cost-effective methods of hazardous waste remediation. A Cost and Performance Work Group was created to discuss the overall scope and specific provisions of the guide and electronic management of case studies. Member agencies recognize the importance of documenting the results of cleanups and the benefits to be realized from a coordinated effort.

The Roundtable and Work Group have met several times since the original version of this document was published to share the experiences of member agencies in using the guide and to discuss improvements. As a result of those efforts, the Roundtable undertook several major revisions to improve and bring the document up to date. Key changes include:

- Expanding the number and types of technologies to a total of 29, including containment, to reflect advances in remediation technologies since 1995.
- Adding procedures for documenting results from demonstration-scale projects and projects that are not yet completed (interim projects).
- Updating the examples to include new technologies.
- Streamlining the documentation for background information.
- Simplifying the recommended procedures for documenting cost to better reflect conventions and to facilitate comparison of technologies and unit costs.
- Providing examples of reporting formats used by member agencies.

- Significantly improving the electronic management of data on cost and performance by developing a searchable database for reports. Although reports have been made available through the Roundtable's World Wide Web site (<*www.frtr.gov*>) for a number of years, case studies can now be searched by a pick-list of key words designed to help the user better target searches and improve search results.

Member agencies have indicated a strong commitment to using the guide and to continuing to work together to collectively improve the process of documenting and managing cost and performance data. The Roundtable will continue to solicit information about experiences in using the guide, suggestions for improving the procedures for documenting remediation projects, and recommendations for improvements to the Roundtable web site. An Advisory Board will meet annually to evaluate and make recommendations for improving the Roundtable web site.

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1.0 INTRODUCTION

This Guide to Documenting and Managing Cost and Performance Information for Remediation Projects provides the recommended procedures for documenting the results of completed and on-going full-scale and demonstration-scale remediation projects. The original version was published by the Federal Remediation Technologies Roundtable (Roundtable) in March 1995 to more effectively coordinate the activities of its member agencies and to assist in documenting their experience with remediation technologies. Member agencies of the Roundtable that were major contributors to this guide are the U.S. Environmental Protection Agency (EPA), the U.S. Department of Defense (DoD), and the U.S. Department of Energy (DOE).

Agencies face a number of challenges in their efforts to increase the effectiveness of remediation projects, while decreasing the costs of cleaning-up sites and the time necessary to do so. Federal agencies are involved in a variety of activities intended to achieve those ends, including the evaluation of new technologies through field demonstrations and implementation of full-scale cleanups. Such activities present important opportunities to gather data that may be valuable in identifying future applications of a technology. However, the types of information collected about projects may vary widely, making it difficult to compare cost and performance data. In providing recommended procedures for documenting remediation projects, the Roundtable's goals are to:

- Increase the availability of standard cost and performance data on remediation technologies to facilitate comparison and help improve remedy selection
- Provide a baseline of information about conventional technologies that can be used as a benchmark in evaluating innovative technologies
- Provide a framework for streamlining future data collection and reporting efforts

Roundtable agencies have made significant progress in preparing cost and performance reports for remediation projects. Agencies published 37 studies in March 1995 and 17 in July 1997. In September 1998, the Roundtable published 86 additional studies covering a wide range of soil and groundwater remediation technologies, including conventional processes and such newer applications as permeable reactive barriers.

Roundtable agencies are committed to using the guide and will continue to explore ways to promote the adoption of standard procedures for reporting cost and performance. While the guide recommends the elements that should be documented, it also provides flexibility in the specific format to be used for reporting information. For example, the U.S. Army Corps of Engineers (USACE) has included the reporting structure of the guide in a document titled *Technical Requirements for Specifications to Report HTRW [Hazardous, Toxic, and Radioactive Waste*] *Environmental Restoration Cost and Performance*. In a July 1997 DOE memorandum on technology deployment, Alvin Alm, Assistant Secretary for Environmental Management, describes DOE's commitment to using the reporting structure identified in the guide for collection and dissemination of information to help line programs, regulators, and stakeholders make informed decisions about site remediation. William Quade, former Director of the Environment, Naval Facilities Engineering Command (NAVFAC), issued a memorandum on November 2, 1992, to all NAVFAC field offices recommending the documentation of cost and performance data for site remediation projects. In addition, EPA encourages inclusion of cost and performance data, developed using the procedures recommended in the guide, in remedial action reports.

The Roundtable also recognizes the value of obtaining as much information as possible on the cost and performance of technologies and agrees that the expansion of such efforts beyond federal agencies has merit. Members of the Roundtable see particular value with involving states in the effort and will continue to encourage state participation. The Roundtable would welcome case studies prepared by states that are consistent with the recommended procedures in the guide and would include these case studies in Roundtable publications as well as the Roundtable web site.

1.1 SUMMARY OF MAJOR IMPROVEMENTS IN THE GUIDE

Since the original guide was published, Roundtable members have participated in several meetings during which they shared their experiences in using the guide and discussed ways to improve procedures for documenting cost and performance. In addition, members reviewed recommendations provided by the National Research Council (NRC) in its report *Innovations in Ground Water and Soil Cleanup: From Concept to Commercialization* (National Academy Press, Washington, D.C. 1997).

As a result of those meetings, the Roundtable has revised the guide to expand the number and type of technologies covered, and to streamline a number of areas to make it easier and more flexible to use. Key improvements include:

- Adding 16 new technologies (for a total of 29), and expanding the attention given to conventional technologies to include containment technologies

- Expanding the scope to address demonstration-scale projects
- Simplifying the procedures for reporting costs to better reflect cost reporting conventions
- Adding a chapter on data management to reflect improvements in dissemination of case studies through the World Wide Web
- Revising the standard terminology and eliminating reporting of background information about sites

1.2 OVERVIEW OF THE GUIDE

This document summarizes the recommended procedures for reporting cost and performance of remediation projects. Chapter 2 focuses on costs, while Chapter 3 focuses on performance. Both chapters include examples on how to use the recommended formats. Chapter 4 identifies factors that affect cost or performance, and Chapter 5 presents information about specific reporting formats. A discussion about the Roundtable web site strategy is provided in Chapter 6.

Appendices provide additional information related to that presented in Chapters 2 through 6. Appendix A discusses the effects of matrix characteristics and operating parameters on cost or performance, while measurement procedures for those parameters are shown in Appendix B. A recommended format for preparing case study abstracts is provided in Appendix C, and a generic format for full case studies is shown in Appendix D. Appendices E and F list the active members of the Ad Hoc Work Group on Cost and Performance, and the members of the Federal Remediation Technologies Roundtable, respectively.

2.0 RECOMMENDED COST FORMAT

2.1 INTRODUCTION

> - The Roundtable recommends a new, simplified cost reporting format.
> - The new format offers several major benefits, including:
>   - Simplifying and standardizing the reporting of costs
>   - Validating cost models
>   - Aiding in evaluating specific technologies
>   - Aiding in comparing technologies to evaluate remedial alternatives

The cost elements recommended in this guide were developed to be consistent with various ongoing federal programs under which costs are collected. The guide recommends a new cost reporting format based on conventional capital and operation and maintenance (O&M) components for reporting costs of specific remediation technologies (technology-specific costs). Such technologies typically include treatment and containment for soil and groundwater.

In addition to technology-specific costs, most agencies also account for the overall costs of remediation efforts (total project costs), and the Roundtable recommends that total project costs also be documented. Overall costs may include a range of items, such as management and support activities; various forms of site work related to security, stormwater control, access, and utilities; permitting; monitoring; and preparation of various plans. Agencies are working together to improve cost data management and recognize the need to establish and maintain common structures to efficiently meet growing agency-specific and interagency reporting requirements. The current work breakdown structure is used to assist agencies in collecting actual project costs and continues to evolve as the cost data backbone by which project cost details are collected, analyzed, managed, and reported.

Identifying costs for a specific technology usually will be undertaken as part of a broad effort to document total project costs. Some technology-specific costs are subsets of overall project costs that are derived by disaggregating project-wide figures. Each agency is responsible for managing its own cost documentation program. However, by agreeing on the common set of reporting elements in this guide, the Roundtable agencies will maximize the use of their data by allowing meaningful comparison and assessment of technologies. Agencies may develop “cross-walk” tables as needed for factoring the Roundtable elements into their reporting formats.

2.2 ROUNDTABLE COST FORMAT

The Roundtable cost format was developed with the following objectives in mind:

- Simplicity: The format should be simple, straightforward, and easily understood by project managers in the field, without the need for extensive training.
- Common conventions: The format should be consistent with the terminology commonly used by project managers in the field, such as the terms "capital costs" and "O&M costs."
- Remediation of contaminated soil and groundwater: The format should be focused on technology applications used for treatment or containment of contaminated soil and groundwater.
- Unit costs: The format should be limited to those cost items that are related directly to the performance of a technology and to those items that would be useful in a comparison of unit costs (cost per unit of measure) for technologies and applications.
- Standardization of cost data: The format should include a standardized approach to reporting technology-specific costs that will aid in comparing data among projects, both among multiple applications of a single technology and among applications of different technologies.
- Compatibility with the reporting of project costs: The format should be designed to allow integration of the data into the reporting structures for total project costs.

Table 2-1 shows the format recommended by the Roundtable for documenting technology-specific costs. The format is based on documentation of capital costs and O&M costs for the technology application. Under those major categories, Table 2-1 shows the types of elements that typically should be reported, such as equipment and appurtenances under capital costs, and labor, materials, and utilities under O&M costs.

Capital cost items for technology include many of the fixed costs that are incurred during construction and startup of a remedial activity, such as mobilization and demobilization of technology equipment and personnel to and from a site, site preparation, and purchase of equipment. O&M cost items include many of the ongoing or recurring costs of a remedial activity, such as the costs of labor, materials, and utilities. For relatively short-term applications, O&M costs may be reported as a total value for the application; however, for longer-term applications, annual O&M costs should be reported.

The format is recommended for full-scale and demonstration-scale applications, and for all types of soil and groundwater remediation technologies, such as in situ and ex situ technologies, innovative and conventional technologies, and treatment and containment technologies. In addition, the format is applicable to both short-term and long-term technology applications.

TABLE 2-1
RECOMMENDED COST FORMAT

Cost Category/Element	Example Items
1. Capital Cost for Technology *	
Technology mobilization, setup, and demobilization	Includes the transportation (freight on board) or delivery of equipment, facilities, and personnel to and from a site, as well as the setup of temporary facilities and utilities necessary for the construction and startup of the remedial technology.
Planning and preparation	Includes permits and licenses including air emission and water discharge permits; license fees associated with use of a technology; regulatory interaction; and various written plans, such as work plans, sampling and analysis plans, health and safety plans, community relations plans, and site management plans.
Site work	Includes all work necessary to establish the physical infrastructure for a technology application and activities necessary to restore a site to pre-remediation conditions or to meet the specifications of a site restoration plan. Includes activities associated with preparing the specific site of the technology, such as clearing and grubbing; earthwork; and construction of utilities, culverts, treatment pads, foundations, and spill control structures.
Equipment and appurtenances - Structures - Process equipment and appurtenances/ construction - Other (specify)	Includes structures, equipment, and appurtenances; construction or installation of remedial technology components and materials, including technology parts and supplies to make the technology and appurtenances operational; ownership (amortization), rental or lease of equipment; and plant upgrades, modifications, or replacements; for containment, this should be broadly interpreted as including structures such as slurry walls or caps; for pump and treat, this includes construction and installation of extraction wells.
Startup and testing	Includes activities associated with the startup of the treatment technology, such as establishment of operating conditions, shakedown, and training of O&M personnel.
Other (Includes non-process equipment)	Includes all other capital costs associated with the specific technology that have not been identified above. Generally, this would include costs for non-process equipment. Non-process equipment includes office and administrative equipment, such as data processing and computer equipment, safety equipment, and vehicles.
2. Operation and Maintenance (O&M) Cost for Technology*	
Labor	Includes labor to operate and maintain the technology and associated equipment, labor supervision, and payroll expenses. Covers ongoing operations, as well as preventive and corrective maintenance activities.
Materials	Includes consumable supplies, process materials, bulk chemicals, and raw materials. Covers ongoing operations, as well as preventive and corrective maintenance activities.
Utilities and fuel	Includes consumable energy supplies, such as fuel, electricity, natural gas, and water. Covers ongoing operations, as well as preventive and corrective maintenance activities.
Equipment ownership, rental, or lease	Includes ownership (amortization), rental, or lease of equipment necessary for operation and maintenance of remedial technology components.
Performance testing and analysis	Includes monitoring, sampling, testing, and analysis related to identifying the performance of a technology. Does not include similar activities related to demonstrating compliance with applicable regulations and permits specific to the technology application.
Other (Includes non-process equipment overhead and health and safety)	Includes all O&M costs associated with a specific technology that were not identified above. Costs generally include non-process equipment overhead and health and safety associated with the O&M of a technology. Non-process equipment overhead includes maintenance and repair of office and administrative equipment, such as data processing and computer equipment, safety equipment, and vehicles. Health and safety costs include those for personal protective equipment and monitoring of personnel for health and safety.

TABLE 2-1
RECOMMENDED COST FORMAT (continued)

Cost Category/Element	Example Items
3. Other Technology-Specific Costs	
Compliance testing and analysis	Includes monitoring, sampling, testing, and analysis related to demonstrating compliance with applicable regulations and permits specific to the technology application. Does not include similar activities related to monitoring the performance of a technology.
Soil, sludge, and debris excavation, collection, and control	Includes activities associated with excavation, collection, or control of contaminated soil, sludge, and debris, prior to ex situ treatment, including staging of contaminated media. This element includes collection of drums containing contaminated media.
Disposal of residues	Includes activities associated with disposal of primary and secondary waste residues from the operation of the technology, such as treated soil disposed of off site. Covers both on- and off-site disposal of waste residues.
4. Other Project Costs	Includes all activities associated with remediation of a contaminated site that are not attributed directly to a specific technology, such as mobilization and demobilization, site work, and site restoration activities. These costs may be helpful in comparing costs of entire remediation projects and in comparing costs for a specific technology to that of the entire project.

* These items should be included in a calculation of unit cost for a specific technology application at a site. Some activities are shown on this table under both capital and O&M (e.g., equipment ownership, rental, or lease). The Roundtable recommends that the costs for those activities be reported as capital if they are related more closely to construction and startup of a technology, and as O&M if they are related more closely to the ongoing, recurring operation or maintenance of a technology. In addition, costs for project engineering and management support should be allocated to the appropriate cost element as an overhead cost, as appropriate.

For demonstration-scale projects, the Roundtable recommends that the projected costs for full-scale applications, rather than the costs of the demonstration, be reported. The assumptions used in extrapolating costs from demonstration-scale projects to full-scale projects also should be documented. In addition, it may be useful to report costs incurred for the demonstration and to document how those costs were used in projecting to full scale. It should be noted that there can be a great deal of uncertainty with projections to full scale that are based on data from a demonstration project. The degree of uncertainty will vary based on the background and experience of the organization extrapolating the date. Therefore, the Roundtable recommends that the organization extrapolating the data be identified.

Costs should be reported for each of the items specified in Table 2-1, and more detailed reporting of each element should be provided, when possible. For example, under equipment and appurtenances for a groundwater pump and treat application, the Roundtable recommends reporting the cost separately for extraction wells, injection wells, and above-ground treatment equipment that were used to calculate a total cost for equipment and appurtenances. In addition, for some applications, it might be illustrative to report the costs for certain O&M elements (such as labor, materials, utilities and fuel, and equipment ownership, rental, or lease) separately for operation and for maintenance. For example, it would be useful to report costs separately between operation and maintenance for applications with relatively large costs for preventive or corrective maintenance.

Table 2-1 includes capital and O&M costs for technology as well as other technology-specific costs and other project costs. Other technology-specific costs include costs for excavation of soil, sludge, and debris (for ex situ processes), disposal of residues, and compliance testing and analysis. As discussed below, under the section on unit cost, only the capital and O&M costs that are specific to a technology (items 1 and 2 on Table 2-1) should be included when calculating a unit cost for a technology application. However, the guide recommends reporting costs for the other elements (items 3 and 4) to provide additional information that may be useful in comparing technologies.

Those items shown on Table 2-1 as other technology-specific costs (excavation of soil, sludge, and debris, disposal of residues, and compliance testing and analysis) are related to use of a technology, and there is disagreement among remediation professionals about whether to include these items in a calculation of technology-specific unit costs (for example as part of O&M). The Roundtable suggests that these other technology-specific costs be reported, but not included in a calculation of unit costs. In this way, the data will be available and provide flexibility to analysts who may chose to include one or more of these items in a unit cost or to use in future comparisons of technologies.

The Roundtable recognizes that some activities, such as project engineering or management support, could be considered as part of either capital or O&M costs. The Roundtable recommends that the costs for project engineering and management support should be accounted for as an overhead expense associated with the appropriate capital or O&M cost element, and generally not as a separate line item cost element. These activities should be reported as capital if they are related more closely to construction and startup of a technology, and as O&M if they are related more closely to the ongoing, recurring operation or maintenance of a technology. It should also be noted that Table 2-1 does not show profit as a separate cost element. Because there are a number of different ways to account for profit, the Roundtable recommends that profit be accounted for within cost elements, as appropriate.

In addition, if detailed costs are not available, then costs should be reported at an aggregate level if it can be verified that the aggregate cost includes only those elements identified in items 1 and 2 of Table 2-1 (capital and O&M costs). For example, a total cost could be reported when data for specific cost elements are not available. Such data will be useful if the project manager can verify that only capital and O&M cost elements are included in a total cost and that other activities at a site, not related to the specific technology application (such as project site work or site restoration), not be included in the total.

RECOMMENDATIONS FOR CALCULATING UNIT COSTS OF SAMPLING AND ANALYSIS

Most remedial applications involve on- or off-site testing and analyses of contaminated media and residues of treatment. Those activities are conducted to monitor the performance of the technology system (process control and operation) or to establish regulatory compliance. While there is disagreement among remediation professionals about whether to include the costs of analysis for both performance monitoring and compliance monitoring in a calculation of unit costs, the guide recommends including only the costs of analysis for performance monitoring in a calculation of unit costs for technology applications. This approach is consistent with that recommended in the original guide, which discussed the significantly site-specific nature of the costs of analysis for regulatory compliance. However, experience with documenting technology costs has shown that it has been difficult to separate these two types of costs.

It may be useful to array the total project costs for a site and identify the portion of those costs that represents technology-specific activities (sometimes referred to as disaggregation of project costs). In addition, several common elements, such as mobilization and demobilization, and site work and preparation, may be included in both project- and technology-specific costs. In those cases, as Table 2-1 shows, the Roundtable recommends that the portion of the costs of these activities that is directly attributed to the technology application be identified and included in the costs of technology-specific activities.

For technology applications that involve use of a treatment train (several specific technologies grouped together for sequential treatment of a contaminated media), the guide recommends that the technology components of the treatment train be considered collectively for cost purposes (i.e., as a "single" specific technology; generally the dominant technology) and that the costs of all components of the treatment train be included in the costs for that single collective technology. A common example of a treatment train is a pump and treat application for groundwater. In these applications, groundwater typically is extracted and treated above ground through application of several technologies in series, such as chemical precipitation, air stripping, and UV/oxidation. In this case, the entire treatment train could be considered "groundwater treatment", and one cost reported for the collection and treatment of the groundwater. Another example of a treatment train is a bioremediation application for soil in which the soil first is treated by soil washing to separate out larger-sized soil fractions, and then is treated by application of the bioremediation technology. In this case, the entire treatment train would be considered as ex situ slurry-phase bioremediation, with one cost reported for both components.

The recommended cost format described in this guide differs from that in the original guide, but is still intended for use with an interagency work breakdown structure. The new elements reflect experience gained to date in collecting cost data, along with adherence to the objectives stated earlier.

INTERAGENCY COST ESTIMATING GROUP WORK BREAKDOWN STRUCTURE

In the late 1980s, the USACE, Navy, Air Force, EPA, and DOE formed the Interagency Cost Estimating Group (ICEG) to develop the Hazardous, Toxic, and Radiological Waste (HTRW) Work Breakdown Structure (WBS). The WBS was published in three sections; studies and design (System 32), remedial actions (System 33), and operations and maintenance (System 34). The WBS has been used as a common cost structure by federal agencies to assist in collecting historical costs. The ICEG mission continues with maintaining this structure with upgrades including new technologies and cost and performance data requirements.

Unit Costs

Calculated unit costs are used to compare and contrast remediation technologies. Therefore, it is important that such costs be calculated in a manner that allows comparison of different technologies and of multiple applications that involve the same technologies. In general, unit costs should be expressed as a total cost for the technology-specific application, divided by an appropriate unit of measure. Unit costs are highly dependent on site-specific conditions and should be extrapolated to other sites with caution. One of the challenges, as cost data become available in the future, is to better understand how site conditions affect remediation costs.

To achieve consistency in calculating unit costs, it is important that the basis used to develop the total cost and the basis used to develop the unit of measure be consistent. To simplify the calculation of unit costs, the guide provides a worksheet for compiling costs, shown as Exhibit 2-1. The worksheet shows all the cost elements included on Table 2-1 and specifies that only capital and O&M cost elements should be included in a calculation of technology-specific unit costs. The total cost for an application should not include other project phases/activities, such as preliminary assessment/site investigation, remedial investigation/feasibility study, remedial design, or post-closure surveillance and long-term monitoring. Items that may be derived by disaggregation of overall project costs are marked with a double asterisk (**) on Exhibit 2-1.

The Roundtable recognizes that the appropriate basis for calculating the unit of measure for each application will vary by site, depending on the remediation technology used, the media treated, and the performance data available. In addition, there are differences of opinion among remediation professionals about the most appropriate basis for calculating unit costs. Agencies use different bases for calculating unit costs, and there is no universal standard basis for calculating unit costs.

However, for the guide, the Roundtable recommends that the unit cost be stated either as the amount of medium treated (for example, cost per cubic yard) or as the amount of contaminant removed (for example, cost per pound) during the remediation. Typical unit costs for groundwater remediation are cost per 1,000 gallons of water treated and cost per pound of contaminant removed. For soil remediation, typical unit costs are cost per cubic yard of soil treated and cost per pound of contaminant removed.

Unit costs should be calculated and reported for each specific technology application. In addition, enough information should be reported to provide a detailed explanation of the unit cost basis, which will enable a level comparison of calculated unit costs with those of other remedial technology applications. As discussed under Chapter 3 of this guide (Recommended Performance Reporting), this might include information such as initial and final contaminant concentrations.

Specific recommendations are provided about the following aspects related to calculating unit costs:

- Recommendations for calculating unit costs for ex situ applications
- Recommendations for calculating unit costs for in situ applications
- Recommendations for calculating unit costs for groundwater pump and treat applications
- Recommendations for calculating unit costs for containment applications

EXHIBIT 2-1
SAMPLE WORKSHEET FOR COMPILING TECHNOLOGY-SPECIFIC UNIT COSTS

Cost Category/Element	Cost ($ Year Basis)	Cost for Calculating Unit Cost
1. Capital Cost for Technology		
Technology mobilization, setup, and demobilization**		
Planning and preparation		
Site work**		
Equipment and appurtenances - Structures - Process equipment and appurtenances/ construction - Other (specify)		
Startup and testing		
Other** (Includes nonprocess equipment)		
Total capital costs		
2. O&M for Technology		
Labor		
Materials		
Utilities and fuel		
Equipment ownership, rental, or lease		
Performance testing and analysis		
Other** (Includes nonprocess equipment overhead and health and safety)		
Total operation and maintenance costs		
3. Other Technology-Specific Costs		
Compliance testing and analysis		
Soil, sludge, and debris excavation, collection, and control		
Disposal of residues		
4. Other Project Costs		
Total cost (year basis for cost)		
Total cost for calculating unit cost		
Quantity treated		
Calculated unit cost		
Basis for quantity treated		

* 1. Please provide additional details and supporting information for all cost elements as appropriate.
2. For longer-term applications, please modify this worksheet by adding columns to track costs year by year.

** These figures are from apportionment of those costs attributable to the specific technology that may be derived by disaggregation of overall project costs.

RECOMMENDATIONS FOR CALCULATING UNIT COSTS FOR EX SITU APPLICATIONS

Ex situ applications, such as thermal desorption and solidification and stabilization, typically involve: (1) excavating soil or other contaminated media, (2) treating the media, and (3) disposing of treated residues. While there is disagreement among remediation professionals about whether to include all three cost elements in a calculation of unit costs, the guide suggests that only costs of treating the contaminated media be used in calculating the unit costs for comparing among ex situ technology applications. This approach is consistent with that recommended in the original guide, in which excavation and disposal of residues were reported separately as before- and after-treatment costs, respectively, and were not included in the unit cost calculation. One advantage of that approach is that it allows an analyst the flexibility to include those costs in or omit them from the calculation of unit cost, as desired. Further, the approach allows more meaningful comparison of ex situ technologies by eliminating such site-specific costs from consideration.

RECOMMENDATIONS FOR CALCULATING UNIT COSTS FOR IN SITU APPLICATIONS

Several special considerations apply to in situ applications such as soil vapor extraction (SVE) and in situ bioremediation and should be considered for those applications. These include the basis for the quantity of material treated, the basis for the quantity of contaminant removed versus treated, and the purpose of the technology (treatment only, containment only, or treatment and containment), and whether there is a continuing source of contamination. The Roundtable's recommendation for each situation is presented below, along with examples**.**

Basis for quantity of material treated: Specify whether the quantity of material treated in situ is the amount of material that is contaminated (for example, areal extent of contamination) or the amount of material that was affected by the treatment technology (for example, radius of influence of a technology), and provide both types of amounts as available.

Example: SVE; for these applications, the amount of material contaminated may differ from the amount included in the zone of influence of the treatment system.

Basis for quantity of contaminant removed versus treated: Specify whether the technology included in situ bioremediation as part of the application. In such cases, the amount of contaminant treated will be greater than the amount of contaminant removed (also relevant for ex situ applications).

Example: Combination of a pump and treat system and in situ bioremediation

Presence of a continuing source of contamination: Specify whether a continuing source of contamination, such as non aqueous phase liquids (NAPLs), was identified or suspected at the site. The presence of continuing sources such as NAPLs sometimes tend to cause the unit costs of an application to be higher than the costs of similar applications when NAPLs are not present.

Examples: SVE and in situ bioremediation

RECOMMENDATIONS FOR CALCULATING UNIT COSTS FOR GROUNDWATER PUMP AND TREAT APPLICATIONS

Groundwater pump and treat applications consist of technologies used for extraction of groundwater from the subsurface and above-ground treatment equipment, such as air strippers, carbon adsorption units, and chemical treatment systems. Some of the considerations discussed above for ex situ and in situ applications also are relevant to groundwater pump and treat applications. In addition, the guide provides the following specific recommendations related to calculating unit costs for groundwater pump and treat applications:

Cost basis: The costs of all groundwater extraction and above-ground treatment equipment should be included as a capital cost item in the total cost of groundwater pump and treat applications. The costs of operating and maintaining all extraction and injection wells, pumps, and treatment equipment should be included as O&M cost items.

O&M costs: Because implementation of groundwater pump and treat applications often requires an extended amount of time (for example, 10 years or more), the O&M costs should be provided both as a total value and on an annual basis. Doing so will aid analysts who choose to calculate a net present value for such applications.

Quantity of media removed and treated: The Roundtable recommends that unit costs be reported on the basis of both the quantity of groundwater extracted and the quantity of contaminant removed from the aquifer. For applications that involve biodegradation of contaminants, the Roundtable recommends including an accounting of the quantity removed specifically by biodegradation.

Cost of source control: Many groundwater pump and treat applications also include source control activities, such as excavation of soil (for hot spots), treatment of soil (SVE), and recovery of free product. The Roundtable recommends including costs of source control activities in the cost basis for groundwater pump and treat applications only if they are an integral part of the application.

Purpose of the technology: Specify whether the technology was operated for treatment only, containment only, or for both treatment and containment. Unit costs for pump and treat systems operated for containment of an aquifer may differ from unit costs for applications in which a pump and treat system is operated for both remediation of an aquifer and hydraulic control.

RECOMMENDATIONS FOR CALCULATING UNIT COSTS FOR CONTAINMENT APPLICATIONS

Containment projects are typically those involving vertical barrier walls (such as slurry or sheet pile walls) or caps (such as on landfills). These applications include construction of physical barriers, and labor and performance monitoring for conducting routine and ongoing maintenance of the barriers. The Roundtable recommends that the costs for construction of the barriers be included under capital costs and the routine and ongoing maintenance of the barriers be included under O&M costs. In this way, the costs for construction and maintenance of the barriers will be included in a calculation of unit costs for the barriers.

2.3 EXAMPLES OF USE OF THE RECOMMENDED COST FORMAT

Two examples of actual remediation projects are provided to show how to report technology-specific costs and how to use the sample worksheet. Example 1, a pump and treat system for treating contaminated groundwater at McClellan Air Force Base, Operable Unit (OU) B/C, shows that capital costs are limited to those for equipment and appurtenances, while O&M costs include those for labor, materials, and analysis. In that example, O&M costs are shown as a total and as an annual value. Example 2, in situ enhanced soil mixing at Portsmouth Gaseous Diffusion Plant, shows that capital costs include those for equipment and appurtenances, nonprocess equipment, permits, and site work and preparation, while O&M costs include those for labor, materials, overhead, and analysis. In addition, in the second example, costs were incurred for disposal of residues and analysis related to compliance monitoring (separate from that for technology performance); those items are not included in the total cost when calculating the unit cost.

2.4 COST COMPARISONS

To compare the costs of one technology with those of another, or to compare costs of a technology application at one location with those at another, federal agencies have developed analytical methodologies and cost factors. The following sources of information may be useful in evaluating cost data.

- Standard Life-Cycle Cost-Savings Analysis Methodology for Deployment of Innovative Technologies, DOE Federal Energy Technology Center, October 30, 1998 (final draft). (Note that at the time this guide was published, the DOE methodology was not yet complete; it will be available soon after publication of the guide.)
- Department of Defense (DoD) Area Cost Factors
- Compendium of Cost Data for Environmental Remediation Technologies, 2nd Edition, DOE Los Alamos Laboratory, August 1996
- Remediation Technologies Screening Matrix, Version 3.0, Federal Remediation Technologies Roundtable

Example 1. Pump and Treat System at McClellan Air Force Base, OU B/C									
Type of Cost	**Techno-logy Cost($)**	**Cost for Calculating Unit Cost($)**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**
1. Capital									
Mobilization/demobilization	0								
Planning and preparation	0								
Site work	0								
Equipment and appurtenances									
Incinerator	300,000		300,000						
Air stripper	400,000		400,000						
Scrubber	300,000		300,000						
Heat exchangers (3)	300,000		300,000						
Electric motors (6)	180,000		180,000						
Blowers (2)	40,000		40,000						
Pumps (6)	180,000		180,000						
GAC tanks (4)	360,000		360,000						
Water holding tank	40,000		40,000						
Berm and foundation	150,000		150,000						
Air compressors (2)	60,000		60,000						
Water pipes to plant	300,000		300,000						
Wells and pumps (10)	300,000		300,000						
Control center	140,000		140,000						
Indirect costs	910,000		910,000						
TOTAL	4,000,000		4,000,000						
Startup and testing	0								
Other	0								
Total capital costs		4,000,000							
2. Operation and Maintenance									
Labor Labor, operations support, staff labor	730,000								
Materials Reimbursables, electricity, natural gas	320,000								
Utilities and Fuel	Included with materials								
Equipment ownership, rental or lease	0								
Performance testing and analysis	40,000								
Other Equipment overhead (Other direct costs)	150,000								
Total operation and maintenance costs		1,240,000	180,000	180,000	180,000	180,000	180,000	180,000	180,000
3. Other Technology-Specific Costs									
Compliance Testing and Analysis	0								
Soil, Sludge, and Debris Excavation, Collection, and Control	0								
Disposal of Residues	0								
4. Other Project Costs	0								
Total technology cost	5,240,000		4,180,000	180,000	180,000	180,000	180,000	180,000	180,000
Total cost for calculating unit		5,240,000							
Quantity treated	660,000,000 gallons groundwater extracted; 42,000 lbs VOCs removed								
Calculated unit cost	$8 per 1,000 gallons extracted and $120 per pound of VOC removed								

Example 2. In Situ Enhanced Soil Mixing at Portsmouth Gaseous Diffusion Plant

Type of Cost	Technology Cost	Cost for Calculating Unit Cost ($)
1. Capital		
Mobilization/demobilization	60,000	
Planning and preparation	0	
Site work	142,000	
Equipment and appurtenances - Structures - Process equipment and appurtenances	745,000	
Startup and testing	0	
Other - Nonprocess equipment - Management support	 124,000 199,500	
Total	323,500	
Total capital costs		1,270,500
2. Operation and Maintenance		
Labor	270,750	
Materials	56,000	
Utilities and fuel	Included with materials	
Equipment ownership, rental, or lease	0	
Performance testing and analysis	73,500	
Other Equipment overhead	50,000	
Total operation and maintenance costs		450,250
3. Other Technology-Specific Costs		
Compliance testing and analysis	*	
Soil, Sludge, and Debris Excavation Collection and Control	0	
Disposal of residues	150,000*	
4. Other Project Costs	0	
Total technology cost	1,870,750	
Total cost for calculating unit cost		1,720,750
Quantity treated		10,300 - 15,000 cubic yards soil (soil density 120 lbs/cubic foot)
Calculated unit cost		$115 - $167 per cubic yard of soil treated

* For this application, information was available only for the sum of items 3 and 5; that sum is shown here in item 5.

Life-Cycle Cost-Savings Analysis

The DOE methodology is a systematic approach to developing and reporting estimated life-cycle cost savings achieved through the deployment of innovative technologies. The methodology, which requires reporting of total project costs and not just technology costs, consists of the following steps: identifying credible sources of technical data on the innovative technology, identifying the applicable baseline systems, automating the analysis, performing cost analyses, and identifying organizational roles and responsibilities.

The methodology requires that innovative and conventional options be compared on an equitable basis, with factors common to both options (such as waste volumes) equal to the maximum extent possible, and that effects "upstream" and "downstream" of an innovative technology (such as monitoring and waste disposal) be considered in a total life-cycle cost comparison.

Cost analyses described in the DOE methodology include cash-flow schedules, net present value (NPV), break-even times, uncertainty analyses, and sensitivity analyses. According to the methodology, the appropriate discount rate established by the Office of Management and Budget (OMB) in OMB Circular A-94 (revised periodically) should be used in calculating the NPV of each option. Under the DOE methodology, the cost savings for an innovative technology option compared with a conventional technology option should be based on the difference between the NPVs of their estimated total life cycle cost.

Area Cost Factors

All DoD services use area cost factors (ACF) to adjust average historical facility costs to a specific project location. This approach provides increased accuracy in comparing and projecting costs at a various locations. According to the DoD methodology, the combination of local labor, material, and equipment (LME) has the greatest effort on total construction costs. A market basket of 10 labor crafts, 20 materials, and four pieces of construction equipment was selected, and each of the 34 individual items was given a relative weight to represent its contribution to the total cost of construction at a typical facility. Once every two years, USACE surveys the prices of the 34 items in the market basket in 188 cities. In addition to the local LME cost, other local conditions that affect construction costs, referred to as matrix factors, are included in the ACF. These matrix factors include such items as regional design loads for seismic activity, wind, snow, and heat. The results of the survey and consideration of the matrix factors are used in developing the ACF. ACFs are available on the Internet through the USACE's Cost Engineering & Programs Formulation Branch web site at <*http://www.hq.usace.army.mil/cemp/e/ec/ec_new.htm*>. As of October 1998, this web site provides ACFs from April 1998; the ACFs are updated on a yearly basis.

Compendium of Cost Data

The *Compendium of Cost Data for Environmental Remediation Technologies, Second Edition* (LA-UR-96-2205) was compiled in August 1996 under the Environmental Technologies Cost-Savings Analysis Project (ETCAP) at the Los Alamos National Laboratory. The effort was supported by DOE's Office of Science and Technology, EM-50. The first edition of the compendium was assembled in 1989. The second edition is available as hard copy or a searchable database from the Los Alamos National Laboratory's web site at <*http://www.lanl.gov/projects/etcap*>.

The compendium provides a representative sample of cost information for both conventional and innovative remediation technologies for the treatment of hazardous, radioactive, and mixed wastes. The compendium describes approximately 250 commercial or pilot-scale remedial projects. Cost data for the projects were gathered from a variety of sources (for example, National Center for Environmental Publications and Information [NCEPI] repository, the Vendor Information System for Innovative Treatment Technologies [VISITT] database, and Roundtable remediation case studies) and summarized to provide actual cost summaries, site characteristics, and comments about details of remedial projects. The cost information provided varies according to source in level of detail.

Remediation Technologies Screening Matrix

The Remediation Technologies Screening Matrix, Version 3.0, prepared under the auspices of the Roundtable, is a web-based product that allows a user to view information about remedial technologies from contaminant, media, or technology perspectives. In addition, the screening matrix includes links to related web sites such as for cost and performance reports. Users can identify the range of technologies that are applicable to a specific type of contaminant or media, and then draw on the collection of cost and performance reports to view historical information about actual field applications of those technologies. Roundtable member agencies plan to frequently update the screening matrix web site to keep pace with the ever-changing range of available technologies.

3.0 RECOMMENDED PERFORMANCE REPORTING

- Procedures are recommended for reporting site remediation project performance
- Analysts should document all cleanup objectives, and how well a remedial action met each objective
- Consistency in reporting project performance will aid in comparing among technologies and applications

The recommended procedures for reporting performance cover full-scale and demonstration-scale projects and address both completed and ongoing projects. Exhibit 3-1 lists the types of performance information, by topic area, that should be reported for a technology application. The level of detail and data available for each topic will vary by technology type and the specific application; therefore, the items listed in Exhibit 3-1 provide a guide to ensure that the important topics related to technology performance are documented. For example, performance often is characterized only in terms of a removal percentage or the level of concentration attained. However, that information alone, in the absence of information about the other topics listed in Exhibit 3-1, may not be adequate to assess the overall performance of the technology. Exhibit 3-2 presents an example that shows how to document performance for a completed remediation project.

The parameters to be documented for demonstration-scale projects are similar to those for full-scale projects, taking into account the following additional parameters (developed by DOE for its reports): commercialization issues, including market influences and patents, and competing technologies. Exhibit 3-3 presents an example that shows how to document performance for a demonstration-scale project. A primary goal of reporting on demonstration-scale projects is documentation of performance information.

For ongoing projects, such as a groundwater pump and treat applications, it is useful to document interim results, including information about the progress and status of the project that gives an indication of how well a technology is performing over time, whether problems arose during the technology application, and how such problems were or are being resolved. Interim reports should be updated when new data are available or when the project is completed. One benchmark for updating a report would be periodically scheduled reviews, such as the five-year Superfund review process. However, decisions about when it is appropriate to update a report should be made on a case-by-case basis. Exhibit 3-4 presents an example that shows how to document performance for an ongoing project.

EXHIBIT 3-1
RECOMMENDED PERFORMANCE REPORTING

Performance Topic	Type of Information
Types of samples collected	• Types of media sampled • Types of constituents analyzed • Use of surrogates (for example, soil gas as a surrogate for soil borings)
Sample frequency and protocol	• Where samples were collected • How samples were collected • When samples were collected • Who collected samples
Quantity of material treated	• Quantity of material treated during application • For in situ technologies, area and depth of contaminated material treated
Concentrations of untreated and treated contaminants	• Measurement of initial conditions (even if not required to demonstrate compliance with cleanup criteria) • Measurement of concentrations of contaminants during or after treatment (noting whether there are matched pairs of data on treated and untreated contaminants or whether there are operating data that correspond with performance data) • Assessment of percent removal achieved (noting procedure used to derive percent removal) • Correlations of performance data with other variables
Cleanup objectives	• Cleanup goals or objectives • Criteria for ceasing operation
Comparison with cleanup objectives	• Assessment of whether the technology operation achieved the cleanup objectives • Assessment of whether the technology was operated to achieve reductions in concentrations of contaminants beyond the established cleanup objectives
Method of analysis	• Method of analysis used (including field screening or analyses, portable instruments, mobile laboratory, off-site laboratory, laboratory procedures, nonstandard methods) • Exceptions to standard methodology

EXHIBIT 3-1 (continued)
RECOMMENDED PERFORMANCE REPORTING

Performance Topic	Type of Information
Quality assurance and quality control (QA/QC)*	• Who was responsible for QA/QC • Type of QA/QC measures performed • Level of procedures • Exceptions to QA/QC protocol or data quality objectives
Other residues	• Types of residues generated (for example, off-gases, wastewaters, or sludges) • Measurement of mass or volume, and concentration of contaminants in each treatment residue

* Note that only very general QA/QC information is recommended; any exceptions to the QA/QC procedures should be documented.

EXHIBIT 3-2
EXAMPLE OF REPORTING PERFORMANCE INFORMATION
FOR A FULL-SCALE COMPLETED PROJECT

Dubose Oil Products Co. Superfund Site, Cantonment, Florida	
Types of samples collected	Soil analyzed for volatile organic compounds (VOCs), including trichloroethene (TCE); pentachlorophenol (PCP); and polycyclic aromatic hydrocarbons (PAHs)
Sample frequency and protocol	Soil in each 165-cubic yard batch analyzed prior to and after 14-day treatment
Quantity of material treated	19,705 tons of contaminated soil were treated in 165-cubic yard batches
Untreated and treated contaminant concentrations	Average Concentrations: Total PAHs Initial - 50.8 to 576.2 mg/kg Final - 3.3 to 49.7 mg/kg PCP Initial - 7.67 to 160 mg/kg Final - 16.5 to 36.3 mg/kg Total Xylenes Initial - 0.07 to 69.5 mg/kg Final - 0.03 to 1.05 mg/kg TCE Initial - 0.01 to 1 mg/kg Final - 0.01 to 0.04 mg/kg Benzene and 1,1-dichloroethene (DCE) were not reported above detection limits in any samples
Cleanup objectives	Cleanup goals for soil: Total PAHs - 50 mg/kg PCP - 50 mg/kg Total Xylenes - 1.5 mg/kg Benzene 10 mg/kg TCE - 0.05 mg/kg 1,1-DCE - 0.07 mg/kg
Comparison with cleanup objectives	Cleanup objectives were met for all treated soil batches
Method of Analyses	EPA Method 8270 for PAHs and PCP EPA Method 8010 and 8020 for VOCs
Quality assurance and quality control (QA/QC)*	QAPP prepared for project Remediation contractor was responsible for QA/QC Trip blanks, field blanks, matrix spike and matrix spike duplicate samples were taken; no exceptions to data quality objectives were noted
Other residues	None generated

EXHIBIT 3-3
EXAMPLE OF REPORTING PERFORMANCE INFORMATION
FOR A DEMONSTRATION-SCALE PROJECT

In Situ Air Stripping of Contaminated Groundwater at U.S. Department of Energy, Savannah River Site, Aiken, South Carolina	
Types of samples collected	Soil vapor and groundwater; analyzed for VOCs
Sample frequency and protocol	- Soil vapor monitored for VOCs continually during demonstration - Groundwater monitored weekly
Quantity of material treated	Area of VOC-contaminated groundwater has an approximate thickness of 150 feet and covers about 1,200 acres
Untreated and treated contaminant concentrations	- Substantial changes in groundwater VOC concentrations measured during demonstration - Increased microbial numbers and metabolic activity exhibited during an air injection period
Cleanup objectives	No specific cleanup goals identified for the field demonstration (total VOC removal to be measured)
Comparison with cleanup objectives	139 day demonstration removed nearly 16,000 pounds of VOCs
Method of Analyses	VOCs monitored using a FID
Quality assurance and quality control (QA/QC)	None identified for field demonstration
Other residues	- Decontamination fluids - Off-gas
Additional Information for Demonstration-Scale Project — Refer to Exhibit 4-1	

EXHIBIT 3-4
EXAMPLE OF REPORTING PERFORMANCE INFORMATION FOR AN ONGOING PROJECT

Twin Cities Army Ammunition Plant, New Brighton, Minnesota	
Project status	Ongoing; report covers period October 1987 through September 1992
Types of samples collected	Groundwater; analyzed for VOCs
Sample frequency and protocol	Sample frequency from 17 groundwater extraction wells was not specified
Quantity of material treated	1.4 billion gallons of groundwater were treated from October 1991 to September 1992
Untreated and treated contaminant concentrations	- Chlorinated VOCs (CVOCs) were detected in the aquifer - TCE was the most prevalent with concentrations up to 10,000 µg/l - No substantial change in the contaminant concentrations in the aquifer has been noted
Cleanup/remediation objectives	- Cleanup goals for groundwater (based on the site ROD): TCE - 5 µg/l PCE - 6.9 µg/l 1,2-DCE - 70 µg/l 1,1,1-TCA - 200 µg/l - Containment of the contaminant plume
Comparison with cleanup objectives	- Cleanup goals have not been met to date - Plume containment has been achieved
Method of Analyses	Not identified in interim report
Quality assurance and quality control (QA/QC)	Not identified in interim report
Other residues	Not identified in interim report

4.0 FACTORS THAT AFFECT COST OR PERFORMANCE

4.1 BACKGROUND

- Specific parameters are identified for documenting matrix characteristics and operating parameters of 29 remediation technologies
- Parameters were selected as those items most important for influencing a technology's cost or performance

As discussed in the original guide, a number of parameters, including matrix characteristics and operating parameters can affect the cost or performance of a treatment technology. Tables 4-1 and 4-2 presented at the end of this chapter list, by technology, the key parameters that affect cost or performance and that should be documented for a specific application. The matrix characteristics to be documented include soil types, soil properties, and organic contaminants that may be present in a matrix. The operating parameters include system parameters, such as residence time and system throughput.

The recommended reporting factors were developed with the following objectives and basic principles in mind:

- **Only technologies used in large-scale field projects are included:** The guide is limited to an evaluation of technologies that have been used in a relatively large-scale field demonstration and are considered ready for full-scale application; technologies that have been used only in relatively small bench- or pilot-scale research studies were not included.

- **Matrix characteristics are limited to soil types and media properties:** In identifying the matrix characteristics that are most important for documenting technology applications, only those characteristics that represent soil types and media properties (such as hydraulic conductivity) were included. Other parameters that affect the cost and performance of remedial technologies are addressed elsewhere. The other parameters include items such as the types and concentrations of specific contaminants, the environmental setting (for in situ technologies), the quantity of material treated, and cleanup goals or requirements.

- **Operating parameters are those items that can be modified or changed:** Several of the parameters referred to below, such as moisture content, might be considered either matrix characteristics or operating parameters, depending on when and how they are discussed. Items were considered to be operating parameters when they could be modified or changed by an engineered process, such as adding nutrients for in situ bioremediation.

The original guide recommended reporting factors that affect cost or performance for 13 specific technologies. Since that time, several technologies have become ready for full-scale remedial applications.

This guide includes recommended reporting factors for 29 specific technologies, including both treatment and containment technologies. The following specific technologies are listed in Tables 4-1 and 4-2.

In Situ Soil Remediation and Containment	**Groundwater Remediation and Containment**
Bioventing	Pump and treat system
Soil flushing	Dual-phase extraction
Soil vapor extraction	Air sparging
Bioslurping	Circulating wells (UVB)
Phytoremediation	Dynamic underground stripping
In situ heating	Steam flushing
Vitrification	Cosolvents and surfactants
Capping	Natural attenuation (chlorinated compounds)
Ex Situ Soil Remediation	Natural attenuation (nonchlorinated hydrocarbons)
	Bioremediation
Land treatment	Phytoremediation
Composting	Vertical barrier walls
Soil washing	Reactive permeable barriers
Stabilization	In situ oxidation (Fenton's reagent)
Incineration	
Thermal desorption	
Slurry-phase bioremediation	

Appendix A presents information about the potential effects on cost or performance of each of the matrix characteristics and operating parameters listed in Tables 4-1 and 4-2. This appendix provides additional background information about how specific parameters may affect the cost or performance of a technology.

4.2 DEMONSTRATION-SCALE PROJECTS

The parameters listed in Tables 4-1 and 4-2 constitute a standard set of data that will facilitate the comparison of cost and performance among technologies. The need to collect information about additional parameters should be decided on a site-specific basis, and such information should be included in the project documentation, as appropriate. For demonstration-scale projects, the information in Tables 4-1 and 4-2 should be documented, when possible. The following additional information (obtained from DOE's Innovative Technology Summary Reports on demonstration-scale projects) also should be documented if possible to address specific issues associated with the demonstration aspects of the technology, as follows:

- **Applicability of the technology:** Include information about the suitability and limitations of the technology in light of such factors as hydrogeologic setting or specific considerations related to the matrix or contaminant. Discuss information related to commercialization and intellectual property.

- **Competing technologies:** Include information about other technologies currently in use that may compete with the technology of concern. Identify the organization providing the information on the baseline and any competing technology and whether the organization is a vendor, developer, investor, or other entity that may have an interest in the technology.

- **Maturity of the technology:** Include information about the development status of the technology, including the types of demonstrations that have been performed and the extent to which there are current applications of the technology.

Exhibit 4-1 presents an example for reporting additional information on issues associated with a specific demonstration-scale project (demonstration of in situ air stripping [ISAS] using horizontal wells at DOE's Savannah River site in Aiken, South Carolina).

EXHIBIT 4-1

EXAMPLE FOR REPORTING ADDITIONAL INFORMATION ABOUT DEMONSTRATION-SCALE PROJECTS

Applicability of the Technology

- ISAS has been demonstrated to remediate soils, sediments, and groundwater contaminated with VOCs, both above and below the water table.
- Quantitative modeling and bench- and pilot-scale work indicate that ISAS would be effective at removing light nonaqueous phase liquids (LNAPL). It is not suitable for dense nonaqueous phase liquids (DNAPL).
- ISAS is not well suited to sites having highly stratified soils with low permeability layers, fractured rock or clay geologies. ISAS does not effectively remediate large dilute plumes, but would be useful near source areas.
- Similar to pump and treat, ISAS may not be able to attain drinking-water standards (without such enhancements as addition of nutrients to promote biodegradation).
- For this project, 19 licenses have been applied for and 8 licenses have been granted.
- ISAS is commercially available through the Westinghouse Savannah River Company Technology Transfer Center.

EXHIBIT 4-1 (continued)

EXAMPLE FOR REPORTING ADDITIONAL INFORMATION ABOUT DEMONSTRATION-SCALE PROJECTS

Competing Technologies

- ISAS competes with conventional baseline technologies of pump and treat and pump and treat combined with SVE. Numerous other thermal, physical and chemical, and biological technologies that treat VOC-contaminated soils and groundwater in situ or aboveground are available or under development.
- This analysis was prepared by an environmental services company under contract to DOE's Hazardous Waste Remedial Actions Program (HAZWRAP). The environmental services company identified no potential interests in the technology of concern (in situ air stripping) or the baseline technology (pump and treat).

Maturity of the Technology

- Air sparging with vertical wells is a relatively established technology offered by dozens of vendors. Variations of the technique have been implemented at hundreds of sites.
- ISAS using horizontal wells currently is being applied at an airport in New York and at industrial sites in North Carolina, Minnesota, and Missouri. The technology also is being implemented at full scale at two locations at the Savannah River Site.

4.3 MEASUREMENT PROCEDURES

Because the use of different methods of measurement can cause results to vary, documentation of measurement procedures for many of the matrix characteristics and operating parameters is important to allow a comparison of results among projects. It is especially important to document measurement procedures when different methods are available or when less standardized methods are used for measuring an individual parameter (e.g., for clay content). In these cases, measurement procedures should be documented. Appendix B provides information about the measurement procedures recommended for documentation.

TABLE 4-1

SUGGESTED PARAMETERS TO DOCUMENT TECHNOLOGY APPLICATIONS: MATRIX CHARACTERISTICS THAT AFFECT COST OR PERFORMANCE OF A TECHNOLOGY

Matrix Characteristics	In Situ Soil Remediation								Ex Situ Soil Remediation						
	Bioventing	Soil Flushing	Soil Vapor Extraction	Bioslurping	Phytoremediation	In Situ Heating	Vitrification	Capping	Land Treatment	Composting	Soil Washing	Stabilization	Incineration	Thermal Desorption	Slurry-Phase Bioremediation
SOIL TYPES															
Soil Classification	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Clay Content and/or Particle Size Distribution	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
AGGREGATE SOIL MATRIX PROPERTIES															
Hydraulic Conductivity		●		●	●			●							
Moisture Content	●		●	●	●	●	●	●	●	●		●	●	●	●
Air Permeability	●		●	●		●	●								
pH	●	●		●	●				●	●		●			●
Porosity	●		●	●		●									
Depth bgs or thickness of zone of interest	●	●	●	●	●	●	●								
ORGANIC PROPERTIES															
Total Organic Carbon	●	●	●	●	●	●			●		●	●	●		
Oil and Grease or Total Petroleum Hydrocarbons		●		●								●		●	
Presence of NAPLs	●	●	●	●		●									
MISCELLANEOUS						●[1]	●[2]	●[3]	●[4]		●[5]		●[6]	●[7]	

Nonmatrix Characteristics that Affect Cost or Performance:	
Contaminants: Type and concentration of contaminants Environmental Setting for in situ technologies: Geology, stratigraphy, and hydrogeology (primarily)	Quantity of material treated: Cubic yards or 1,000 gallons of groundwater Cleanup goals and requirements: Cleanup levels, schedules, sampling and analysis

1 Electrical conductivity (for electrical heating)
2 Lower explosive limit, glass forming materials, electrical conductivity, and presence of inclusions
3 Future use; rainfall or infiltration rate; and permeability of clay liner, geomembrane, or other polymer layers
4 Field capacity
5 Cation exchange capacity of soils
6 BTU value, halogen content, and metal content
7 Bulk density

TABLE 4-1 (continued)

SUGGESTED PARAMETERS TO DOCUMENT TECHNOLOGY APPLICATIONS: MATRIX CHARACTERISTICS THAT AFFECT COST OR PERFORMANCE OF A TECHNOLOGY

Matrix Characteristics	Groundwater Remediation													
	Pump and Treat	Dual-Phase Extraction	Air Sparging	Circulating Wells (UVB)	Dynamic Underground Stripping	Steam Flushing	Cosolvent/Surfactants	Natural Attenuation (chlorinated compounds)	Natural Attenuation (nonchlorinated hydrocarbons)	Bioremediation	Phytoremediation	Vertical Barrier Walls	Permeable Reactive Barriers	In Situ Oxidation (Fenton's reagent)
SOIL TYPES														
Soil Classification	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Clay Content and/or Particle Size Distribution	●	●	●	●	●	●	●	●	●	●	●	●	●	●
AGGREGATE SOIL MATRIX PROPERTIES														
Hydraulic Conductivity	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Moisture Content														
Air Permeability		●	●	●	●	●	●							
pH								●	●	●	●		●	●
Porosity		●	●		●							●	●	
Depth bgs/thickness of zone of interest	●	●	●	●	●	●	●	●	●	●	●	●	●	●
ORGANIC PROPERTIES														
Total Organic Carbon							●	●	●	●	●		●	
Oil & Grease or Total Petroleum Hydrocarbons		●				●	●		●	●				
Presence of NAPLs	●	●	●	●	●	●	●	●	●	●			●	
MISCELLANEOUS								●[8]	●[9]					

[8] Redox conditions, electron acceptors (oxygen, nitrate, iron, sulfate, methane), electron donors (carbon source, for example, presence of toluene).

[9] Dissolved oxygen levels and electron acceptors (oxygen, nitrate, iron, sulfate, methane).

TABLE 4-2

SUGGESTED PARAMETERS TO DOCUMENT TECHNOLOGY APPLICATIONS: OPERATING PARAMETERS THAT AFFECT COST OR PERFORMANCE OF A TECHNOLOGY

	In Situ Soil Remediation								Ex Situ Soil Remediation						
Operating Parameters	**Bioventing**	**Soil Flushing**	**Soil Vapor Extraction**	**Bioslurping**	**Phytoremediation**	**In Situ Heating**	**Vitrification**	**Capping**	**Land Treatment**	**Composting**	**Soil Washing**	**Stabilization**	**Incineration**	**Thermal Desorption**	**Slurry-Phase Bioremediation**
SYSTEM PARAMETERS															
Air Flow Rate	●		●	●						●			●		●
Mixing Rate/Frequency									●	●					●
Operating Pressure/Vacuum	●		●	●		●									
pH		●			●	●		●	●	●	●				●
Pumping Rate		●		●											
Residence Time		●							●	●	●		●	●	●
System Throughput										●	●	●	●	●	●
Temperature	●				●	●	●	●	●	●	●	●	●	●	●
Washing/Flushing Solution Components/Additives and Dosage		●									●	●			
BIOLOGICAL ACTIVITY															
Biomass Concentration															●
Microbial Activity															
Oxygen Uptake Rate	●			●						●					
Carbon Dioxide Evolution	●			●											
Biodegradation Rate for Organics	●			●					●	●					●
Nutrients and Other Soil Amendments	●			●	●				●	●					●
MISCELLANEOUS					●[1]	●[2]	●[3]	●[4]	●[5]	●[6]		●[7]			●[8]

[1] Plants per unit area and plant type
[2] Electrical or radio frequency (RF) power input
[3] Power consumption per unit volume
[4] Design infiltration rates
[5] Moisture content
[6] Moisture content and soil loading rate
[7] Curing time, compressive strength, volume increase, and permeability
[8] Density of slurry and volume fraction of water

TABLE 4-2 (continued)

SUGGESTED PARAMETERS TO DOCUMENT TECHNOLOGY APPLICATIONS: OPERATING PARAMETERS THAT AFFECT COST OR PERFORMANCE OF A TECHNOLOGY

	Groundwater Remediation													
Operating Parameters	**Pump and Treat**	**Dual-Phase Extraction**	**Air Sparging**	**Circulating Wells (UVB)**	**Dynamic Underground Stripping**	**Steam Flushing**	**Cosolvent/Surfactants**	**Natural Attenuation (chlorinated compounds)**	**Natural Attenuation (nonchlorinated hydrocarbons)**	**Bioremediation**	**Phytoremediation**	**Vertical Barrier Walls**	**Permeable Reactive Barriers**	**In Situ Oxidation (Fenton's reagent)**
SYSTEM PARAMETERS														
Air Flow Rate		●	●	●	●									
Mixing Rate/Frequency														
Operating Pressure/Vacuum		●	●	●	●	●								
pH	●						●	●	●	●	●		●	●
Pumping Rate	●	●		●	●	●	●							●
Residence Time							●							
System Throughput														
Temperature					●	●		●	●	●	●			
Washing/Flushing Solution Components/Additives and Dosage							●			●				●
BIOLOGICAL ACTIVITY														
Biomass Concentration														
Microbial Activity								●	●	●				●
Oxygen Uptake Rate									●	●				
Carbon Dioxide Evolution								●	●	●				
Biodegradation Rate for Organics								●	●	●				
Nutrients and Other Soil Amendments								●	●	●	●			
MISCELLANEOUS	●[9]						●[10]	●[11]			●[12]	●[13]	●[14]	●[15]

[9] For the treatment component of the pump and treat system, the operating parameters will vary by the specific type of treatment used (for example, carbon adsorption, air stripper). For a more extensive list of operating parameters for those treatment technologies, please refer to *Technical Requirements to Report HTRW Environmental Restoration Cost and Performance*, USACE (EP 1110-1-19), November 15, 1996

[10] Efficiency of recovery and recycling

[11] Presence of breakdown products and levels of ethene, ethane, or methane

[12] Plants per unit area and plant type

[13] Permeability of wall material and depth of key

[14] Flow rate through the gate (for funnel-and-gate system) and type of reactant (for example, iron granules)

[15] Injection rates and cost of chemicals

5.0 REPORT FORMATS

As discussed above, the guide recommends a minimum set of reporting elements for documenting the cost and performance of remediation projects; however, agencies may use formats of their choosing for preparing reports. Those formats may include additional information beyond the minimum set of items recommended by the guide. For example, formats might include detailed descriptions of treatment technologies.

The technology vendor or developer (provider) is a valuable resource for providing information on the cost and performance of technologies. While the Roundtable encourages these sources to continue to provide information, there should be independent preparation or review of cost and performance reports.

Several agencies have developed report formats that incorporate items recommended in this guide, including formats prepared by USACE, DOE, the U.S. Air Force, and EPA. Information about the report formats listed below, prepared by USACE and DOE, are available on the Internet at the addresses indicated:

- USACE. 1996. Engineering and Design - Technical Requirements for Specifications to Report HTRW Environmental Restoration Cost and Performance. Publication Number EP 1110-1-19. CEMP-RT. November 15. <*http://www.usace.army.mil/inet/usace-docs/eng-pamphlets/ep1110-1-19/toc.htm*>

- DOE Office of Environmental Management. 1996. Documenting Cost and Performance for Environmental Remediation Projects. DOE/EM-0302. August 8. <*http://www.em.doe.gov/costperf/index.html*>

Some agencies are considering more streamlined formats that are adapted to specific purposes, such as for reporting summary information about cost and performance for relatively common treatment applications.

For all reports prepared under the cost and performance effort, an abstract should be prepared that extracts key information from the report. The abstract allows a user to quickly screen key information about a particular remedial application and decide whether to obtain the full case study report. Appendix C to this guide presents a format recommended for preparing abstracts.

Appendix D presents a generic format that illustrates how to prepare cost and performance reports. The generic format includes all the key features identified in this guide and was developed as a composite of the reporting elements identified by EPA, USACE, and DOE in their case study reports. The format is intended for documenting full-scale technology applications, but also includes elements specific to demonstration-scale applications, which are identified as such in the format.

6.0 WEB SITE STRATEGY

- The Roundtable web site is a primary means for dissemination of information on remediation case studies
- A key word based search function is included on the web site
- Ready access to targeted case studies helps facilitate their use by remediation professionals

The Roundtable will use its web site at <*http://www.frtr.gov*> as a primary means of distributing case studies. The Roundtable will publish and distribute printed copies when a sufficient number of reports are available. (Some case study reports will be published first as separate documents by the sponsoring agency and then collated with other, similar reports and published again under a Roundtable cover.) The Work Group discussed electronic management of the case studies as part of a broader effort to improve the web site. This chapter presents the strategy for managing this site.

6.1 INTRODUCTION

In 1996, the Roundtable established a web site to provide general information about its activities, to provide information and documents related to site remediation, and to provide a central point of entry for users to connect to member agencies' web sites.

The Roundtable web site contains information about remedial and site characterization technologies; case studies of field remedial applications; and information about the business of the Roundtable, such as meeting summaries and published reports. Use of the Roundtable web site has increase substantially over time, and it has been used by U.S. government sources, such as the military service; educational institutions; agencies of other countries; and private consulting and engineering firms.

In late 1997, the members of the Roundtable identified a need to update and revise the format and functionality of the web site. On April 2, 1998, members of an ad hoc Web Site Task Force, including representatives of DoD, DOE, and EPA, met to review the current status of the web site and to develop plans for updating it. The task force recommended that the web site be revised to update its design and improve its functionality, including expansion of the search capabilities. The members of the task force recommended that all member agencies of the Roundtable participate in supporting the site. The task force also recommended that an "advisory board" be established to provide direction and leadership to those responsible for maintaining the site.

6.2 PURPOSES FOR ROUNDTABLE WEB SITE

The Web Site Task Force recommended that the purpose of the site be clarified, that is the scope be narrowed, and that certain functions be improved. The following purposes for the Roundtable web site were identified:

- Provide information about the Roundtable and its products, such as recent remedial technology and site characterization screening guides.
- Serve as a point of entry to the web sites of member agencies and direct users to site characterization and remediation links on those web sites.

6.3 IMPLEMENTATION

Figure 6-1 presents a general site map of the Roundtable web site. As the figure shows, the main components of the web site, which is coordinated by USACE, are:

- Remediation technologies screening matrix
- Field sampling and analysis technologies matrix
- Cost and performance case studies
- Roundtable business items
- Roundtable publications
- Links to other agencies

Table 6-1 provides a brief description of each of these components and identifies the responsible member agencies for maintaining them. In addition, member agencies have agreed to identify key points of contact to assist in keeping information on the web site current.

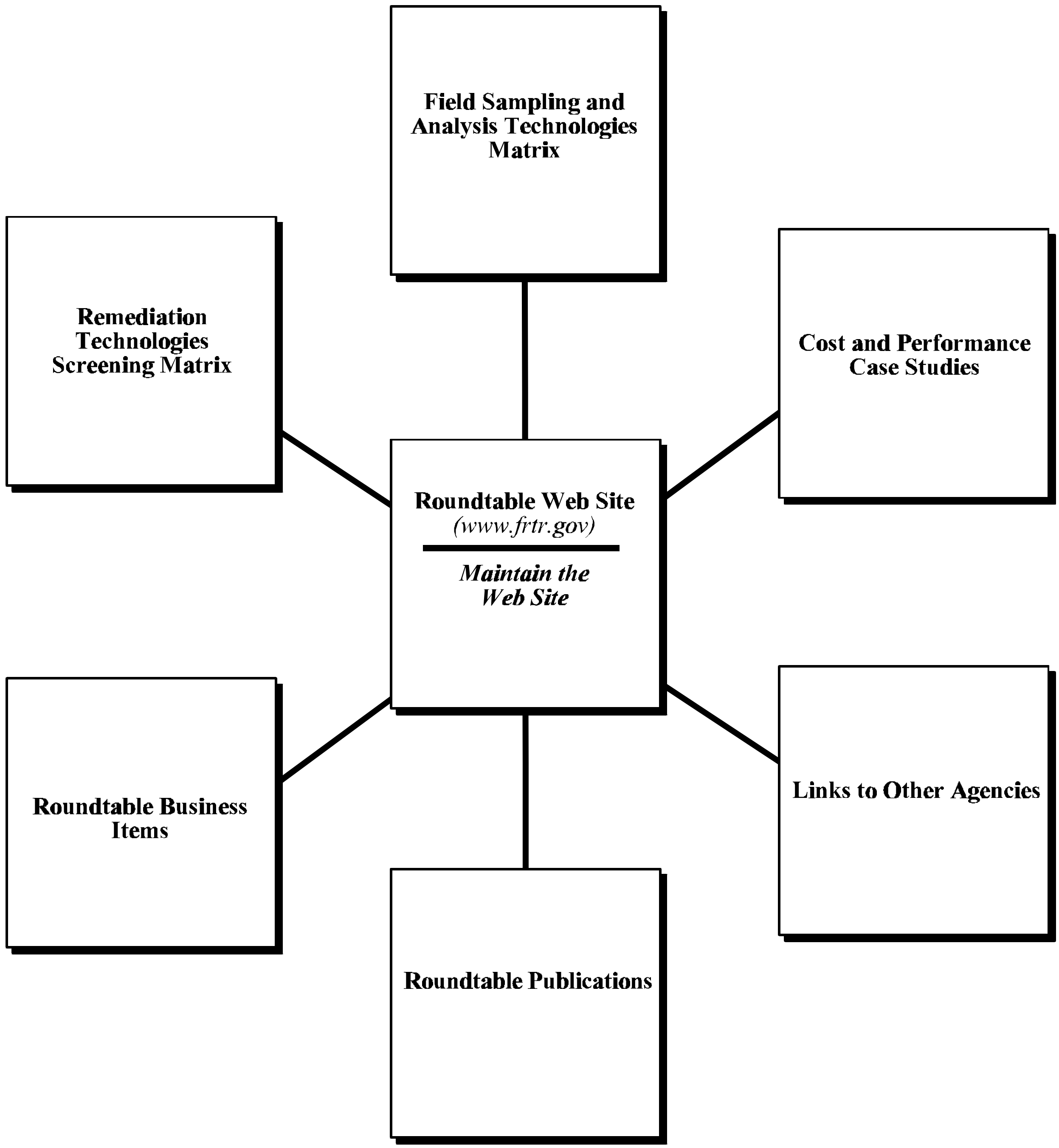

Figure 6-1. General Site Map for Federal Remediation Technologies Roundtable Web Site

TABLE 6-1

SUMMARY OF INFORMATION ON THE ROUNDTABLE WEB SITE

Web Site Component	Information Included	Responsible Member Agency
Remediation Technologies Screening Matrix	The remediation technologies screening matrix (Version 3.0) is a web-based product that allows a user to view information about remedial technologies from contaminant, treatment, or technology perspectives. This product is updated weekly to incorporate current information about specific remedial technologies and links to appropriate web sites.	Army Environmental Center (AEC); maintained and updated by AEC
Field Sampling and Analysis Technologies Matrix	The field sampling and analysis technologies matrix provides users with an introduction to site characterization technologies to promote the use of potentially cost-effective methods for on-site monitoring and measurement. For a variety of field sampling and collection techniques and sample analysis tools, the matrix summarizes such items as applicability, status of the technology, certification and validation, and relative cost. At the time this guide was prepared, no plans had been made to update the matrix.	U.S. Navy and EPA prepared matrix USACE created web version of matrix and may maintain web version
Cost and Performance Case Studies	Cost and performance case studies document actual full-scale and demonstration-scale applications of innovative and traditional technologies used to remediate sites having a wide variety of contaminants. The case studies support the remediation technologies screening matrix by providing detailed information about actual field experiences in application of remedial technologies included in the matrix.	All member agencies prepare case studies; searchable database developed and maintained by EPA
Roundtable Business Items	Roundtable business items include information about the mission and objectives of the Roundtable; Roundtable meetings, such as announcements of upcoming meetings and minutes of previous meetings, and items distributed at meetings, as well as similar information about meetings of work groups of the Roundtable, such as the Cost and Performance and Accelerated Site Characterization and Monitoring workgroup.	All member agencies
Roundtable Publications	Roundtable publications include Site Remediation Technology InfoBase: A Guide to Federal Programs, Information Resources, and Publications on Contaminated Site Cleanup Technologies (EPA/542/B-98/006)	All member agencies
Links to Other Agencies	The Roundtable web site provides links to the web site of the following member agencies: AEC; U.S. Air Force Environmental Management; Department of the Navy Environmental Program; U.S. Naval Facilities Engineering Service Center; DOE; EPA Cleanup Information (Clu-In); USACE Environmental Division; and the U.S. Department of Interior, U.S. Geological Survey. In addition, the FRTR web site provides links to other related web sites.	All member agencies

The task force recommended that the advisory board meet annually to provide guidance to those responsible for maintaining the Roundtable web site. The advisory board will review information about the use of the web site during the preceding year, including statistics on use and comments from users on format and functionality. In addition, the advisory board will help keep links provided on the web site current, and help to keep the information web site consistent with the priorities and responsibilities of the member agencies.

The Roundtable web site has a search function that allows a user to search the site or portions of the site, as follows: (1) the entire web site, (2) the remediation technologies screening matrix only, (3) the field sampling and analysis technologies matrix only, or (4) the cost and performance case studies only. The search functions are text-based (open-ended indexed search), allowing a search based on terms selected by the user.

6.4 INTERAGENCY PARTICIPATION

The Roundtable web site provides access to information about innovative environmental technologies that is available from member agencies of the Roundtable. The site also encourages communication and collaboration among member agencies, regulatory and academic personnel, and the general public. Member agencies are encouraged to submit comments to update information included on the web site and identify information to be added to it.

6.5 SEARCHABLE DATABASE OF COST AND PERFORMANCE CASE STUDIES

The cost and performance case studies have been compiled into a database that can be searched through the Roundtable web site. The web site allows a user to complete a text-based or key word (pick list) search (see the discussion of key words below). Key word searches prompt the user for categories of information based on a selection of key words. The key words were chosen to facilitate searches by allowing the user to select such topics as medium treated, contaminant type, and technology. Once a selection has been made, the search will return basic information about applications that meet the search criteria, including site name, location, and primary technology type. The results will be organized by categories selected by the users (for example, project scale or lead agency). The user then will be able to view a two-page abstract of the case study or the complete case study.

The system for searching case studies on the Roundtable web site may be expanded to incorporate related information from other sources. For example, programs such as EPA's SITE program, the report Completed North American Innovative Remediation Technology Demonstration Projects, the Advanced Applied Technology Demonstration Facility (AATDF) program at Rice University, and DoD's Strategic Environmental Research and Development Program (SERDP) program all have information about technology evaluation. By developing a flexible system, the Roundtable hopes to be able to incorporate studies prepared under these type of programs.

6.6 KEY WORDS

To facilitate storage and retrieval of information in the case studies through the Roundtable web site, a list of key words has been developed. The key words are commonly used terms that describe media, contaminants, and primary and supplemental technologies. As Tables 6-2 through 6-5 show, the key words are organized as pick-lists; the user can search for projects of interest by one or more combinations of the key words from the lists.

In developing the lists of key words, the Roundtable examined several systems currently in use for projects related to remediation and reviewed the lists of key words used in those systems. For example, the Roundtable reviewed the Programs and Project Management Information System (PROMIS) developed by USACE; the Installation Restoration Information System (IRIS) developed by the U.S. Army; NORM developed by the U.S. Navy; AFRIMS developed by the U.S. Air Force; the Comprehensive Environmental Response, Compensation, and Liability Information System (CERCLIS) developed by EPA; and the Vendor Information System for Innovative Treatment Technologies (VISITT) developed by EPA.

Most of the systems examined include key words for medium, contaminant, and primary technology. However, since many of the primary technologies listed may be qualified further or have residue management components of interest, it is important to identify any supplemental technologies used in the application. Such systems include those used in pretreatment and post-treatment. Dewatering solids before treatment is an example of a supplemental technology. Table 6-5 lists the terms to be used to document supplemental treatment systems.

TABLE 6-2

RECOMMENDED KEY WORDS FOR MEDIA

Media	
Soil (in situ) Soil (ex situ) Sludge Solid (for example slag) Sediment (in situ) Sediment (ex situ) Debris Off-gases	Groundwater Free product Organic liquids Light nonaqueous phase liquids (LNAPL) Dense nonaqueous phase liquids (DNAPL) Surface water Wastewater Leachate

TABLE 6-3

RECOMMENDED KEY WORDS FOR CONTAMINANTS

Contaminants	
• Organic Compounds (all) -- Volatiles—halogenated (all) - Chlorinated solvents PCE, TCE, DCE -- Volatiles—nonhalogenated (all) - BTEX Benzene, toluene, ethylbenzene, xylene - Ketones - MTBE -- Semivolatiles—halogenated (all) - Dioxins/furans - PCBs - Organic corrosives - Organic cyanides - Organic pesticides/herbicides -- Semivolatiles—nonhalogenated (all) - Phthalates - Polycyclic aromatic hydrocarbons (PAHs) - Organic pesticides/herbicides -- Petroleum Hydrocarbons (all) - Gasoline range hydrocarbons - Diesel range hydrocarbons - Residual range hydrocarbons	• Inorganic Compounds (all) -- Asbestos -- Heavy metals (for example, Be, Cd, Cr, Cu, Hg, Pb, Ni, Se, Zn) -- Inorganic cyanides -- Inorganic corrosives -- Nonmetallic elements (for example, As) -- Radionuclides (for example, tritium) • Radon • Explosives/propellants • Organometallic compounds (all) Pesticides/herbicides

TABLE 6-4

RECOMMENDED KEY WORDS FOR PRIMARY TECHNOLOGIES

Soil In Situ	Soil Ex Situ	Groundwater In Situ	Groundwater Ex Situ
Bioslurping Biosparging Bioventing Bioremediation (in situ) - Soil Cap Dual-Phase Extraction Dynamic Underground Stripping Electrokinetics Hot Air Injection In Situ Heating Phytoremediation Soil Flushing (in situ) Soil Vapor Extraction Solidification/ Stabilization Steam Extraction Thermally Enhanced Recovery (e.g., EM, RF, ISTD) Vitrification	Bioremediation (ex situ) - Composting Bioremediation (ex situ) - Land Treatment Bioremediation (ex situ) - Slurry Phase Chemical Reduction/ Oxidation Contained Recovery of Oily Waste (CROW) Critical Fluid Extraction Cyanide Oxidation Dehalogenation Incineration (off-site) Incineration (on-site) Physical Separation Plasma High Temperature Metals Recovery Pyrolysis Solar Detoxification Soil Washing Solidification/ Stabilization Solvent Extraction Thermal Desorption Vitrification	Aeration Air Sparging (in situ) - Groundwater Bioremediation (in situ) - Groundwater Chemical Reduction/ Oxidation Circulating Wells (UVB) Cosolvent Flushing Dual-Phase Extraction Dynamic Underground Stripping Electrokinetics Hot Water/Steam Flushing/Stripping In Situ Oxidation Monitored Natural Attenuation Permeable Reactive Barrier Phytoremediation Surfactants/Surfactant Flushing Vertical Barrier Wall	Free Product Recovery Pump and treat with: Air Stripping Bioreactors Carbon Adsorption Chemical Reduction/ Oxidation Chemical Treatment - Groundwater Distillation Electrochemical Treatment Filtration Precipitation Reverse Osmosis Solar Detoxification Solvent Extraction Supercritical Water Oxidation UV/Oxidation

TABLE 6-5

RECOMMENDED KEY WORDS FOR SUPPLEMENTAL TECHNOLOGIES

Pretreatment (Solids)	Augmentation (for In Situ Process)	Post-Treatment (Air)	Post-Treatment (Solids)	Post-Treatment (Water) *
Crushing Dewatering Milling Mixing Screening Shredding	Horizontal Wells Fracturing - Hydraulic Mixing Fracturing - Pneumatic Drilling	Baghouse Biofiltration Carbon Adsorption Catalytic Oxidation Condenser Corona Cyclone Photolytic Destruction Scrubber Thermal Destruction	Compaction Quench Stabilization	Air Stripping Biological Carbon Adsorption Centrifugation Chemical Decanting Filtration Ion Exchange Neutralization

* Other than for treatment of primary contaminants as part of a pump and treat system

APPENDIX A

POTENTIAL EFFECTS ON TREATMENT COST OR PERFORMANCE OF MATRIX CHARACTERISTICS AND OPERATING PARAMETERS

APPENDIX A

POTENTIAL EFFECTS ON TREATMENT COST OR PERFORMANCE OF MATRIX CHARACTERISTICS AND OPERATING PARAMETERS*

Parameter	Potential Effects on Cost or Performance
Matrix Characteristics	
Soil Types	
Soil classification	Soil classification effects the relative ease of treating soil and groundwater. For example, in soil vapor extraction, sandy soils typically are more amenable to treatment than clayey soils. (See related information under clay content or particle size distribution below.)
Clay content or particle size distribution	Clay and particle size distribution affect the flow of air and fluid through contaminated media. In slurry-phase bioremediation systems, particle size affects ability to hold media in suspension. In soil washing, the relationship between particle size and contaminant concentration affects the potential for physical separation and reductions of volume. For thermal desorption systems, clay and particle size affect mass and heat transfer, including agglomeration and carryover to air pollution control devices.
Aggregate Soil Properties	
Hydraulic conductivity/ water permeability	This characteristic is important to groundwater remediation technologies, including in situ groundwater bioremediation, groundwater sparging, and pump and treat systems. Hydraulic conductivity and water permeability affect the zone of influence of the extraction wells and therefore affect the number of wells needed for the remediation effort and the cost of operating the extraction wells.
Moisture content	The moisture content of the matrix typically affects the performance, both directly and indirectly, of such in situ technologies such as bioventing and soil vapor extraction and such ex situ technologies such as stabilization, incineration, and thermal desorption. For example, air flow rates during operation of soil vapor extraction technologies are affected by moisture content of the soil. Thermal input requirements and air handling systems for incineration and desorption technologies also can be affected by soil moisture content.
Air permeability	This characteristic is important to in situ soil remediation technologies that involve venting or extraction. Air permeability affects the zone of influence of the extraction wells and therefore affects the number of extraction wells needed for the remediation effort and the cost of operating the extraction wells.

APPENDIX A (continued)

POTENTIAL EFFECTS ON TREATMENT COST OR PERFORMANCE OF MATRIX CHARACTERISTICS AND OPERATING PARAMETERS*

Parameter	Potential Effects on Cost or Performance
pH	The pH of the matrix can affect the solubility of contaminants and biological activity. Therefore, this characteristic can affect such technologies as soil bioventing, soil flushing, land treatment, composting, stabilization, and in situ groundwater bioremediation. In addition, pH can affect the operation of treatment technologies. pH in the corrosive range (<2 and >12) can damage equipment and typically requires use of personal protection equipment and other special handling procedures.
Porosity	This characteristic is important to in situ technologies, such as soil bioventing, soil vapor extraction, and groundwater sparging, that rely upon use of a driving force to transfer contaminants into an aqueous or air-filled space. Porosity affects the driving force and therefore the performance achieved by the technologies.
Transmissivity	This characteristic is important for groundwater pump and treat or fluid cycling systems. Transmissivity affects the zone of influence in this type of remediation, thereby affecting the number of wells needed and the cost of operating the wells.
Organics	
Total organic carbon (TOC)	TOC affects the desorption of contaminants from soil and affects in situ soil remediation, soil washing, stabilization, and in situ groundwater bioremediation. TOC content may differ in uncontaminated and contaminated soil.
Oil and grease (O&G) or total petroleum hydrocarbons (TPH)	O&G and TPH affect the desorption of contaminants from soil. For thermal desorption, elevated levels of TPH may result in agglomeration of soil particles, resulting in shorter residence times.
Nonaqueous phase liquids (NAPL)	NAPLs may be a continuing source of contaminants for in situ technologies. The presence of NAPLs may lead to increased contaminant loads and therefore to increases in the costs or length of operating periods necessary to achieve cleanup goals. Under certain conditions, NAPLs may interfere directly with the operation of the treatment process.

APPENDIX A (continued)

POTENTIAL EFFECTS ON TREATMENT COST OR PERFORMANCE OF MATRIX CHARACTERISTICS AND OPERATING PARAMETERS*

Parameters	Potential Effects on Cost or Performance
Operating Parameters	
System Parameters	
Air flow rate	Air flow rate affects the rate of volatilization of contaminants in technologies that rely on transferring contaminants from a soil or aqueous matrix to air, such as soil bioventing, soil vapor extraction, and groundwater sparging. For technologies that involve oxidation processes, this parameter affects the availability of oxygen and the rate at which oxidation occurs (for biotreatment or incineration processes).
Mixing rate/frequency	The mixing rate affects the rate of biological activity (through increased contact between oxygen and contaminants) and volatilization of contaminants.
Moisture content	The moisture content affects the rate of biological activity in soil bioventing, land treatment, composting, and slurry-phase bioremediation technologies. Contaminants must be in an aqueous phase if biodegradation is to occur, and water typically is added to a soil to maintain a level of moisture sufficient to support biodegradation.
Operating pressure/vacuum	Operating pressure or vacuum affects the rate of volatilization of contaminants in technologies that rely on transferring contaminants from a soil or aqueous matrix to air, such as soil bioventing, soil vapor extraction, and groundwater sparging.
pH	pH affects the operation of technologies that involve chemical or biological processes, such as soil flushing, soil washing, and bioremediation processes. For example, in soil washing, contaminants are extracted from a matrix at specified pH ranges on the basis of the solubility of the contaminant at that pH.
Pumping rate	Pumping rate affects the amount of time required to remediate a contaminated area and is important to technologies that involve extraction of groundwater, such as soil flushing, and pump and treat systems.
Residence time	Residence time is important for ex situ technologies, such as land treatment, composting, slurry-phase soil bioremediation, incineration, and thermal desorption, to measure the amount of time during which treatment continues.
System throughput	System throughput affects the costs of capital equipment required for a remediation and operating labor for such ex situ technologies as slurry phase soil bioremediation, soil washing, incineration, and thermal desorption.

APPENDIX A (continued)

POTENTIAL EFFECTS ON TREATMENT COST OR PERFORMANCE OF MATRIX CHARACTERISTICS AND OPERATING PARAMETERS*

Parameters	Potential Effects on Cost or Performance
Temperature	In bioremediation technologies, temperature affects the rate of biological activity. In stabilization, incineration, and thermal desorption, temperature affects the physical properties and rate of chemical reactions of soil and contaminants.
Washing/flushing solution components/additives and dosage	For soil flushing and washing technologies, the types and dosages of additives affect the solubility and rate of extraction of contaminants and therefore affect the costs of constructing and operating flushing and washing equipment.
Biological Activity	
Biomass concentration	Biomass concentration is an important parameter for slurry-phase soil bioremediation and in situ groundwater biodegradation. Biomass is necessary to effect treatment and therefore the concentration of biomass is related directly to performance.
Microbial activity Oxygen uptake rate (OUR) Carbon dioxide evolution Hydrocarbon degradation	Microbial activity is an important parameter for soil bioventing, land treatment, composting, and slurry-phase soil bioremediation technologies. Hydrocarbon degradation commonly is used as an indicator of treatment performance for these technologies, while OUR and carbon dioxide evolution are used in specific applications to supplement the data on hydrocarbon degradation.
Nutrients and other soil amendments	Nutrients and other soil amendments can affect ex situ soil remediation technologies, such as land soil bioventing, treatment, composting, and slurry-phase soil bioremediation, and in situ groundwater biodegradation, since this parameter directly affects the rate of biological activity and therefore biodegradation of contaminants
Soil loading rate	The soil loading rate affects the rate of biological activity and can affect the costs of operation of the technology.

* The parameters shown here are in addition to the items identified on Table 4-1 as important for affecting a technology's cost or performance. These additional parameters are:

1. Contaminants: type and concentration (initial and final, organic and inorganic, as appropriate)
2. Environmental setting: geology, stratigraphy, and hydrogeology
3. Quantity of material treated
4. Cleanup goals and requirements: cleanup levels, schedules, sampling and analysis

APPENDIX B

MEASUREMENT PROCEDURES FOR MATRIX CHARACTERISTICS AND OPERATING PARAMETERS

APPENDIX B

MEASUREMENT PROCEDURES FOR MATRIX CHARACTERISTICS AND OPERATING PARAMETERS*

Parameter	Measurement Procedures	Important to Document Measurement Procedure?
Matrix Characteristics		
Soil Types		
Soil Classification	Soil classification is a semiempirical measurement of sand, silt, clay, gravel, and loam content. Several soil classification methods are in use, including the ASTM Standard D 2488-90, the *Practice for Description and Identification of Soils (Visual-Manual Procedure),* and the USDA and CSSC systems.	Yes
Clay Content and/or Particle Size Distribution	Clay content or particle size distribution is measured by application of a variety of soil classification systems, including ASTM D 2488-90 under soil classification.	Yes
Aggregate Soil Properties		
Hydraulic Conductivity/ Water Permeability	Hydraulic conductivity/water permeability can be determined through several procedures. Hydraulic conductivity, which is a measure of the ease with which water flows through soil, typically is calculated as a function of permeability or transmissivity. ASTM D 5126-90, *Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone,* is a guide for determining hydraulic conductivity. Water permeability is often calculated by pumping out groundwater, measuring groundwater draw-down rates and recharge times through surrounding monitoring wells, and factoring in the distance between the wells and the pump. Method 9100 in U.S. Environmental Protection Agency SW-846 is used to measure permeability, as well as several ASTM standards: D 2434-68 (1974), *Test Method for Permeability of Granular Soils (Constant Head);* D 4630-86, *Test Method for Determining Transmissivity and Storativity of Low Permeability Rocks by In Situ Measurements Using the Constant Head Injection Test;* and D 4631-86, *Test Method for Determining Transmissivity and Storativity of Low Permeability Rocks by In Situ Measurements Using the Pressure Pulse Technique.*	Yes
Moisture Content	Procedures for measuring soil moisture content are standard. Soil moisture content typically is measured according to a gravimetric ASTM standard, D 2216-90, *Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock.*	No

APPENDIX B (continued)

MEASUREMENT PROCEDURES FOR MATRIX CHARACTERISTICS AND OPERATING PARAMETERS*

Parameter	Measurement Procedures	Important to Document Measurement Procedure?
Air Permeability	Air permeability is a measure of the ease with which air flows through soil and is a calculated value. For example, air permeability may be calculated by applying a vacuum to soil with a pump, measuring vacuum pressures in surrounding monitoring wells, and fitting the results to a correlation derived by Johnson et al., 1990.	Yes
pH	pH is a measure of the degree of acidity or alkalinity of a matrix. Procedures for measuring and reporting pH are standard and include EPA SW-846 Method 9045 and ASTM methods for soil (ASTM D 4972-89, *Test Method for pH of Soils*) and groundwater (ASTM D 1293-84).	No
Porosity	Porosity is the volume of air- or water-filled voids in a mass of soil. Procedures for measuring and reporting porosity are standard. Porosity is measured by ASTM D 4404-84, *Test Method for Determination of the Pore Volume and Pore Volume Distribution of Soil and Rock by Mercury Intrusion Porosimetry*.	No
Transmissivity	Transmissivity, the flow from a saturated zone, is the product of hydraulic conductivity and aquifer thickness.	No[1]
Organics		
Total Organic Carbon (TOC)	TOC is a measure of the total organic carbon content of a matrix. Measurement of TOC is standard (for example, Method 9060 in EPA SW-846).	No
Oil & Grease (O&G) or Total Petroleum Hydrocarbons (TPH)	Procedures for measuring O&G and TPH are standard. O&G is measured by Method 9070 in EPA SW-846, and TPH is measured by Method 9073. A TPH analysis is similar to an O&G analysis, with an additional extraction step. TPH does not include nonpetroleum fractions, such as animal fats and humic and fulvic acids.	No
Nonaqueous Phase Liquids (NAPLs)	There is no standard method of measurement for determining the presence of NAPLs; rather, their presence is determined by examining groundwater and identifying a separate phase. NAPLs are reported as present or not present.	Yes

[1] The measurement of hydraulic conductivity is important to document; since transmissivity is a product of hydraulic conductivity and thickness of the aquifer, it would not be necessary to document the measurement procedure for this characteristic.

APPENDIX B (continued)

MEASUREMENT PROCEDURES FOR MATRIX CHARACTERISTICS AND OPERATING PARAMETERS*

Parameter	Measurement Procedures	Important to Document Measurement Procedure?
Operating Parameters		
System Parameters		
Air Flow Rate	The air flow rate is a parameter set for a vapor extraction or treatment system. The measurement of air flow rate is standard (for example, measured by flow meters).	No
Mixing Rate/Frequency	Mixing rate or frequency is the rate of tilling for land treatment, the rate of turning for composting, and the rotational frequency of a mixer for slurry-phase bioremediation.	No
Moisture Content	Procedures for measuring soil moisture content are relatively standard. Soil moisture content typically is measured according to a gravimetric ASTM standard: D 2216-90, *Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock*. Moisture content as are operating parameter of a treatment system characterizes the amount of water and aqueous reagent added to the soil (for example, moisture content for slurry-phase bioremediation refers to the ratio of solid to liquid).	No
Operating Pressure/Vacuum	Operating pressure or vacuum is measured by a pressure or vacuum gauge, such as a manometer. The measurement of this parameter is standard.	No
pH	Procedures for measuring and reporting pH are standard (for example, Method 9045 in EPA SW-846). During ex situ treatment, the pH of soil and groundwater is adjusted as an operating parameter by the addition of acidic and alkaline reagents.	No
Pumping Rate	Pumping rate is the volume of groundwater extracted from the subsurface. The pumping rate is measured through a production well or treatment system by a flow meter or a bucket and stopwatch.	No
Residence Time	Residence time is the amount of time during which a unit of material is processed in a treatment system. Residence time is measured by monitoring the length of time that a unit of soil remains in the treatment system.	No
System Throughput	System throughput is the amount of material that is processed in a treatment system per unit of time.	No

APPENDIX B (continued)

MEASUREMENT PROCEDURES FOR MATRIX CHARACTERISTICS AND OPERATING PARAMETERS*

Parameter	Measurement Procedures	Important to Document Measurement Procedure?
Temperature	Temperature is measured by a thermometer or thermocouple.	No
Washing/Flushing Solution Components/Additives and Dosage	The components and dosages of washing and flushing solutions are site- and waste-specific "recipes" of polymers, flocculants, and coagulants. The types and concentrations of additives for a particular treatment application are determined by site and waste characterization, conducted of treatability and performance tests, and application of the operator's judgment. The actual amounts added are measured by the volume and concentration of additive solutions metered into the treatment system.	No
Biological Activity		
Biomass Concentration	Biomass concentration is the number of microorganisms per unit volume in a treated or untreated aqueous matrix. Biomass concentrations typically are measured by direct plate counts. Portable water test kits are available for field tests. Methods 10200 through 10400 from *Standard Methods for the Examination of Water and Wastewater* are used in laboratory analyses of biomass concentration.	Yes
Microbial Activity Oxygen Uptake Rate (OUR) Carbon Dioxide Evolution Hydrocarbon Degradation	Oxygen uptake, carbon dioxide evolution, and hydrocarbon degradation are used to measure the rate of biodegradation in a treatment system. Oxygen uptake is measured according to ASTM D 4478-85, *Standard Test Methods for Oxygen Uptake*. Carbon dioxide evolution is measured with a carbon dioxide monitor. Hydrocarbon degradation is measured by sampling the influent to and effluent from the treatment system and analyzing samples for organic constituents, such as TPH (EPA SW-846 Method 9073).	Yes

APPENDIX B (continued)

MEASUREMENT PROCEDURES FOR MATRIX CHARACTERISTICS AND OPERATING PARAMETERS*

Parameter	Measurement Procedures	Important to Document Measurement Procedure?
Nutrients and Other Soil Amendments	Nutrients usually consist of nitrogen and phosphorus (and trace inorganic constituents such as calcium and magnesium) and typically are reported as a ratio of carbon to nitrogen to phosphorus. Carbon is measured as total organic carbon by with EPA SW-846 Method 9060. Nitrogen is measured as both ammonia nitrogen according to using ASTM D 1426-89, *Test Methods for Ammonia Nitrogen in Water,* and as nitrite-nitrate according to ASTM D 3867-90, *Test Method for Nitrite-Nitrate in Water*. Phosphorus is measured according to ASTM D 515-88, *Test Methods for Phosphorus in Water*. Calcium and magnesium are measured according to ASTM D 511-88, *Test Method for Calcium and Magnesium in Water*. Other soil amendments may include bulking agents for composting (for example, sawdust).	Yes
Soil Loading Rate	Soil loading rate is the amount of soil applied to a unit area of a composting system.	No

* The parameters shown here are in addition to the items identified on Table 4-1 as important for affecting a technology's cost or performance. These additional parameters are:

1. Contaminants: type and concentration (initial and final, organic and inorganic, as appropriate)
2. Environmental setting: geology, stratigraphy, and hydrogeology
3. Quantity of material treated
4. Cleanup goals and requirements: cleanup levels, schedules, sampling and analysis

APPENDIX C

RECOMMENDED FORMAT FOR CASE STUDY ABSTRACT

APPENDIX C

RECOMMENDED FORMAT FOR CASE STUDY ABSTRACT
TECHNOLOGY AT SITE NAME, LOCATION

<table>
<tr><td>Site Name:</td><td rowspan="2">Contaminants:
Type and concentration</td><td>Period of Operation:</td></tr>
<tr><td>Location:</td><td>Cleanup Type:
Full-scale, demonstration-scale</td></tr>
<tr><td>Vendor:
Name, address, phone no.</td><td rowspan="2">Technology:
Type, design, and operations</td><td>Cleanup Authority:
Type, date, lead</td></tr>
<tr><td>Additional Contacts:
Name, address, phone no.</td><td>Regulatory Contacts:
Name, address, phone no.</td></tr>
<tr><td>Waste Source:</td><td colspan="2" rowspan="2">Type/Quantity of Media Treated:
Type, quantity, properties</td></tr>
<tr><td>Purpose/Significance of Application:</td></tr>
<tr><td colspan="3">Regulatory Requirements/Cleanup Goals:
• Bulleted information</td></tr>
<tr><td colspan="3">Results:
• Bulleted information</td></tr>
<tr><td colspan="3">Cost:
• Bulleted information</td></tr>
<tr><td colspan="3">Description:
Brief text description of site, technology application, results, and lessons learned</td></tr>
</table>

APPENDIX D

GENERIC FORMAT FOR COST AND PERFORMANCE CASE STUDY REPORT

APPENDIX D

GENERIC FORMAT FOR
COST AND PERFORMANCE CASE STUDY REPORT

Site Name

SITE INFORMATION

IDENTIFYING INFORMATION:

Site Name:

Location:

CERCLIS ID No.:

Regulatory Context: (for example, date for Record of Decision)

TECHNOLOGY APPLICATION

Period of Operation:

Quantity of Material Treated during Application: (also provide basis for estimate)

BACKGROUND

Waste Management Practice That Contributed to Contamination: (for example, leaks and spills from waste storage)

Site History: (brief, focusing on sources of contamination)

Remedy Selection: (brief summary of the selected remedy and the basis for selection)

SITE LOGISTICS/CONTACTS
(Provide name, address, telephone, e-mail)

Site Lead:

Oversight:

Regulatory Contact:

Technology System Vendor/Consultant:

Additional Contacts:

MATRIX DESCRIPTION

MATRIX IDENTIFICATION

Type of Matrix Processed Through Technology System: (for example, soil or groundwater)

CONTAMINANT CHARACTERIZATION

Primary Contaminant Groups and Concentrations Measured During Site Investigation:
Identify nature and extent of contamination; include site map showing locations, as appropriate

Contaminant Properties:
Include tabular list of properties such as solubility, partition coefficients, boiling points

MATRIX CHARACTERISTICS AFFECTING TECHNOLOGY COST OR PERFORMANCE
(Provide information on relevant parameters for the application)

Parameter	Value	Measurement Procedure
Soil Classification		
Clay Content and/or Particle Size Distribution		
Additional Soil Characteristics (specify)		

SITE GEOLOGY/STRATIGRAPHY

Describe heterogeneity, depth to groundwater, size and characteristics of applicable aquifers and units (especially important for in situ technologies)

TECHNOLOGY SYSTEM DESCRIPTION

PRIMARY TECHNOLOGY

Technology name

SUPPLEMENTAL TECHNOLOGY TYPES

Example - Post-Treatment (Air): Technology name(s)

Example - Post-Treatment (Water): Technology name(s)

SYSTEM DESCRIPTION AND OPERATION

System Description
(Include a description of system; provide a process flow diagram if available; identify key design criteria)

System Operation
(Include a description of system operation, identify the remediation technology plan and how operation compared with the plan, including any operational problems; describe activities used to perform system optimization)

OPERATING PARAMETERS AFFECTING TECHNOLOGY COST OR PERFORMANCE

(Provide information on relevant operating parameters for the application.)

Parameter	Value
Example: Temperature	
Others (as appropriate)	

TIMELINE

(Provide dates for key activities for the application, focusing on events related to technology.)

Start Date	End Date	Activity

TECHNOLOGY SYSTEM PERFORMANCE

CLEANUP GOALS/STANDARDS

Please specify for media treated as well as applicable standards for related parameters such as air emissions and effluent discharges.

PERFORMANCE DATA

Tabular and/or graphical presentation of analytical data for media treated before, during, and after technology application, as appropriate. (Include site map showing sampling locations, as appropriate)

PERFORMANCE DATA ASSESSMENT

Objective comparison of performance data, including direct comparison of performance data with cleanup goals and standards.

PERFORMANCE DATA QUALITY

Briefly describe quality assurance/quality control (QA/QC) procedures used in application, and note any exceptions to those procedures.

COST OF THE TECHNOLOGY SYSTEM

PROCUREMENT PROCESS

Number of bids, competitive nature of procurement process, names and roles of selected contractors.

COST DATA

(Identify organization that provided cost data and whether cost data are actual or estimated costs)

Item	Cost ($ Year Basis)	Actual or Estimated (A or E)
Capital (specify cost/activity)		
Operation and maintenance (specify cost/activity)		
Other (specify)		

(For relatively short-term applications, O&M costs may be reported as a total value for the application; however, for longer-term applications, annual O&M costs should be reported.)

REGULATORY/INSTITUTIONAL ISSUES

Identify the approvals, licenses, and permits required to operate the technology at the site.

TECHNOLOGY APPLICABILITY AND ALTERNATIVES

(Provide only for demonstration-scale reports)

Identify technology applicability, competing technologies, and technology maturity; may also discuss commercialization and intellectual property issues.

Observations and Lessons Learned

COST OBSERVATIONS AND LESSONS LEARNED

Provide observations and lessons learned related to cost of the application.

PERFORMANCE OBSERVATIONS AND LESSONS LEARNED

Provide observations and lessons learned related to performance of the application.

OTHER OBSERVATIONS AND LESSONS LEARNED

Provide additional observations and lessons learned for the application, and an assessment about potential use at other sites.

References

List of references used in preparation of the cost and performance report.

Acknowledgments

Name of organization(s) that prepared case study report, and corresponding contract number (as appropriate).

APPENDIX E

ACTIVE MEMBERS OF THE AD HOC WORK GROUP ON COST AND PERFORMANCE

APPENDIX E

ACTIVE MEMBERS OF THE AD HOC WORK GROUP ON COST AND PERFORMANCE

Listed below are members of the Work Group who participated in revising the Interagency Guide. The members listed may also be involved in efforts to collect cost and performance data.

William Anderson
American Academy of
Environmental Engineers
130 Holiday Court, Suite 100
Annapolis, MD 21401

Maria Bayon
NASA (Code JE)
300 E Street, SW
Washington, DC 20546

Skip Chamberlain
U.S. Department of Energy
EM-53, Clover Leaf Bldg.
19901 Germantown Road
Germantown, MD 20874-2290

Scott Edwards
OADUSD
3400 Defense Pentagon
Washington, DC 20301-3400

Edward Engbert
U.S. Army Environmental Center
ATTN: SFIM-AEC-ETD
Aberdeen Proving Ground, MD 21010

Gordon Evans
U.S. Environmental Protection Agency
ORD/NRMRL
26 W. Martin Luther King Drive
Cincinnati, OH 45268

Bob Furlong
HQ-USAF/CEVR
1260 Air Force Pentagon
Washington, DC 20330-1260

Mike Goldstein
U.S. Environmental Protection Agency
401 M Street, SW (5202G)
Washington, DC 20460

Stan Hanson
U.S. Army Corps of Engineers
CEMRD-ET-E
12565 West Center Road
Omaha, NE 68144

Steve Hirsh
U.S. Environmental Protection Agency
Region 3
841 Chestnut Building (3HW50)
Philadelphia, PA 19107

John Kingscott (Chairman)
U.S. Environmental Protection Agency
Technology Innovation Office
401 M Street, SW (5102G)
Washington, DC 20460

Donna Kuroda
U.S. Army Corps of Engineers
CEMP-RT
20 Massachusetts Avenue, NW
Washington, DC 20314

Mac Lankford
U.S. Department of Energy (EM-55)
1000 Independence Ave., SW
Washington, DC 20585

Kelly Madalinski
U.S. Environmental Protection Agency
Technology Innovation Office
401 M Street, SW (5102G)
Washington, DC 20460

Jeff Marqusee
ODUSD (ES)
3400 Defense Pentagon
Washington, DC 20301-3400

APPENDIX E (continued)

ACTIVE MEMBERS OF THE AD HOC WORK GROUP ON COST AND PERFORMANCE

Mary McCune
U.S. Department of Energy
(EM-43), Clover Leaf Bldg.
19901 Germantown Road
Germantown, MD 20874-1290

Steven McNeely
U.S. Environmental Protection Agency
OUST
401 M Street, SW (5403G)
Washington, DC 20460

David Morganwalp
U.S. Geological Survey
412 National Center
Reston, VA 22092

Robert Nash
Naval Facilities Engineering
Service Center (ESC414RN)
1100 23rd Avenue
Port Hueneme, CA 93043-4370

Margaret Patterson
U.S. Air Force
129 Andrews Street, Suite 102
ACC CEVRW
Langley AFB, VA 23665

Kate Peterson
U.S. Army Corps of Engineers
CEMRD-ET-E
12565 West Center Road
Omaha, NE 68144

Johnnie Shockley
U.S. Army Corps of Engineers
CEMRD-ET-E
12565 West Center Road
Omaha, NE 68144

Ken Skahn
U.S. Environmental Protection Agency
OERR (5203G)
401 M Street, SW
Washington, DC 20460

Bryan Skokan
U.S. Department of Energy
EM-42
Cloverleaf Building
Washington, DC 20585

Rob Smith
Code ENV-CLEANUP
Naval Facility Engineering Command
Washington Navy Yard
1322 Patterson Avenue, S.E., Suite 1000
Washington, DC 20374-5065

Dennis A. Teefy
U.S. Army Environmental Center
ATTN: SFIM-AEC-ETD
Aberdeen Proving Ground, MD 21010-5401

Stephen Warren
U.S. Department of Energy (EM-43)
19901 Germantown Rd.
Germantown, MD 20874

Stan Wolf
U.S. Department of Energy (EM-55)
100 Independence Ave., SW
Washington, DC 20585

APPENDIX F

MEMBERS OF FEDERAL REMEDIATION TECHNOLOGIES ROUNDTABLE

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MEMBERS OF FEDERAL REMEDIATION TECHNOLOGIES ROUNDTABLE

James Arnold
U.S. Army Environmental Center
SFIM-AEC-ET Building E4430
Aberdeen Proving Ground, MD 21010

Gerald Boyd
Deputy Assistant Secretary
U.S. Department of Energy
ERWM (EM-50)
1000 Independence Avenue, SW
Washington, DC 20585

Col. James Dries DAIM-ED
Asst. Chief of Staff - Installation Management
600 Army Pentagon
Washington, DC 20310-0600

James Fiore
U.S. Department of Energy (EM-40)
1000 Independence Avenue, SW
Washington, DC 20585

Brian Harrison
Code ENV
Naval Facility Engineering Command
Washington Navy Yard
1322 Patterson Avenue, S.E., Suite 1000
Washington, DC 20374-5065

Dr. Joe Hoagland, Manager
Land and Water Sciences and Remediation
Tennessee Valley Authority
Environmental Research and Services/CTR-2R
Muscle Shoals, AL 35662

Craig Hooks
U.S. Environmental Protection Agency
OFFE
401 M Street, SW (2261)
Washington, DC 20460

Dr. Tom Houlihan, Director
Interagency Environmental Technologies Office
730 Jackson Place, NW
Washington, DC 20503

Lt. Col. Ray Knight
USAF/ILEVR
1260 Air Force Pentagon
Washington, DC 20330-1260

Walter W. Kovalick, Jr., Ph.D. (Chairman)
U.S. Environmental Protection Agency
Technology Innovation Office
401 M Street, SW (5102G)
Washington, DC 20460

Phillip Newkirk, Acting Center Director
U.S. Environmental Protection Agency
ORIA
Center for Remediation, Technology & Tools
401 M Street, SW (6602J)
Washington, DC 20460

Timothy Oppelt
U.S. Environmental Protection Agency
ORD
National Risk Management Laboratory
26 West Martin Luther King Drive
Cincinnati, OH 45268

John Powell
U.S. Geological Survey
12201 Sunrise Valley Drive, MS 404
Reston, VA 20192

Patricia Rivers
Environmental Division
U.S. Army Corps of Engineers
CEMP-RT
20 Massachusetts Avenue, NW
Washington, DC 20314-1000

Col. John Selstrom
AFCEE/ERT
3207 North Road
Brooks AFB, TX 78235

Edward Wandelt (G-HCV-1)
U.S. Coast Guard Headquarters
2100 Second Street, SW, Room 6109
Washington, DC 20593-0001

APPENDIX F (continued)

MEMBERS OF FEDERAL REMEDIATION TECHNOLOGIES ROUNDTABLE

James Woolford
U.S. Environmental Protection Agency
FFRRO
401 M Street, SW (5101)
Washington, DC 20460

Dr. Robert J. York
U.S. Army Environmental Center
SFIM-AEC-IR, Building E4480
Aberdeen Proving Ground, MD 21010

Dr. James Wright
Code ENV
Naval Facilities Engineering Command
Washington Navy Yard
1322 Patterson Avenue, S.E., Suite 1000
Washington, DC 20374-5065