Oak Ridge National Laboratory Technology Logic Diagram

Executive Summary

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ACRONYMS

ADS	activity data sheet
BRC	below regulatory concern
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
EM	environmental management
ER	environmental restoration
ORNL	Oak Ridge National Laboratory
OSTI	Office of Scientific and Technical Information
RA	remedial action
RCRA	Resource Conservation and Recovery Act
SWSA	Solid Waste Storage Area
TLD	Oak Ridge National Laboratory Technology Logic Diagram
TSCA	Toxic Substances Control Act
TTP	Technical Task Plan
WAG	Waste Area Grouping
WM	waste management

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FOREWORD

The *Oak Ridge National Laboratory Technology Logic Diagram* (TLD) was developed to provide a decision-support tool that relates environmental restoration (ER) and waste management (WM) problems at Oak Ridge National Laboratory (ORNL) to potential technologies that can remediate these problems. The TLD identifies the research, development, demonstration, testing, and evaluation needed to develop these technologies to a state that allows technology transfer and application to decontamination and decommissioning (D&D), remedial action (RA), and WM activities.

The TLD consists of three fundamentally separate volumes: Vol. 1, *Technology Evaluation*; Vol. 2, *Technology Logic Diagram*; and Vol. 3, *Technology Evaluation Data Sheets*. Part A of Vols. 1 and 2 focuses on D&D of contaminated facilities. Part B of Vols. 1 and 2 focuses on RA of soils, groundwater, and surface water. Part C of Vols. 1 and 2 focuses on WM. Each part of Vol. 1 contains an overview of the TLD, an explanation of the program-specific problems, a review of identified technologies, and the rankings of technologies applicable to the remediation of the problem. Volume 2, Pts. A, B, and C, contains the logic diagrams themselves, logic linkages among EM goals, environmental problems, and the various technologies that have the potential to solve these problems. Volume 3, Pts. A, B, and C, contains the TLD data sheets, which are expanded versions of single logic paths from Vol. 2.

This executive summary contains a description of the logic diagram format; some examples from the diagram (Vol. 2) and associated technology evaluation data sheets (Vol. 3); a complete (albeit condensed) listing of the RA, D&D, and WM problems at ORNL; and a complete listing of the technology rankings for all the areas covered by the diagram.

The TLD document is available in paper copy for Vols. 1 and 2 and as disk (3.5-in. high-density diskette, WordPerfect version 5.1) for Vol. 3. Please request RA, D&D, or WM sections by FAX to 615-576-2820 by August 16, 1993. The TLD can also be obtained from the Office of Scientific and Technical Information (OSTI) as either printed copy or microfiche by calling 615-576-1284.

Document numbers from OSTI follow:

- D&D—Vol. 1, Pt. A (DE93016144), Vol. 2, Pt. A (DE93016147), and Vol. 3, Pt. A (DE93016167).
- RA—Vol. 1, Pt. B (DE93016145), Vol. 2, Pt. B (DE93016148), and Vol. 3, Pt. B (DE93016168).
- WM—Vol. 1, Pt. C (DE93016146), Vol. 2, Pt. C (DE93016149), and Vol. 3, Pt. C (DE93016169).

The technology evaluations contained in these volumes are based on the best information available during compilation of the TLD. New or more accurate information is solicited to improve the TLD data base. Please send comments to R. L. Fellows, Editor, *Oak Ridge National Laboratory Technology Logic Diagram*, Martin Marietta Energy Systems, Inc., P.O. Box 2003, Oak Ridge, TN 37831-7274. FAX (615-576-8558).

1. TECHNOLOGY LOGIC DIAGRAM

1.1 DESCRIPTION OF THE TECHNOLOGY LOGIC DIAGRAM

The *Oak Ridge National Laboratory Technology Logic Diagram* (TLD) is a planning and management document for the U.S. Department of Energy (DOE), DOE operating contractors, and private industry, that relates the environmental management (EM) problems at Oak Ridge National Laboratory (ORNL) to the technologies that can be used to remediate these problems. This TLD follows the format established for the *Technology Logic Diagram for the K-25 Site*. The TLD evaluates the status of the reasonable, potential remediation technologies and identifies areas within these technologies that require development. In addition, the TLD addresses the enforceable compliance and cleanup agreements that have designated timetables for ameliorating the specific site problems.

In assessing the appropriateness of each technology, the following factors affecting implementation are considered:

1. Potential efficacy of the technology—how successful will its application be to the site problem?
2. Level of maturity of the technology—when can it be applied to site problems?
3. Level of waste management (WM) required for the technology—what wastes are generated as a result of the use of the technology?

For potentially attractive but immature technologies, or those for which improvement paths (which make them faster, better, safer, and cheaper) are visualized, priorities are assigned to technology development activities. The technology listings in the diagrams are judged to be reasonable and applicable at ORNL. In a few cases, however, the prospects are limited.

These technologies may apply to the following EM areas: decontamination and decommissioning (D&D), remedial action (RA), and WM. (The RA and D&D activities are referred to collectively as environmental restoration [ER] activities.) The TLD has been organized to reflect the EM areas

For the purposes of the TLD, D&D activities are defined as those that involve remediation of facilities. RA activities involve cleaning of contaminated soil, sludge, groundwater, etc., although, some wastes presently stored from past DOE operations are also addressed in the RA section. WM problems are confined to wastes from current or future operations. The exception is inclusion of some stored transuranic waste from past activities. Wastes that are generated from present and future RA or D&D activities are included in the WM discussion.

The TLD is published as three separate documents, covering D&D, RA, and WM. Each document is made up of three volumes: Vol. 1 contains details of the various problems, delineations of the possible technologies that can reasonably be used to remediate these problems, and rankings of the technologies that indicate the most applicable to the problem area; Vol. 2 contains the logic diagrams; and Vol. 3 contains the technology evaluation data sheets, each of which follows a single unique logic path and, therefore, addresses a single technology in considerably more detail than possible in diagram format.

1.2 TECHNICAL APPROACH

This section describes the overall layout and development of the TLD. The logical progression flows from (DOE) EM Goal → EM Problem → ORNL Problem → Problem Area (Target Constituent) → Regulatory Compliance → Subelement (several of which are necessary to define the universe of activities associated with D&D, RA, and WM) → Alternative (Generic Technology) → Technology → Technology Status → Science/Technology Need → Implementation Need. The information found under each logic element is described below.

EM Goal has three components: clean up DOE legacy waste from past operations, prevent future environmental insult, and develop environmental stewardship. These goals are shared by all installations in the DOE complex.

EM Problem identifies problem areas agreed upon by EM/DOE, such as decommissioning of facilities (D&D); cleanup of soils, groundwater, and surface water (RA); and WM from inception to final disposition.

ORNL Problem describes the problem areas identified at ORNL. These problem areas have been defined by D&D, ER, and WM staff. The magnitudes of the site problems will be indicated when possible in terms of floor areas, estimated metal tonnages, etc.

Problem Area/Constituent addresses subelement-specific (see below) list of problems, all of which are traceable directly to the ORNL problems.

Reference Requirements identifies milestones, scheduled commitments, etc., that are related to the problem areas. Typically, requirements are determined after consideration of detailed site-, waste-, and technology-specific characteristics, as well as site-specific legal agreements, such as Federal Facility Compliance Agreements..

Subelement specifies the different components that must be addressed to solve the problem. The universe of D&D-related activities has been categorized into the following subelement groups: characterization, decontamination, dismantlement, robotics/automation, materials disposition, and regulatory compliance. The subelements for RA are characterization; treatment and fixation; retrieval; robotics/automation; materials disposition; and regulatory compliance. For WM, related activities consist of characterization; waste processing, stabilization, and minimization; transportation, retrieval, and disposal; robotics/automation; and regulatory compliance. Table 1.1 lists these various subelements for D&D, RA, and WM.

Alternative defines the general or generic technology approaches that may be applied to the problem.

Technology identifies the specific technology that may be applied to remediate the EM Problem. An associated technology code refers to more detailed information in Vol. 3, a compilation of technology evaluation data sheets.

Status provides information on the status of the technologies identified in the previous column using the standard descriptions that follow.

Table 1.1. Subelement categories in the Technology Logic Diagram

Area of environmental management	Subelements (or "Universe" of Activities)					
Decontamination and decommissioning	Characterization	Decontamination	Dismantlement	Robotics/automation	Materials disposition	Regulatory compliance
Remedial action	Characterization	1. Treatment 2. Fixation	Retrieval	Robotics/automation	Materials disposition	Regulatory compliance
Waste management	Characterization	1. Processing 2. Stabilization 3. Minimization	1. Transportation 2. Retrieval 3. Disposal	Robotics/automation	Materials disposition	Regulatory compliance
	Crosscutting			Crosscutting	Crosscutting	Crosscutting

- *In Use*—technology is presently being used to remediate the identified problem.
- *Accepted*—demonstrated technology exists for use at ORNL and is accepted by site personnel.
- *Demonstration*—technology is available but is not demonstrated and/or accepted for the problem at ORNL.
- *Predemonstration*—technology is under laboratory-, bench-, or pilot-scale testing.
- *Evolving Technology*—technology status is at a conceptual or preconceptual stage.
 - *Conceptual*—a scientific or knowledge basis for the technology exists.
 - *Preconceptual*—only a partial scientific or knowledge basis for the technology exists.

These classifications should provide relevant information on the present view of the short-term or long-term availability of technologies.

Several different areas are specifically addressed to further clarify the status designations chosen above.

- *Efficacy*—effectiveness of the technology in remediating the problem. Normally, quantitative measures are given for the technology's performance in standard practice, such as estimating the final dpm/cm² of surface contamination for a decontamination technology; the time to cut a 24-in. pipe for a dismantlement technology; or the analysis time and detection limit for a characterization technology.
- *Waste*—output from the technology. This describes the nature and volume of both the waste and the potentially useful materials for disposition.

Science and Technology Needs are identified areas where support or development is needed for an "immature" technology. Science needs are related to the fundamental understanding of the scientific phenomena that form the basis for the technology. These needs are typically for laboratory or bench-scale experiments. Technology development needs identify areas where work is necessary to successfully implement scientific principles leading to a technology. Technology improvement needs suggest improvements that will make a currently available technology more economical to apply, safer, and more effective or efficient. The demonstration of a technology on a site-specific problem is a technology improvement need.

If scientific needs are specified, it should be understood that technology development or improvement is necessary to implement newly developed scientific understanding. Likewise, testing a technology development opportunity implies that technology improvements are also likely to be needed.

DOE funding for a project that addresses the technology deficits is indicated by a Technical Task Plan (TTP) number, Activity Data Sheet (ADS) number, or other reference number. Other work related to the technology area may also be referenced.

Most technologies that are not in common use will require a large-scale test or demonstration to show that they are capable of achieving expected results on the site-specific problem. These tests demonstrate that a suitable and workable process or facility can be designed, built, and operated successfully. They show that no unknown condition prevents the process from functioning as it was intended and that the equipment can last an acceptable lifetime. Demonstrations are intended to provide final tests of all aspects of a technology.

Implementation Needs or specialized needs were evaluated for both development of a technology and deployment of a mature technology. These needs were evaluated in the areas of (1) resources such as financial or personnel; (2) hardware such as process equipment, development equipment, and computers; (3) software such as models,

procedures, computer programs; (4) facilities such as labs, shops, and buildings; and (5) education such as training classes or degreed personnel. Only extraordinary needs are highlighted (i.e., those needs that would require long lead time or unusual procurements such as line items for facility construction). The cost of applying the technology and the payback-cost potential has been estimated. There are many possibilities for cost payback, such as reducing the waste volume compared to a reference process, the sale of useable products, and the reduction of cost compared to a reference or baseline technology. In future updates of this work, technology integration needs will be specifically identified, where integration of additional technologies is either necessary or will allow a particular technology to be implemented in a faster, better, safer, or cheaper manner.

1.3 TECHNOLOGY LOGIC DIAGRAM

Three sample diagrams (one each from D&D, RA, and WM) are provided, along with the "explanation and understanding key" from the TLD, Vol. 2. Sample technology evaluation data sheets (which are referenced from the diagram by the technology evaluation data sheet code associated with the technology name) are also provided as examples from Vol. 3.

The samples are presented as follows:

- Exhibit 1.1—explanation and understanding key;
- Exhibit 1.2—sample logic diagram for decontamination technologies;
- Exhibit 1.3—sample data sheet for a decontamination technology;
- Exhibit 1.4—sample logic diagram for remedial action technologies;
- Exhibit 1.5—sample data sheet for a remedial action technology;
- Exhibit 1.6—sample logic diagram for waste management technologies; and
- Exhibit 1.7—sample data sheet for a waste management technology.

The logic elements described in the "Technical Approach" section of Chap. 1 of the Executive Summary serve as column headings in this diagram.

[illegible]

Exhibit 1.2. Sample logic diagram for decontamination technologies.

EM Goals	ORNL Problems	Problem Areas Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
<ul style="list-style-type: none"> Clean Up Legacy Waste Prevent Future Insult Develop Environmental Stewardship 	Oak Ridge Reactor Biological Shield Bldg. 3028 Hot Cell Interiors Bldg. 3029 Hot Cell Interiors Bldg. 3030 Hot Cell Interiors Bldg. 3031 Hot Cell Interiors Bldg. 3032 Hot Cell Interiors Bldg. 3036 Floor Homogeneous Reactor Test Structure Bldg. 3317 Hot Cell Interiors Bldg. 3414 1st Floor 1st Floor Molten Salt Cells Bldg. 3038 Cell Interiors Graphite Reactor Biological Shields Graphite Reactor Canal Graphite Reactor Ductwork Graphite Reactor Stack Sub Supporting Low-Intensity Test Reactor Components	Concrete Fission Products, Corrosion Products Concrete Fission Products, Cm-244, Pm-147, Am-241 Concrete Cs-137, Sr-90, Co-60, I-192 Concrete 43 Beta/Gamma Emitters Concrete Gd-153, Am-241 Concrete P-32, Am-241 Concrete Cs-137, Sr-90 High-Density Concrete Fission Products, Corrosion Products, Induced Radiation Concrete Cs-137, Sr-90, Co-60 Concrete U, Th, Molten Salt Concrete Sr-90, Cs-137, Co-60, I-129 Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products Concrete Fission Products, Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, Activation Products Concrete Fission Products, Corrosion Products, Activation Products	Refer to Vol. 1, P.L.A., Chap. 7, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology specific regulatory requirements will be specified.	Decontamination	Surface Cleaning Methods continued Chemical Surface Cleaning Methods	Strippable Coatings DCON-63-OL Ranking: M-3-0 (<\$0.1M>-\$1M) Vacuum Cleaning DCON-7-OL Ranking: M-3-0 (<\$0.1M>-\$1M) Chemical Foams DCON-8-OL Ranking: M-4-0 (\$3M-\$50-2M) Fluoroboric Acid Treatment DCON-11-OL Ranking: M-4-2 (\$2M)	Accepted Technology has been used for decontamination applications involving hazardous and radioactive contaminants. Efficacy: Decontamination factors of one to several hundred can be expected with two applications. Waste: Waste is a solid polymer (volume = 1 mm x surface area decontaminated) containing the removed contaminants. Accepted Vacuum cleaners have long been used to clean up loose contamination. Efficacy: Since little of the listed contaminants are expected to be in loose form, this technique is not expected to be effective in cleaning concrete floors at ORNL. Waste: The waste is a HEPA filter filled with the contaminants and other materials that are removed by the vacuum. Demonstration Widely used throughout the nuclear industry. Foam is used as a carrier of chemical decontamination agents, not as the agent itself. It is sprayed on to component walls or the component is filled with the foam. It can be wiped, rinsed, or vacuumed off. Efficacy: Decontamination effectiveness was 63-92% with DF = 2.7 to 12.5 inside a hot cell in one study. Waste: Small amount of contaminated saturated wetting agents, coupling agents, rinse water, and drying cloth. Demonstration Technology was designed specifically for D&D. Efficacy: Unrestricted use of materials should be possible after decontamination, due to high decontamination factor (DF). Fluoroboric (or fluosulfonic) acid can dissolve activation cement and brickwork, if contaminated to a depth of only a few mm, concrete flooring and structures can be returned to unrestricted use. Waste: Contamination and dissolved outer layer of concrete.	Technology Improvement: Develop coatings with lower material costs and greater ease of application. None Development: Scale-up/development of the process to a size appropriate for ORNL use. The technology itself is inexpensive, but development and scale-up will probably require support. Technology Improvement: Full control over the mean bubble dimensions and the volume swell factor are needed. Development: Although the method has seen application at Chernobyl with good results, development work is needed to test applicability at ORNL.	Normal Implementation needs. Capital cost: <\$10K Operating cost: \$1-\$1.40/m ² labor to apply, remove and dispose Normal Implementation needs. Capital cost: <\$10K Operating cost: >\$1/m ² Normal Implementation needs. Development cost: \$1M-\$4M; Capital cost: \$50K Operating cost: \$0.50-\$2/m ² Fluoroboric acid exhibits low vapor pressure and requires only standard precautions for acid or base work. The plant can be manufactured in modular form and installed in existing buildings. Hardware (equipment): Fabrication of all key plant parts from polypropylene or from Halar-coated metal. Capital Costs: In 1990 to set up a plant for decontaminating 5 km ² of steel cost \$774K, excluding development, planning, and buildings. Operating cost: Relatively low; this is a very simple process.
<ul style="list-style-type: none"> Facility Decontamination and Decommissioning (D&D) 									
<ul style="list-style-type: none"> Remedial Action (RA)—Soils, Groundwater and Surface Water 									
<ul style="list-style-type: none"> Waste Management (WM) 									

Exhibit 1.3. Sample data sheet for a decontamination technology.

FLUOBORIC ACID TREATMENT

DCON-11-OL

EM Problem: Decommissioning

ORNL Problem: See Appendix A, lists A, B, C, E, F, H

Problem Area/Constituents: See Appendix A, lists A, B, C, E, F, H

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 (Pt. A, B, or C as appropriate) for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and non-regulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Decontamination

Alternative: Chemical surface cleaning (fixed and transferable contamination) methods

Technology: Fluoboric acid treatment. Decontamination and decommissioning (D&D) using fluoboric acid (HBF_4) in dipping baths, loop systems, or by spraying.

Status: Demonstration. Technology was designed specifically for D&D.¹ Attacks nearly every metal surface and metallic oxide or concrete surface. Removes oxide and contaminated outer layer in controllable, uniform, and efficient manner. Unrestricted use of materials should be possible after decontamination, due to high decontamination factor (DF); however, corrosion is high (DF is a function of the depth of metal removed).

Additional Comments:

Amount of Waste Produced—The fluoboric acid technology generates metal waste as a result of surface removal. About 1-g of this waste is generated per square meter per micron depth of bare metal removal. The acid can be electrolytically regenerated and recycled, with the radioactive waste plated out at the cathode and solidified in cement. Final quantity of cement-solidified waste is 20–50 g/m² decontaminated metal. Other waste treatment options are neutralization and precipitation with solidification in cement (200–500 g/m² or treatment by ion exchange followed by solidification of the resin in cement (400–700 g/m²). The optimum material for solidification of this waste needs to be determined.²

Overall cost—Capital costs in 1990 to set up a plant for decontaminating 5 tons/day of steel was \$1.3M (\$774K excluding development, planning, and buildings).² Operating costs will be relatively low; this is a very simple process. The plant can be manufactured in modular form² and installed in existing buildings.

Efficacy/strengths/weaknesses—The reaction is heterogeneous and proceeds as follows:

1. $n\text{HBF}_4 + \text{Me} = \text{Me}(\text{BF}_4)_n + n/2 \text{H}_2$
2. $n\text{HBF}_4 + \text{metallic oxide} = \text{Me}(\text{BF}_4)_n + \text{water}$

Exhibit 1.3 (continued)

FLUOBORIC ACID TREATMENT

DCON-11-OL

Fluoboric (or fluosilicic) acid can also scabble and clean cement and brickwork. If it is contaminated to a depth of only a few millimeters, concrete flooring and structures can be returned to unrestricted use.¹ Fluoboric acid exhibits low-vapor pressure and requires only the standard precautions for acid or base work.

Science/Technology Needs: Depends to a certain extent on similarities between ORNL and Chernobyl operations.² Results of the technology usage at Chernobyl may answer many questions for us.

Implementation Needs: Equipment, fabrication of all key plant parts from polypropylene or from Halar-coated metal.

Author: D.E. Beck/615-574-0706. Reviewed by J. R. DeVore/615-574-7092

References:

1. J. D. Hanulik and W. T. Rippin, "Chemical Decontamination for Decommissioning with Application of DECOHA Technology on Metal, Concrete, and Brickwork." from *Proc. Ins. Mech. Eng. Nucl. Decom '92*, Decommissioning of Radioactive Facilities International Conference, London. February 17-19, 1992.
2. H. W. Beaujean, J. Fiala-Goldiger, and J. Hanulik, "DECOHA at Chernobyl," *Nucl. Eng. Int.* April 30, 1991.

Exhibit 1.4. Remedial action logic diagram.

Exhibit 1.5. Sample data sheet for a remedial action technology.

VITRIFICATION

REMA-117-OL

EM Problem: Remedial action

ORNL Problem: Buried waste

Problem Area/Constituents: Low-level waste, organics, metals, mixed waste

Reference Requirements: Refer to the Regulatory Compliance chapter of Vol. 1 (Pt. A, B, or C as appropriate) for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, Department of Energy (DOE) Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Treatment

Alternative: Fixation

Technology: Vitrification. This device adds glass-forming constituents to waste feed to produce a pool of molten glass at the bottom of a reactor in which solid wastes react. Gases produced during combustion are released from the surface of the glass pool. Ash remains in the pool and is periodically removed with the carrier glass matrix. The removed glass is collected in storage containers and solidifies upon cooling.

Status: Predemonstration. A large database exists for high-level radioactive wastes, but not for low-level radioactive wastes or hazardous wastes.

Vitrification is a physical encapsulation technique that has been accepted for high-level waste. Vitrification results in a net volume reduction, even starting with a bed of solids and no liquids. This results in significant economic savings for ultimate disposal to compensate for the higher capital and production costs required to generate this waste form (compared to cementitious waste forms). Ostensibly, no interaction with the waste occurs, but it is questionable whether vitrified waste will pass the Toxicity Characteristic Leaching Procedure (TCLP) test. The waste form is nonporous and less leachable than cementitious waste forms, but the RCRA metals may be just as extractable after treatment as before, if truly allowed to come to equilibrium, as intended in the TCLP test. Laboratory testing is required, as with cementitious waste forms, to identify the compatible melt compositions. This technique occurs at higher temperatures than for thermoplastic encapsulations. Thus, water is driven off, but it is inappropriate for volatiles and may not be appropriate for semivolatiles. Organics are likely destroyed, but other volatiles and semivolatiles that cannot be destroyed (e.g., mercury, tritium, cesium, and technetium) may not be amenable to vitrification. Such contaminants are commonly found in low-level radioactive wastes.

The white paper prepared for EG&G Idaho, Inc., (EGG-WTD-9449) evaluates the advantages, disadvantages, and costs of thermal treatment technologies, including vitrification by glass furnace and vitrification by microwave melting. Included among the disadvantages were

Exhibit 1.5 (continued)

VITRIFICATION

REMA-117-OL

relatively high energy and capital costs and unproven technology for hazardous wastes. The capital cost and operating costs for glass furnace vitrification were estimated to be \$3.9M and \$0.78/kg feed. (Assuming a feed density of 1 kg/L, operating costs convert to \$780/m³ or \$2.95/gal.)

In making a case for vitrification of low-level wastes, Gimpel and Diggs have made economic assessments and have published several papers (1992), together or separately, either claiming that the costs for vitrification are comparable with those of solidification/stabilization or that the costs for making the glass waste forms are higher, but the total life cycle costs (including disposal costs and monitoring costs for 100 y after disposal) are comparable for the two options because of the higher volumes that must be disposed and monitored from S/S. They estimate the direct costs to be \$90–\$220/m³ (\$0.34–\$0.83/gal) for S/S and \$400/m³ (\$1.51/gal) for vitrification, but total costs (including disposal) at \$1186–\$2090/m³ (\$4.49–\$7.91/gal) and \$922–\$1500/m³ (\$3.49–\$5.52/gal), respectively. The assumptions made regarding S/S appear reasonable, but are more questionable regarding vitrification. However, the authors make a valid point that most cost estimates are the direct costs of making the wastes and do not include disposal costs. The cost deficit from increasing the waste volume should be estimated for S/S or the cost benefit estimated from the volume decrease for vitrification.

Koegler et al. (1988) had the following insights into waste vitrification:

- Estimated capital cost of \$24.1M and total operating costs of \$73M for granular glass, or \$97M for casting into canisters, for a facility to vitrify 264K tons of waste over 6.5 y. This works out to \$91/ton capital costs and \$277–\$367/ton operating costs.
- “A favorable property of glass is its ability to accommodate a wide variety of compositional variations and still maintain its basic durability.”
- “The amount of glass to be produced is expected to be determined by the fluoride solubility limit in the glass. Fluoride, a major constituent in the raffinate sludges, has a maximum glass solubility of about 5 wt%.”
- “Of the priority pollutant metals, mercury is known to escape from the glass during vitrification due to its high vapor pressure.”
- “On a cost-per-volume basis, the disposal costs are estimated at \$256/m³ or \$322/m³, depending on whether the glass product is fritted or placed in canisters.”

Buelt (1985) has the following insights about vitrification:

- “The process is not amenable to waste solutions with significant concentrations of sulfates (i.e., <2% on a dry solids basis). Sulfate solubility in glass is limited to 0.5 wt%.”
- “In addition to producing a geologically stable waste form, MEVS significantly reduces the volume of the waste to be destroyed.” (MEVS stands for the Mobile Encapsulation and Volume Reduction System touted by the author. MEVS employs a joule-heated glass melter to vitrify low-level wastes.)
- “The cementation process actually increases the evaporated waste volume by a factor of 1.3, which increases the transportation and disposal cost.”

Exhibit 1.5 (continued)

VITRIFICATION

REMA-117-OL

- The estimated disposal cost for cementation, MEVS of resins, and MEVS of concentrated liquid are \$295, \$218, and \$191/ft³ wet wastes (\$39.44, \$29.14, and \$25.53/gal wet wastes), respectively, including amortized capital, processing, transportation, and disposal costs. (Processing costs for cementation in this reference are orders of magnitude higher compared to other sources.)
- "Burial costs are 1/3 and 1/2 of the cementation disposal costs for resins and concentrated liquids respectively."

Science/Technology Needs: The need exists to demonstrate the technology's effectiveness for those semivolatile species commonly found in low-level waste. For hazardous waste, incinerator efficiencies must be demonstrated for organics as well as the ability to handle volatile and semivolatile metals. Typically, mercury must be removed before vitrification, and Cs-137 has been found in the off-gas. Catholic University is studying this technique for DOE. Claims are made that vitrified wastes pass the TCLP test, but this must be verified, and the Resource Conservation and Recovery Act metal limits in the vitrified waste must be quantified.

Implementation Needs: Laboratory testing of a specific waste or waste stream is necessary to establish the glass composition. Some laboratory testing of certain wastes has been done, but these would need repeating for ORNL wastes, and pilot-scale testing and demonstrations have not been done. Likely, this must be repeated on a case-by-case basis, just as with cementitious waste forms.

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Exhibit 1.5 (continued)

VITRIFICATION

REMA-117-OL

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Exhibit 1.6. Sample logic diagram for waste management technologies.

EM Goals	ORNL Site Problems	Problem Areas/Constituents	Reference Requirements	Subelements	Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
<ul style="list-style-type: none"> Clean Up Legacy Waste Prevent Future Insult Develop Environmental Stewardship 	<ul style="list-style-type: none"> Waste Of Gases from BLU, HX, and HX Operations 	<ul style="list-style-type: none"> Volatile Organic Compounds (VOC) in Gases 	<p>Refer to Vol. 1, Pt. C, Chap. 4, for proposed and promulgated environmental limits, signed and pending agreements for ORR, DOE Orders, and regulatory guidance. Also, waste-specific characteristics are provided for each technology. Or, specific regulatory requirements will be specified.</p>	<p>Waste Processing</p>	<p>Thermal Treatment</p>	Incineration WPHO-108-OL Ranking: E-4 (1.5M/3500)	Advanced The EPA considers incineration the best demonstrated available technology (BDAT) for organic destruction. Incineration can achieve destruction efficiencies (DE) of 99.99% for volatile organics. However, additional research, development, and demonstration (RD&D) on semi-volatile organics is still needed. Waste: Oil gas and salt air.	Technology Improvement: Though the EPA considers the use of the technology to meet the requirements needs to be demonstrated. Also, RD&D is required to develop technology to improve process technology to improve its acceptability.	Knowledge of process applications, hazards, and regulatory approval. (For example, the 60-day site TSCA incinerator is a go-to-site unit permitted to destroy hazardous waste. Obtaining regulatory approval for the TSCA incinerator took over eight years.) Capital Costs: \$100 million (1992 dollars). Operating Costs: \$200 million (1992 dollars).
						Gasification WPHO-109-OL Ranking: H-4 (1.5M/3500)	Pre-demonstration This technology has been demonstrated to be effective for the destruction of liquid and gaseous waste streams. However, the gas to be treated and destroy the organics from solid waste needs additional RD&D.	Technology Improvement: Further RD&D on the process to develop technology to deployment.	The RD&D effort is estimated to require \$0.75-1.5 million.
						Molten Salt Oxidation WPHO-110-OL Ranking: H-4 (2.5M/4000)	Demonstration This technology has been demonstrated to be effective for the destruction of liquid and gaseous waste streams. However, the gas to be treated and destroy the organics from solid waste needs additional RD&D.	Technology Improvement: Further RD&D on the process to develop technology to deployment.	Development Costs: \$100 million (1992 dollars). Operating Costs: \$200 million (1992 dollars).
						Electron Beam Destruction WPHO-304-OL Ranking: L-4 (2.5M/4000)	Pre-demonstration Development work with the Electron Beam Destruction process is ongoing. The process is being scaled up to justify scale-up testing.	Technology Improvement: Further RD&D on the process to develop technology to deployment.	RD&D effort estimated at \$0.75-1.5 million.
<ul style="list-style-type: none"> Remedial Action (RA)—Soils, Groundwater and Surface Water 	<ul style="list-style-type: none"> Waste Of Gases from BLU, HX, and HX Operations 	<ul style="list-style-type: none"> Non-Volatile Organics in Gases 	<p>Refer to Vol. 1, Pt. C, Chap. 4, for proposed and promulgated environmental limits, signed and pending agreements for ORR, DOE Orders, and regulatory guidance. Also, waste-specific characteristics are provided for each technology. Or, specific regulatory requirements will be specified.</p>	<p>Waste Processing</p>	<p>Thermal Treatment</p>	Low Temperature Separation WPHO-220-OL Ranking: H-4 (1.5M/3500)	Pre-demonstration This is an accepted industrial process for the separation of low-boiling components from high-boiling components. The process can achieve separation efficiencies > 99%.	Technology Improvement: Further RD&D needed on the process to develop optimum processing conditions.	RD&D effort estimated at \$1-2 million to meet site-specific needs.
						Flameless Thermal Oxidation WPHO-305-OL Ranking: H-4 (1.5M/3500)	Demonstration Development work with the Flameless Thermal Oxidation process is ongoing. The process is being scaled up to justify scale-up testing.	Technology Improvement: Further RD&D on the process to develop technology to deployment.	RD&D effort estimated at \$1-2 million.
<ul style="list-style-type: none"> Waste Management (WM) 	<ul style="list-style-type: none"> Waste Of Gases from BLU, HX, and HX Operations 	<ul style="list-style-type: none"> Non-Volatile Organics in Gases 	<p>Refer to Vol. 1, Pt. C, Chap. 4, for proposed and promulgated environmental limits, signed and pending agreements for ORR, DOE Orders, and regulatory guidance. Also, waste-specific characteristics are provided for each technology. Or, specific regulatory requirements will be specified.</p>	<p>Waste Processing</p>	<p>Thermal Treatment</p>				

Exhibit 1.7. Sample data sheet for a waste management technology.

INCINERATION

WPRO-108-OL

EM Problem: Waste management

ORNL Problem: Treatment and disposal of uncontaminated, hazardous, toxic and/or mixed-waste-contaminated solids, liquids, and gases generated from decontamination and decommissioning (D&D), remedial action (RA), and waste management (WM) operations

Problem Area/Constituents: Uncontaminated and hazardous, toxic, and/or mixed-waste-contaminated solids, sludges, liquids, and gases generated as a result of D&D, RA, and WM operations at the site

Reference Requirements:

- Resource Conservation and Recovery Act of 1976, as amended (RCRA) Land Disposal Restriction (LDR) Federal Facilities Compliance Agreement (FFCA) dated 12 June 1992
- Federal Facilities Agreement (FFA) for Oak Ridge Reservation
- Federal Facilities Compliance Agreement-Toxic Substances Control Act (FFCA-TSCA) dated 20 February 1992
- Resource Conservation and Recovery Act and the Hazardous and Solid Waste Amendments of 1984, 40 CFR 260-270
- NEPA, 40 CFR 1500-1508
- National Emissions Standards for Hazardous Air Pollutants, 40 CFR 61, Subpart H
- DOE Order 5480.11, "Radiation Protection for Occupational Workers" (draft)
- DOE Order 5480.12, "Prevention, Control, and Abatement of Environmental Pollution"
- 40 CFR 270.32 ("omnibus" authority)
- 40 CFR 264.342(b) (POHC selection)
- Clean Air Act regulations under 40 CFR 60-65
- Clean Water Act regulations under 40 CFR 110-146 and 400-471
- Toxic Substances Control Act
- RCRA Part 64 Subpart O

Refer to the Regulatory Compliance chapter of Vol. 1, Pt. C, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation, radiation protection standards, DOE orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.

Subelement: Waste processing

Alternatives: Thermal treatment

Technology: Incineration. Incineration is an engineered process that employs decomposition via thermal oxidation at high temperature (usually 900°C or greater) to destroy the organic fraction of the waste and reduce volume.¹ Generally, combustible wastes or wastes with significant organic content are considered most appropriate for incineration. Technically, however, any waste with an organic fraction is a candidate for incineration. For instance,

Exhibit 1.7 (continued)

INCINERATION

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significant amounts of contaminated water were being incinerated in the United States during the early 1980s.² Contaminated soils are also being incinerated with increasing frequency. The U. S. Environmental Protection Agency (EPA), for example, has employed a mobile incinerator to decontaminate 40 tons of Missouri soil that had been contaminated with four pounds of chlorinated dioxin compounds.³⁻⁶

The key element of any incineration system is the combustion reactor, or combustor. The combustor is supported by several subsystems that together with the combustion reactor make up a total incineration system. These subsystems include feed preparation and delivery systems, ash removal and packaging systems, off-gas cleaning systems, system controls, and auxiliary utility supply systems. The state of technology of incineration systems could be made sufficient to provide safe and effective treatment of low-level radioactive, hazardous, and toxic wastes. Not all proven incineration systems are designed to handle all these waste feed types.⁷ The incinerator design is based on specific waste profiles to establish basis flows, temperatures, residence times, and mixing requirements to meet waste treatment processing objectives and pollutant destruction and removal efficiencies (DREs).

Several different types of incinerators are available for waste destruction [e.g., rotary kiln, fluidized bed, multiple hearth (or Herreshoff furnace), liquid injection, and controlled air incinerators, to name a few]. Brief descriptions of these incinerators follow:

Rotary kiln. A rotary kiln incinerator is a slowly-rotating, refractory-lined horizontal cylindrical shell mounted at a slight slope. Waste can move concurrent or countercurrent to gas flow. The primary function is to destroy the wastes. This occurs through a series of steps including volatilization, destructive distillation, and combustion reactions. A secondary chamber is generally required for complete destruction of the wastes. The advantages of a rotary kiln are that it is robust and highly versatile and that it can handle solids, slurries, liquids, and gases. The disadvantages of a rotary kiln incinerator include difficulty in controlling the incineration process, seals in-leakage, and refractory replacement.

Fluidized bed. A fluidized-bed incinerator is basically a vertical single refractory-lined vessel partially filled with sand, alumina, or crushed lime or limestone. Fluidized bed incinerators can be either circulating or bubbling bed in design. Combustion air is supplied through a distribution plate to fluidize the bed of particles. Wastes to be incinerated are usually fed into the bed of particles. Circulating bed incinerators usually require a cyclone to return the entrained particles to the bed. The advantages of the fluidized bed incinerator include the uniformity of the bed temperature (thus ensuring better control of the waste DRE), its ease of operation in the range of 1400 to 1600°F with wide range in excess air to allow better metal volatility control, and its compact size. Some of the disadvantages of the fluidized bed incinerator include the requirement that the solid wastes generally be <2 in. in size (thus it cannot be used for incinerating large bulk solids), significant carryover of the bed material, and the presence of tarry wastes can cause operational problems due to "slumping" or defluidization of the bed.

Exhibit 1.7 (continued)

INCINERATION

WPRO-108-OL

Multiple hearth. The multiple hearth incinerator⁸ (also called the Herreshoff furnace) basically consists of a vertical cylindrical refractory-lined furnace or combustion chamber containing several hearths. These hearths are stacked one on top of the other inside the furnace. A slowly rotating hollow vertical shaft passes through the center of the hearths. Hollow rabble arms are attached to this central shaft on each hearth to rake the wastes on the hearth. The rabble arms and shaft are cooled by passing combustion air through the assembly. This combustion air is then fed to the bottom of the furnace below the lowest hearth. Temperatures in the furnace can reach upwards of 1800°F. The wastes to be incinerated are usually fed on the top hearth. The wastes then pass through the many hearths in the furnace and the uncombusted residue is discharged at the bottom. The advantages of a multiple hearth incinerator include its versatility, large throughput, and ability to control the residence time of the solid wastes in the incinerator. The disadvantages include higher capital, operating, and maintenance costs.

Liquid injection. A liquid injection incinerator consists of a hollow refractory-lined horizontal or vertical cylinder equipped with one or more burners where liquids are atomized into droplets and burned in suspension. The incinerator is especially designed for the destruction of fluid wastes. The advantages of the incinerator include excellent control of the destruction of the liquid wastes. The disadvantages include its limitation to the destruction of pumpable liquids only and the need to ensure excellent atomization of the liquid wastes to obtain the required DREs.

Controlled air. A controlled-air incinerator⁸ is also known as a fixed-hearth incinerator or pyrolytic furnace. Briefly, it consists of a simple incinerator employing two combustion chambers. In the first chamber the waste is pyrolyzed by operating at 50 to 80% stoichiometric air. This causes the volatile fraction of the waste to be vaporized by the exothermic heat provided by the oxidation of the fixed carbon fraction. Complete combustion of the pyrolyzed waste is then obtained in the second chamber by operating at significant excess air. The advantages of the controlled air incinerator include minimization of the particulate entrainment from the primary to the secondary combustion chamber and the generally compact size of the incinerator. Disadvantages include its smaller capacity due to physical limitations in feeding and transporting the waste through the incinerator.

Status: Accepted. The EPA considers incineration to be the best demonstrated accepted technology (BDAT) for the destruction and disposal of combustible hazardous and/or toxic wastes.

Science/Technology Needs: Incineration is proven technology for the disposal of combustible hazardous, toxic, and low-level radioactive mixed wastes. However, off-gas particulate emission regulations, overall stack emissions of metals, and final ash waste form leachability characteristics are general areas where applying research, development, and demonstration (RD&D) could prove to be cost-effective. The RD&D effort is both regulation and public perception driven. Understanding steady-state and upset trace emissions from incinerators (and thereby instituting mitigative feed and operational controls to reduce emissions) are other science and technology needs.

Exhibit 1.7 (continued)

INCINERATION

WPRO-108-OL

Implementation Needs: It is impractical to predict the cost of a new incinerator without having information on the incineration system design. However, it is instructional to note that the capital cost for the 30MBtu/h K-25 Site Toxic Substances Control Act (TSCA) Incinerator was \$26M (1987 dollars) and that it took 8-10 years to obtain the necessary regulatory permits for operation. The current (circa 1993) waste destruction costs at the K-25 Site TSCA incinerator are estimated to be \$6/lb of waste.

The estimated costs for an RD&D program to address some of the science and technology needs is \$5M (1992 dollars) for a three-year program.

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2. ORNL ENVIRONMENTAL MANAGEMENT PROBLEMS

2.1 DECONTAMINATION AND DECOMMISSIONING PROBLEMS

Past research and development, isotope production, and WM programs at ORNL have resulted in a significant surplus of contaminated facilities. These facilities range in size and complexity from shielded shipping casks to large experimental reactors. The programs that formerly used these facilities had both defense and nondefense sponsors.

Currently, there are 39 individual facilities awaiting decommissioning. These facilities are grouped into 17 major decommissioning projects in the D&D Program currently and 16 isotope facilities that are undergoing safe shutdown before being accepted by and turned over to the D&D Program. Section 2.1.3 describes two special-case facilities that will require D&D and whose acceptance into the ORNL D&D Program is anticipated in the future.

2.1.1 ORNL Facilities Already in D&D Program

This section briefly describes the facilities and building numbers that have already been accepted into the ORNL D&D Program.

Bldg. 3001 ORNL Graphite Reactor Building was an air-cooled, graphite-moderated and -reflected, heterogeneous, natural-uranium-fueled reactor placed in service in 1943.

Bldg. 3005 Low-Intensity Test Reactor was a water-moderated and -cooled reactor, using enriched uranium as fuel and beryllium as a reflector.

Bldg. 3042 Oak Ridge Research Reactor was a 20-MW materials testing reactor used for neutron beam experiments, isotope production, and materials irradiation.

Bldg. 3087 Oak Ridge Research Reactor Heat Exchanger was the original heat dissipation system for Oak Ridge Research Reactor.

Bldg. 3505 Metal Recovery Facility was a pilot- and small-scale production nuclear fuel reprocessing plant.

Bldg. 3506 Waste Evaporator Facility received the liquid low-level waste streams for concentration prior to final disposition by shale fracture techniques.

Bldg. 3515 Fission Product Pilot Plant was used in the fission product recovery development program for the separation of curie quantities of various radionuclides from liquid low-level waste streams.

Bldg. 3517 Fission Product Development Laboratory, Inactive Cells were used to separate kilocurie quantities of fission products from Redox- and Purex-type waste streams.

Bldg. 4507 High-Level Chemical Development Laboratory was used for studies of reactor-fuel processing.

Bldg. 7500 Homogeneous Reactor Experiment housed two experimental aqueous homogeneous reactors that were developed for nuclear power application analyses.

Bldg. 7503 Molten Salt Reactor Experiment was a single-region, unclad graphite-moderated, homogeneous-fueled reactor using a circulating fuel solution of lithium-, beryllium-, and zirconium-fluoride salts.

Bldg. 7852 Old Hydrofracture Facility was an experimental and operational plant for the injection of waste grout underground into a fractured shale formation.

Bldg. 9201-3 Mezzanine Storage Tank (Y-12) contains U, contaminated molten salt residue, and an oil residue.

Bldg. 9201-3 Coolant Salt Technology Facility (Tritium Test Loop) was used to support the development of molten salt reactor technology and specifically to study the effects of injecting tritium into a flow of boron trifluoride.

Bldg. 9201-3 Molten Salt Corrosion Loop was used to study the preparation and handling of fuel for the molten salt reactor.

Bldg. 9419-1 Decontamination Facility was used to decontaminate equipment and materials associated with the Molten Salt Reactor Experiment.

Shielded Transfer Tanks were used to ship ^{137}Cs -loaded ion exchange resins.

2.1.2 Isotope Facilities Scheduled for D&D Program

The following isotope preparation facilities are undergoing safe shutdown and will be included in the D&D Program in the near future.

Bldg. 3026-C Krypton-85 Enrichment Facility was used to develop methods of isolating fission products and to process radioisotopes for research and medical purposes.

Bldg. 3028 Alpha Powder Facility housed the Short-Lived Fission Product Processing Cells.

Bldg. 3029 Source Development Laboratory was used for ^{60}Co - and ^{137}Cs -source fabrication.

Bldg. 3030 Radioisotope Production Laboratory-C was designed for limited production and development processing of reactor-produced beta-/gamma-emitting radioisotopes for industrial, medical, and research applications.

Bldg. 3031 Radioisotope Production Laboratory-D was designed for limited production and development processing of reactor-produced beta-/gamma-emitting radioisotopes for industrial, medical, and research applications.

Bldg. 3033 Radioactive Gas Processing Facility houses the tritium and krypton production facility and was used to process gaseous isotopes.

Bldg. 3033-A Actinide Fabrication Facility was used for the preparation and distribution of highly enriched actinide isotopes.

Bldg. 3038 Isotope Research Materials Laboratory was constructed to house all the radioisotope shipping activities for ORNL.

Bldg. 3047 Radioisotope Development Laboratory handled ^{60}Co , ^{152}Eu , ^{154}Eu , ^{153}Gd , ^{14}C , and other alpha and beta/gamma isotopes.

Bldg. 3093 Storage Cubicle for Krypton was used to support the gaseous isotopes production processes.

Bldg. 3099 Storage Pad is a concrete pad used for temporary storage of prepackaged shipments, casks, and other materials.

Bldg. 3118 Radioisotope Production Laboratory-H is basically a storage shed covering the rear-entry doors to the hot cells in Bldgs. 3030 and 3031.

Bldg. 3517 Fission Products Development Laboratory kilocurie quantities of fission products from Redox- and Purex-type waste streams were separated here.

Bldg. 7025 Tritium Target Facility housed a tritium target fabrication system and produced titanium tritide accelerator targets and used to prepare metallurgical samples for helium embrittlement studies related to fusion energy materials research.

2.1.3 ORNL Special-Case Facilities

The D&D project intends to perform D&D of Bldgs. 3019-A and -B together when they are introduced into the D&D Program.

Bldg. 3019-A Radiochemical Development Facility was the first U.S. production plant for actinide separations. It is used for dispensing and storing fissile material and for radiochemical process experimentation and development.

Bldg. 3019-B High-Level-Radiation Analytical Facility was used for separating, processing, and analyzing highly radioactive samples.

2.1.4 Summary of Contaminants

Outstanding characteristics of the contaminants in a selection of these facilities are summarized in Table 2.1.

Table 2.1. Outstanding characteristics of contaminants

Facility	Highest contamination	Location	Contaminants
Bldg. 3001 ORNL Graphite Reactor	2-4 R/h	Surfaces, reactor core, duct work, process piping, and equipment	Fission products and traces of plutonium, ^{14}C , ^{55}Fe , ^{137}Cs , ^{90}Sr , and ^{60}Co
Bldg. 3005 Low-Intensity Test Reactor	200-300 R/h	Interior surfaces of reactor tank and primary water piping	Corrosion products and long-lived fission products
Bldg. 3042 Oak Ridge Research Reactor	>50,000 R/h	Surfaces, reactor core, process piping, and equipment	Primarily ^{60}Co , ^{137}Cs , and ^{90}Sr
Bldg. 3505 Metal Recovery Facility	600 mrad/h 2.5×10^6 dpm/100 cm ²	Cell walls and floors	Most likely ^{137}Cs and ^{238}Pu
Bldg. 3508 Waste Evaporator Facility	1-10 mrad/h 1,350 dpm/100 cm ² transferable 11,400 dpm/100 cm ² transferable	Valve pit, piping, and some surfaces	^{137}Cs and ^{90}Sr
Bldg. 3515 Fission Product Pilot Plant	1-100 R/h (prior to entombment)	Entombed in concrete (surfaces, piping, valving, and controls)	Primarily ^{137}Cs and ^{90}Sr and possibly Ce and Ru
Bldg. 3517 Fission Products Development Laboratory	10-10,000 R/h	Cell surfaces, process equipment, and piping	Primarily ^{137}Cs and ^{90}Sr ; also ^{144}Ce and ^{147}Pm
Bldg. 4507 High-Level Chemical Development Laboratory	2.5×10^8 dpm/100 cm ²	Cell surfaces and equipment	Transuranic materials and fission products
Bldg. 7500 Homogeneous Reactor Experiment	600 R/h 32,000 dpm/100 cm ² (max)	Cell walls, equipment surfaces, and process piping	Primarily ^{90}Sr , ^{137}Cs , and other fission and corrosion products

Table 2.1 (continued)

Facility	Highest contamination	Location	Contaminants
Bldg. 7503 Molten Salt Reactor Experiment	2200 R/h	Reactor vessel, fuel storage cells, process piping, and equipment	Primarily ^{60}Co and other fission products
Bldg. 7852 Old Hydrofracture Facility	8 R/h (max)	Surfaces, equipment, and piping	Fission products, ^{137}Cs , ^{90}Sr , and ^{60}Co
Bldg. 9201-3 Coolant Salt Technology Facility	1.0×10^6 dpm/100 cm^2 (max) 1,000 dpm/100 cm^2 transferable 3,500 dpm/100 cm^2 fixed	Interior of flow system (pumps, tanks, valves, and piping)	Tritium
Bldg. 9201-3 Molten Salt Corrosion Loop	50,000 dpm/100 cm^2 (max) 1,200 dpm/100 cm^2 transferable 3,500 dpm/100 cm^2 fixed	Interior of fuel handling cell and support equipment	^{233}U , ^{228}Th , and low levels of transferable Be
Bldg. 9419 Decontamination Facility	Low levels of alpha	Surface	Tritium
Shielded transfer tanks	2-400 mrad/h	Surface	^{137}Cs
3000-gal Glass Lined Storage Tank in Bldg. 9201-3	4,000 dpm/100 cm^2	Surface	U, Th, Oil

2.2 REMEDIAL ACTION PROBLEMS

2.2.1 Waste Area Groupings

The concept of Waste Area Groupings (WAGs) was developed to facilitate the investigation of potential sources of releases to the environment. Each WAG represents distinct, small EM drainage areas that may encompass multiple sources of contaminants.

WAG 1 includes all the operating R&D facilities located within the main security fence at the ORNL X-10 Site.

WAG 2 represents the major drainage system for ORNL of White Oak Creek and its tributaries and includes the associated floodplain and subsurface. WAG 2 consists of two sites: one is the area encompassed by the stream channels of White Oak Creek and Melton Branch and the other includes White Oak Lake, White Oak Dam, and the embayment leading into the Clinch River and Fort Loudon Lake.

WAG 3 includes Solid Waste Storage Area (SWSA) 3, the closed scrap metal area, and the current operating contractors' landfill.

WAG 4 consists of three sites: the low-level waste line north of Lagoon Road, pilot pits 1 and 2, and SWSA 4. Waste from sources outside ORNL accounts for about half of the waste buried in SWSA 4.

WAG 5 consists of SWSA 5 and SWSA 5 North, two liquid low-level waste line-leak sites, an old landfill, the process waste sludge basin, and the surface facilities constructed in support of both Old and New Hydrofracture Facilities.

WAG 6 includes SWSA 6, covering 28 ha (68 acres), is the only operating low-level waste disposal site at ORNL.

WAG 7 is comprised of seven pits and trenches used for disposal of liquid low-level waste, a decontamination facility, three leak sites, a storage area containing shielded transfer tanks and other equipment, and seven fuel wells containing the acid solutions of enriched uranium fuel and fission products from the Homogeneous Reactor Experiment.

WAG 8 consists of reactor facilities and associated tank and piping systems, six leak sites and an old transfer line, five surface impoundments, a contractor spoils area, and RCRA-permitted hazardous waste storage facilities.

WAG 9 includes the Homogeneous Reactor Experiment, the Homogeneous Reactor Experiment pond, low-level waste collection and storage tanks, a septic tank, waste evaporator and associated pit, and several miscellaneous sites.

WAG 10 consists of the injection wells and grout sheets from four injection sites used to dispose of ORNL's liquid low-level waste. The grout sheets are located at depths of 90 to 300 m (300 to 1,000 ft) below the ground surface. WAG 10 lies under WAG 5.

WAG 11 was used to store contaminated materials from the Oak Ridge Research Reactor.

WAG 13 is a 50-acre area that consists of the ¹³⁷Cs Contaminated Field and the ¹³⁷Cs Erosion/Runoff Study Area.

WAG 17 sites are all tanks that have the capacity of 39,000 gal of domestic sewage, ~13,000 gal of waste oil, and 5,000 gal of photographic wastes. Also, there are four underground tanks (capacity ~31,000 gal) used for diesel fuel and gasoline, and one 4,000-gal aboveground waste oil tank.

2.2.2 Remedial Action Problem Areas

For purposes of the TLD, environmental contamination in the ORNL WAGs has been grouped into problem areas according to source and media and include the following:

1. buried wastes,
2. pits and trenches,
3. tanks,
4. impoundments,
5. pipelines,
6. hydrofracture,
7. soil and sediments, and
8. groundwater/surface water.

These groupings reflect the results of program planning (e.g., Life Cycle Baselines and WAG 5 Remedial Investigation) that has addressed RA activities through currently anticipated site remediation. The anticipated types of remediation are technology based and incorporate present understanding of the general types of contaminant releases from the ORNL WAGs. Considerable data exists from past research and monitoring of various WAGs, and the known contaminants are listed in Table 2.2. Limited data is available concerning the sources of contamination, especially in the burial grounds. Ongoing investigations are currently under way to define the nature and extent of the contamination at WAGs 1, 2, and 5.

Table 2.2. Contaminants known or suspected to have been released from each ORNL WAG

WAG	Contaminants ^a
1	⁶⁰ Cr, ⁹⁰ Sr, ¹³⁷ Cs, ¹⁵² Eu, ²³² Th, ²³⁵ U, ²³⁹ Pu, ²⁴¹ Am, ²⁴⁴ Cm, other radionuclides, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Zn, trichloroethylene, polychlorinated biphenyls, chlordane
3	³ H, ⁹⁰ Sr, ¹³⁷ Cs, TRE
4	³ H, ⁶⁰ Co, ⁹⁰ Sr, ¹⁰⁶ Ru, ¹³⁷ Cs, ²³⁹ Pu, other radionuclides, trichloroethylene
5	³ H, ⁶⁰ Co, ⁹⁰ Sr, ¹³⁷ Cs, ²³³ U, ²³⁹ Pu, ²⁴¹ Am, ²⁴⁴ Cm, other radionuclides, Cr, Hg, Ni, Pb, Zn, polychlorinated biphenyls
6	³ H, ¹⁴ C, ⁶⁰ Co, ⁹⁰ Sr, ¹³⁷ Cs, ¹⁵² Eu, ²³⁵ U, Cr, Cu, Hg, Mo, Ni, Pb, Zn, volatile organic compounds, nitrates
7	³ H, ⁶⁰ Co, ⁹⁰ Sr, ⁹⁹ Tc, ¹⁰⁶ Ru, ¹³⁷ Cs, ²³³ U, Cr, Ni, Zn, nitrates
8	⁶⁰ Co, ⁹⁰ Sr, ¹³⁷ Cs, Cr, Cu, Zn
9	⁶⁰ Co, ⁹⁰ Sr, ¹³⁷ Cs, Cr, Zn
10	⁹⁰ Sr, ¹³⁷ Cs, ²⁴⁴ Cm, transuranic isotopes
13	¹³⁷ Cs
17	¹³⁷ Cs, Cd, Cr, Cu, Zn, fuel-derived hydrocarbons, and solvents

^aBased primarily on data in ORNL RCRA Facility Investigation (unpublished) and environmental data packages for each WAG.

2.3 WASTE MANAGEMENT PROBLEMS

Because ORNL is a multipurpose research facility, it handles numerous chemicals in pursuit of its missions. Because of the nature of its operations, the wastes generated are often small in quantity (volume or mass) but numerous. Sections below provide synopses of the current WM activities at ORNL. This summary was extracted from *Oak Ridge National Laboratory Waste Management Plan*.¹

WM operations are activities that minimize, treat, store, recycle, or dispose of all radioactive, hazardous, mixed, and sanitary wastes generated as a result of operations at active and inactive facilities. Routine WM operations at ORNL are the direct responsibility of the Waste Management and Remedial Action Division. Table 2.3 shows the quantities of solid waste generated and handled at ORNL during FY 1991 and FY 1992. In addition to newly generated wastes, significant quantities of transuranic waste and some solid low-level waste and mixed waste from past operations have been placed in long-term storage.

Table 2.3. Quantities of solid waste generated and handled at ORNL

Waste stream	FY 1991	FY 1992
Radioactive		
• Transuranic waste	8 m ³ (297 ft ³)	23 m ³ (814 ft ³)
• Low-level waste	1,952 m ³ (69,711 ft ³)	2,783 m ³ (99,394 ft ³)
Hazardous	106,343 kg (234,447 lb)	81,902 kg (180,563 lb)
Mixed	22,633 kg (49,898 lb)	19,538 kg (43,074 lb)
Sanitary	13,300 m ³ (474,984 ft ³)	10,310 m ³ (368,199 ft ³)

2.3.1 Radioactive-Waste Management

Transuranic waste (solid transuranic and transuranic-mixed wastes) are stored in various facilities in the north area of SWSA 5. Sludges are stored in the Melton Valley storage tanks and other active and inactive tanks in the Liquid Low-Level Waste System at ORNL.

Solid low-level waste was disposed of on site by shallow land burial in unlined trenches and auger holes from 1969 to 1986.

Solid special-case waste requires special management and disposal strategies. The exact segregation, storage, and disposal requirements for various categories of the special case waste at ORNL have yet to be determined.

Liquid low-level waste are handled and processed by two systems: the Liquid Low-Level Waste System and the Process Waste System.

Process waste solutions generated by various program activities throughout ORNL are collected into central holding tanks and processed through the Process Waste Treatment Plant. In April 1990, the Nonradiological Wastewater Treatment Plant began polishing the Process Waste Treatment Plant effluent and other ORNL process-waste streams before releasing to White Oak Creek.

Gaseous waste is produced in three general types of radioactive air streams at ORNL—process off-gas streams; cell ventilation air streams; and laboratory hoods and individual vents that provide controlled ventilation for laboratory-type operations or exhaust from vessels that are vented through appropriate pollution control devices at the source location.

2.3.2 Hazardous-Waste Management

At ORNL, hazardous wastes include those regulated by the Resource Conservation and Recovery Act (RCRA) or the Toxic Substances Control Act (TSCA), special sanitary wastes, and other wastes identified by ORNL as unacceptable hazards to personnel or to the environment if improperly managed.

Solid- and liquid-hazardous wastes and gaseous (containerized) waste are managed as solid wastes by ORNL because they are considered solid wastes by the Environment Protection Agency and the Tennessee Department of Environment and Conservation (TDEC).

Gaseous-hazardous waste management currently involves the venting of compressed gases to the atmosphere at a remote site (i.e., away from inhabited areas).

2.3.3 Mixed-Waste Management

Mixed waste contains both hazardous and radioactive components. No on-site treatment of mixed waste is available at this time. Until treatment methods become available, these wastes must be stored on site.

2.3.4 Sanitary-Waste Management

Sanitary wastes at ORNL include both solid and liquid wastes.

Solid-sanitary waste is neither treated nor stored at ORNL because no facilities exist for handling solid-sanitary waste. The majority of ORNL sanitary waste is now disposed of in Sanitary Landfill Facility II south of the Y-12 Plant. ORNL has established recycling programs for white paper, cardboard, and aluminum beverage containers.

Liquid-sanitary waste includes nonradioactive waste streams that are discharged, either directly or following treatment, to White Oak Creek.

2.4 TECHNOLOGY RANKINGS

The technologies that were evaluated and ranked for each of the EM problems are tabulated in this chapter for D&D, RA, and WM. The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1-5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site. This is expressed in number of years and depends on the current state of its development.
- The demonstration cost for bringing the technology from its present state to large-scale commercial demonstration and use. The costs are presented as \$M or \$K, which indicate millions or thousands of dollars without escalation.
- Projected unit processing cost for mature technology (\$ per ft² or other unit or N for no estimate). This includes annual ranking costs for software.

An example of a ranking follows:

H-5-5 (\$3.5M;N)

This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of \$3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

2.4.1 Ranking Tables

Technologies that were evaluated for the TLD are listed in summary form in this section. The technologies and their rankings are arranged as follows:

- Characterization (for D&D, RA, and WM), Table 2.4.
- Robotics/automation (for D&D, RA, and WM), Table 2.5.
- Dismantlement rankings, Table 2.6.
- Decontamination, Table 2.7.
- Remedial action, Table 2.8.
- Waste processing, packaging, and handling, Tables 2.9-2.12. (Rankings are given only for technologies that are applicable.)

Table 2.4. Rankings of characterization technologies

Data sheet code number	Technology	D&D	RA	WM
		Ranking ^a		
Generally applicable to all D&D, RA, and WM problem areas				
Sampling design				
CHAR-252-OL	Sequential sampling plans	M-3-5 (\$.1M; \$.5Kam) ^b	M-3-5 (\$.1M; \$.0.5Kam)	M-3-5 (\$0.1; \$.5Kam)
CHAR-71-OL	Optimization of sampling designs	H-5-5 (\$.1M;N)	H-5-5 (\$.1M;N)	H-5-0.5 (\$0.1M;N)
CHAR-228-OL	Sampling program configuration management system	E-5-1 (\$.5M; \$50Kam)	E-5-1 (\$0.5M; \$50Kam)	E-5-1 (\$.5M; \$50Kam)
Sample collection				
CHAR-20-OL	Ultrasonic extraction	M-4-1 (\$.2M; \$400/sample)		M-4-1 (\$.2M; \$400/sample)
CHAR-62-OL	Vacuum-assisted reverse flow, solvent extraction methods	M-4-2 (\$.4M;N)		M-4-2 (\$.4M;N)
CHAR-81-OL	Sampling and mixing methods	E-5-1 (\$.2M;N)	E-5-1 (\$.25M;N)	E-4-1 (\$.25M;N)
CHAR-83-OL	Punch cores	H-5-1 (\$.3M;N)		
CHAR-210-OL	In situ solid-phase micro-extraction of organics		H-5-1 (\$.25M; \$200/sample)	H-4-1 (\$.25M; \$200/sample)
CHAR-82-OL	Wells and punch sources	H-5-1 (\$.3M;N)	H-5-1 (\$.3M;N)	H-5-1 (\$.3M;N)
CHAR-67-OL	Metallographic sectioning and sample preparation	H-4-0 (\$0; <\$500/sample)	M-4-0 (\$0; <\$500/sample)	
CHAR-64-OL	Multi-angle drilling for depth profiling	H-4-1 (\$.2M;N)	M-4-1 (\$.2M;N)	M-4-1 (\$.2M;N)
CHAR-254-OL	Solid sorbent sampling for airborne organics		H-5-1 (\$.2M; \$50/sample)	H-4-1 (\$.2M; \$50/sample)
CHAR-55-OL	Membrane technology for sample collection and concentration		M-5-1 (\$.25M; \$50/sample)	M-4-1 (\$.25M; \$50/sample)
CHAR-271-OL	Sampling interface system for surface contamination by organics	H-4-3 (\$.775M;N)		M-4-3 (\$.775M;N)
CHAR-87-OL	Laser/flashlamp heating to release or desorb surface contaminants	H-4-2 (\$.5M;N)		
CHAR-86-OL	Laser ablation for diagnosing metals and radionuclides	H-4-2 (\$.5M;N)		
CHAR-270-OL	Sampling of heterogeneous wastes		H-5-3 ((\$2.8M;N)	H-4-3 (\$2.8M;N)
CHAR-257-OL	Sampling storage tanks for volatile organics		H-5-1 (\$.26M; \$500/sample)	H-4-1 (\$.26M; \$500/sample)

Table 2.4 (continued)

Data sheet code number	Technology	Ranking ^a		
		D&D	RA	WM
Sample collection (continued)				
CHAR-256-OL	Soil/sediment sampling for volatile organics		H-4-1 (\$1M;\$50/sample)	
CHAR-276-OL	Sediment sampling		M-5-2 (\$45M;N)	M-4-2 (\$45M;N)
Sample preparation				
CHAR-205-OL	Radioactive sample preparation	H-4-1 (\$1M;N)	H-4-1 (\$1M;N)	H-4-1 (\$1M;N)
CHAR-208-OL	Supercritical fluid extraction of organics	H-4-1 (\$33M;\$100/sample)	M-5-1 (\$33M;\$100/sample)	M-3-1 (\$33M;\$100/sample)
CHAR-201-OL	Supercritical fluid extraction of inorganics	M-3-2 (\$2M;N)	M-3-2 (\$2M;N)	M-3-2 (\$2M;N)
CHAR-209-OL	Adaptation of the EPA Toxicity Characteristic Leaching Process test for use with radioactive samples	H-5-1 (\$45M;N)	E-5-1 (\$45M;N)	E-4-1 (\$45M;N)
CHAR-19-OL	Microwave digestion	H-5-1 (\$2M;\$100/sample)	H-5-1 (\$2M;\$100/sample)	H-4-1 (\$2M;\$100/sample)
CHAR-203-OL	Sample preparation: high pressure ashing	H-4-1 (\$1M;N)	H-4-1 (\$1M;N)	H-4-1 (\$1M;N)
CHAR-64-OL	Metallographic sectioning and sample preparation		M-4-0 (\$0;\$500/sample)	M-4-0 (\$0;<\$500/sample)
Detection/measurement—field methods				
CHAR-25-OL	Fiber optic chemical sensors	H-5-1 (\$1M;\$10/sample)	H-5-1 (\$1M;\$10/sample)	H-4-1 (\$1M;\$10/sample)
CHAR-264-OL	Ion mobility mass spectrometry	M-5-2 (\$1M;\$50/sample)	M-5-2 (\$1M;\$50/sample)	M-4-2 (\$1M;\$50/sample)
CHAR-23-OL	Environmental immunoassay detection	H-5-3 (\$1M;\$50/sample)	H-5-3 (\$1M;\$50/sample)	H-4-3 (\$1M;\$50/sample)
CHAR-84-OL	Raman scattering spectroscopy	M-5-2 (\$1M;\$10/sample)	M-5-2 (\$1M;\$10/sample)	M-4-2 (\$1M;\$10/sample)
CHAR-27-OL	Optical absorption spectroscopy	H-5-1 (\$6M;\$50/sample)	H-5-1 (\$6M;\$50/sample)	H-4-1 (\$6M;\$50/sample)
CHAR-59-OL	Air monitoring	H-5-0 (\$25M;\$500/sample)	E-5-0 (\$25M;\$500/sample)	L-4-0 (\$25M;\$500/sample)
CHAR-18-OL	Infrared spectroscopy	M-5-1 (\$5M;\$100/sample)	M-5-1 (\$5M;\$100/sample)	M-4-1 (\$5M;\$100/sample)
CHAR-52-OL	Advanced methods of personnel monitoring	H-5-1 (\$2M;N)	H-5-1 (\$2M;N)	H-4-1 (\$2M;N)
CHAR-10-OL	Electrochemical methods	M-4-2 (\$5M;\$100/sample)	M-4-2 (\$5M;\$100/sample)	M-4-2 (\$5M;\$100/sample)
CHAR-92-OL	Luminescence detection in the field	M-5-1 (\$5M;\$10/sample)	M-5-1 (\$5M;\$10/sample)	M-4-1 (\$5M;\$10/sample)
CHAR-15-OL	Laser photoacoustic spectroscopy	M-5-2 (\$4M;N)		

Table 2.4 (continued)

Data sheet code number	Technology	Ranking ^a		
		D&D	RA	WM
Detection/measurement—field methods (continued)				
CHAR-60-OL	Tomographic seismic monitoring	M-5-N (N:N)		
CHAR-123-OL	Ultrasonic ranging and data system	H-5-0 (\$0:N)		
CHAR-124-OL	Ground-penetrating radar	H-5-0 (\$:03M:N)		
CHAR-125-OL	Electrical and electromagnetic methods	H-5-1 (\$:2M:N)		
CHAR-126-OL	Seismic methods (retraction, profiling, reflection)	M-5-1 (\$:2M:N)		
CHAR-127-OL	Microgravity methods	M-5-1 (\$:2M:N)		
CHAR-128-OL	Magnetics	M-5-1 (\$:2M:N)		
Detection/measurement—laboratory methods				
CHAR-204-OL	Contamination control: analytical equipment	H-5-2 (\$:5M:N)	H-5-2 (\$:5M:N)	H-5-2 (\$:5M:N)
CHAR-8	Fourier transform infrared spectroscopy	M-4-1 (\$:2M;\$100-\$500/sample)	M-5-1 (\$:2M;\$50-\$500/sample)	M-4-1 (\$:2M;\$50-\$500/sample)
CHAR-48-OL	Isotopic dilution mass spectroscopy	H-4-0 (\$0;\$100-\$1000/sample)	M-5-0 (\$0;\$100-\$1000/sample)	M-4-0 (\$0;\$100-\$1000/sample)
CHAR-11-OL	Nuclear magnetic resonance	M-4-0 (\$0;\$200-\$500/sample)	M-5-1 (\$:2M;\$200-\$500/sample)	M-4-1 (\$:2M;\$200-\$500/sample)
CHAR-3-OL	Secondary ion mass spectrometry	H-4-0 (\$0;\$50-\$400/sample)	H-5-0 (\$0;\$400/sample)	H-4-0 (\$0;\$400/sample)
CHAR-9-OL	Ultraviolet/visible spectroscopy	H-5-0 (\$:1M;\$50-\$200/sample)	H-5-0 (<\$:1M;\$50-\$200/sample)	H-4-0 (<\$:1M;\$50-\$200/sample)
CHAR-4-OL	Laser ionization mass spectrometry	M-4-0 (\$0;\$100/sample)	M-5-0 (\$0;\$300-\$500/sample)	M-4-1 (\$:25M;\$300-\$500/sample)
CHAR-10-OL	Electrochemical methods	M-4-1 (\$:25M;>\$100/sample)		
Data analysis/management				
CHAR-221-OL also DISM-152-OL	Network architecture with integrated workstations	E-5-1 (\$:5M;\$50Kam)	E-5-1 (\$5M;\$60Kam)	E-5-1 (\$:5M;\$60Kam)
CHAR-253-OL	Spatial sample and data analysis	H-3-5 (\$:1M;\$:5Kam)	H-3-5 (\$:1M;\$:5Kam)	H-3-0-5 (\$:1M;\$:5Kam)
CHAR-251-OL	Statistical methods for the analysis of large data sets	M-3-3 (\$:5M;\$:5Kam)	M-3-3 (\$:5M;\$:5Kam)	M-3-3 (\$:5M;\$:5Kam)
CHAR-250-OL	Quality control for measurement process	E-4-25 (\$:05M;\$:5Kam)	E-4-25 (\$:05M;\$:5Kam)	E-4-25 (\$:05M;\$:5Kam)
CHAR-249-OL	Analysis of censored data	H-4-25 (\$:05Kam)	H-4-25 (\$:05M;\$:5Kam)	H-4-25 (\$:05M;\$:5Kam)

Table 2.4 (continued)

Data sheet code number	Technology	Ranking ^a		
		D&D	RA	WM
Data analysis/management (continued)				
CHAR-44-OL	Critically indices	L-2-1 (\$.25M;N)	L-2-1 (\$.25M;N)	L-2-1 (\$.25M;N)
CHAR-53-OL	Migration of volatile organics in porous materials	M-4-1 (\$.2M;N)	M-4-1 (\$.2M;N)	M-4-1 (\$.25M;N)
CHAR-241-OL	Task scheduling aids	M-4-1 (0.5M;N)	E-5-1 (\$.5M;\$80Kam)	E-5-1 (\$.5M;\$80Kam)
CHAR-49-OL	Tc geochemistry	L-1-2 (\$.5M;N)	L-1-2 (\$.5M;N)	L-1-2 (\$.5M;N)
CHAR-225-OL	Use of fractals to model/analyze material transport in porous material	M-2-2 (\$.5M;\$20Kam)	M-2-2 (\$.5M;\$20Kam)	
DISM-151-OL	Project information access services	E-5-1 (\$.5M;\$100Kam)	E-5-1 (\$.5M;\$100Kam)	E-5-1 (\$.5M;\$100Kam)
DISM-153-OL	Client/server access to standards and regulatory guidelines	E-5-0.5 (\$.25M;\$25Kam)	E-5-0.5 (\$.25M;\$25Kam)	E-5-1 (\$.5M;\$60Kam)
DISM-154-OL	Data access services	E-5-1 (\$.5M;\$200Kam)	E-5-1 (\$.5M;\$200Kam)	E-5-.5 (\$.25M;\$25Kam)
DISM-181-OL	Geographic information system of DOE sites	E-5-1 (\$1M;\$200Kam)	E-5-1 (\$1M;\$200Kam)	E-5-1 (\$1M;\$200Kam)
DISM-155-OL	Automated scanning and conversion of engineering drawings	E-5-2 (\$2M;\$300Kam)	E-5-2 (\$2M;\$300Kam)	E-5-1 (\$1M;\$200Kam)
DISM-171-OL	Simulated walkthrough facility for robotics task sequence analysis	E-5-1 (\$.3M;\$60Kam)	E-5-1 (\$.3M;\$60Kam)	E-5-2 (\$2M;(\$300Kam)
CHAR-233-OL	Hazard analysis expert system	E-5-2 (\$.5m;\$150Kam)	E-5-2 (\$.5m;\$150Kam)	E-5-2 (\$.5M;\$150Kam)
CHAR-234-OL	Application of approximate reasoning to data analysts/evaluation	E-5-2 (\$.5M;\$150Kam)	E-5-2 (\$.5M;\$150Kam)	E-5-2 (\$.5M;\$150Kam)
DISM-191-OL	Computer-based training systems	E-5-1 (\$.3M;\$100Kam)	E-5-1 (\$.3M;\$100Kam)	E-5-2 (\$.5M;\$150Kam)
DISM-172-OL	Computer-aided task analysis and procedure preparation	E-5-1 (\$.5M;\$150Kam)	E-5-1 (\$.5M;\$150Kam)	E-5-2 (\$.5M;\$150Kam)
DISM-157-OL	Client/server/architecture for database access	E-5-1 (\$.5M;\$200Kam)	E-5-1 (\$.5M;\$200Kam)	E-5-1 (\$.3M;\$60Kam)
DISM-158-OL	Hypertext information systems	E-5-1 (\$.3M;\$150Kam)	E-5-1 (\$.3M;\$150Kam)	E-5-1 (\$.3M;\$100Kam)
CHAR-222-OL	Multi-sensor fusion measurement system		H-3-1 (\$.5M;\$25/measurement)	
CHAR-223-OL	Detection and measurement system with feature extraction		M-4-2 (\$1M;\$1/image scanned)	

Table 2.4 (continued)

Data sheet code number	Technology	Ranking ^a		
		D&D	RA	WM
Data analysis/management (continued)				
CHAR-229-OL	Remediation activities configuration management system		E-5-1 (\$.5M;\$50Kam)	E-5-1 (\$.3M;\$150Kam)
CHAR-242-OL	Stored material neural net identification system		E-5-2 (\$1M;\$100/ container analyzed)	E-5-2 (\$1M;\$100/ container analyzed)
CHAR-45-OL	Subsurface complexation			
CHAR-255-OL	Dynamic modeling		H-5-2 (\$.3M;\$10Kam)	
DISM-159-OL	Electronic access to site history information needed to support environmental restoration activities at DOE sites		E-5-2 (\$2M;\$150Kam)	
CHAR-260-OL	Integrated microprocessor/sensor monitoring system for radioactive waste storage containers			H-5-1 (\$.5M;\$50/ sensor unit installed)
CHAR-230-OL	Waste management configuration management system			E-5-1 (\$.5M;\$25Kam)
CHAR-240-OL	Intelligent materials systems	M-4-3 (\$3M;\$1K/container)		M-4-3 (\$3M;\$1000/ container fabricated)
DISM-156-OL	3-D CAD data base of buildings and other structures	E-5-2 (\$2M;\$300Kam)		E-5-2 (\$2M;\$300Kam)
DISM-173-OL	Application of generalized object-oriented simulation software to process system design and operation	E-3-2 (\$.5M;\$200Kam)		E-3-2 (\$.5M;\$200Kam)
DISM-174-OL	Automated support for engineered system life-cycle planning	E-5-1 (\$.3M;\$60Kam)		E-5-1 (\$.3M;\$60Kam)
DISM-175-OL	Automated support for system reliability and safety analysis	E-5-2 (\$.5M;\$150Kam)		E-5-2 (\$.5M;\$150Kam)
Radioactive elements—field methods				
CHAR-108-OL	Proportional counter for α , β activity	H-5-0 (\$.1M;\$100/sample)	H-5-0 (\$.1M;\$100/sample)	H-5-0 (\$.1M;\$100/sample)
CHAR-102-OL	In situ passive monitors for surface contamination by weak β radionuclides	M-4-2 (\$.6M;\$20/sample)	M-4-2 (\$.6M;\$20/sample)	M-4-2 (\$.6M;\$20/sample)
CHAR-103-OL	Thin 2-dimensional TLD array for spatial characterization of surface α -contamination	M-4-3 (\$.6M;\$20/sample)	M-4-3 (\$.6M;\$20/sample)	M-4-3 (\$.6M;\$20/sample)

Table 2.4 (continued)

Data sheet code number	Technology	Ranking ^a		
		D&D	RA	WM
Radioactive elements—field methods (continued)				
CHAR-65-OL	Small long-range alpha detector	M-4-1 (\$4M;\$100/sample)	M-4-1 (\$4M;\$100/sample)	M-4-1 (\$4M;\$100/sample)
CHAR-263-OL	Portable gamma ray scintillometers	H-4-0 (\$0;\$100/sample)	H-4-0 (\$0;\$100/sample)	H-4-0 (\$0;\$100/sample)
CHAR-269-OL	Advanced radiation monitors	M-4-2 (\$4M;\$50/sample)	M-4-2 (\$4M;\$50/sample)	M-4-2 (\$4M;\$50/sample)
CHAR-216-OL	Bubble dosimeters for neutron flux	M-4-1 (\$2M;\$15/sample)	M-4-1 (\$2M;\$15/sample)	M-4-1 (\$2M;\$15/sample)
CHAR-105-OL	³ H/β/γ floor scanner	H-4-0 (\$0;N)		
CHAR-109-OL	Waste drum γ activity monitor			M-4-0 (\$0;\$200/sample)
CHAR-218-OL	Screening waste drums for fissile material			M-4-1 (\$4M;\$800/drum)
CHAR-95-OL	Electret passive surface monitor	H-4-1 (\$3M;\$15/sample)	H-4-1 (\$3M;\$15/sample)	
CHAR-96-OL	Alpha track etch detectors for surface alpha contamination	H-4-1 (\$4M;\$10/sample)	H-4-1 (\$4M;\$10/sample)	H-4-1 (\$4M;\$10/sample)
Radioactive elements—laboratory methods				
CHAR-107	Neutron activation	H-4-1 (\$2M;\$300/sample)	H-4-1 (\$2M;\$300/sample)	H-4-1 (\$2M;\$300/sample)
CHAR-266-OL	Neutron activation analysis	H-4-1 (\$2M;\$300/sample)	H-4-1 ((\$2M;\$300/sample)	H-4-1 (\$2M;\$300/sample)
CHAR-106-OL	NaI-Ge γ-Spec	H-4-0 (\$0;N)	H-4-0 (\$0;N)	M-4-0 (\$0;N)
CHAR-104-OL	Passive neutron detection			H-4-2 (\$1M;N)
CHAR-202-OL	Upgrade of radioanalytical procedures	H-4-2 (\$1M;N)	H-4-2 (\$1M;N)	H-5-0 (\$1M;\$100/sample)
CHAR-108-OL	Proportional counter for α, β activity	H-5-0 (\$1M;\$100/sample)	H-5-0 (\$1M;\$100/sample)	H-4-0 (\$0;N)
CHAR-97-OL	Photon-electron rejecting alpha liquid scintillation	H-4-0 (\$0;N)		H-5-1 (\$2M;\$100/sample)
CHAR-200-OL	Gross fissile analysis by neutron activation and delayed neutron counting	H-5-1 (\$2M;\$100/sample)	H-5-1 (\$2M;\$100/sample)	H-5-0 (\$1M;\$100/sample)
CHAR-268-OL	Gamma-ray spectrometry	H-5-0 (\$1M;\$100/sample)	H-5-0 (\$1M;\$100/sample)	H-5-0 (\$1M;\$100/sample)
CHAR-267-OL	Liquid scintillation counting	H-5-0 (\$1M;\$100/sample)	H-5-0 (\$1M;\$100/sample)	M-5-1 (\$2M;N)
CHAR-261-OL	Waste drum γ activity monitor			M-4-0 (\$0;\$200/drum)
CHAR-40-OL	Radiographic imaging	M-4-1 (N;N)		

Table 2.4 (continued)

Data sheet code number	Technology	Ranking ^a		
		D&D	RA	WM
<i>Inorganics—field methods</i>				
CHAR-76-OL	Portable atomic emission spark spectrometer	M-4-1 (\$.2M;N)	M-5-1 (\$.2M;N)	M-5-1 (\$.2M;N)
CHAR-6-OL	Field-portable X-ray fluorescence	H-5-1 (\$.2M;\$25/sample)	H-5-1 (\$.2M;\$25/sample)	H-5-1 (\$.2M;\$25/sample)
CHAR-219-OL	X-ray fluorescence for in situ monitoring of toxic heavy metals		H-5-1 (\$.2M;N)	H-5-1 (\$.2M;\$25/sample)
CHAR-111-OL	Laser ablation: inductively coupled emission plasma; atomic emission spectroscopy	H-5-3 (\$1M;N)		
<i>Inorganics—laboratory methods</i>				
CHAR-78-OL	Inductively coupled plasma-mass spectroscopy	H-4-2 (\$1M;\$200/sample)	H-4-2 (\$1M;\$200/sample)	H-4-2 (\$1M;\$200/sample)
CHAR-77-OL	Inductively coupled plasma spectroscopy	H-4-0 (\$.1M;\$200/sample)	H-4-0 (\$1M;\$200/sample)	H-4-0 (\$.1M;\$200/sample)
CHAR-76-OL	Atomic emission spectroscopy	H-4-0 (\$.1M;\$200/sample)	H-4-0 (\$1M;\$200/sample)	H-4-0 (\$.1M;\$200/sample)
CHAR-50-OL	Ion chromatography	H-4-0 (\$.1M;\$100/sample)	H-4-0 (\$.1M;\$100/sample)	H-4-0 (\$.1M;\$100/sample)
CHAR-37-OL	Electron diffraction	M-4-0 (\$0;\$100/sample)	M-4-0 (\$0;\$100/sample)	M-4-0 (\$0;\$100/sample)
CHAR-38-OL	Wavelength dispersive X-ray spectroscopy	M-4-0 (\$0;\$100/sample)	M-4-0 (\$0;\$100/sample)	M-4-0 (\$0;\$100/sample)
CHAR-35-OL	Energy dispersive X-ray spectroscopy	M-4-0 (\$0;\$100/sample)	M-4-0 (\$0;\$100/sample)	M-4-0 (\$0;\$100/sample)
CHAR-34-OL	Transmission electron microscopy	M-4-0 (\$0;\$100/sample)	M-4-0 (\$0;\$100/sample)	M-4-0 (\$0;\$100/sample)
CHAR-33-OL	Scanning electron microscopy	M-4-0 (\$0;\$100/sample)	M-4-0 (\$0;\$100/sample)	M-4-0 (\$0;\$100/sample)
CHAR-17-OL	Particle-induced X-ray emission	M-4-0 (\$0;\$100/sample)	M-4-0 (\$0;\$100/sample)	M-4-0 (\$0;\$100/sample)
CHAR-24-OL	Cold-vapor (mercury) analysts	H-4-0 (\$0;\$100/sample)	H-4-0 (\$0;\$100/sample)	H-4-0 (\$0;\$100/sample)
CHAR-266-OL	Neutron activation analysis	H-4-1 (\$.2M;\$200/sample)	H-4-1 (\$.2M;\$200/sample)	H-4-1 (\$.2M;\$200/sample)
CHAR-31-OL	Powder X-ray diffraction	M-4-0 (\$0;>\$100/sample)	M-4-0 (\$0;>\$100/sample)	M-4-0 (\$0;>\$100/sample)
CHAR-1-OL	Electron spectroscopy for chemical analysis	M-4-0 (\$0;\$200–\$600/sample)	M-4-0 (\$0;\$200–\$600/sample)	M-4-0 (\$0;\$200–\$600/sample)
CHAR-2-OL	Auger electron spectroscopy	M-4-0 (\$0;\$300–\$800/sample)	M-4-0 (\$0;\$300–\$800/sample)	M-4-0 (\$0;\$300–\$800/sample)
CHAR-56-OL	Glow discharge ionization mass spectrometry	H-4-1 (\$.5M;N)	H-4-1 (\$.5M;N)	H-4-1 (\$.5M;N)

Table 2.4 (continued)

Data sheet code number	Technology	Ranking ^a		
		D&D	RA	WM
Organics—field methods				
CHAR-100-OL	Portable gas chromatograph with electron capture detector for polychlorinated biphenyl (PCB) analysis	H-4-0 (\$.25M;\$50/sample)	H-4-0 (\$.25M;\$50/sample)	M-4-0 (\$.25M;\$50/sample)
CHAR-99-OL	PCB immunoassay kit	H-4-0 (\$.25M;\$80/sample)	H-4-0 (\$.25M;\$80/sample)	H-4-0 (\$.25M;\$80/sample)
CHAR-5-OL	Portable volatile organic compounds detectors	H-5-0 (\$.25M;\$10/sample)	H-5-0 (\$.25M;\$10/sample)	M-4-0 (\$.25M;\$10/sample)
CHAR-110-OL	Fluorescence diagnosis of contaminated surfaces	M-3-2 (\$1M;\$10/sample)		
CHAR-85-OL	Infrared absorption (laser based)	M-4-2 (\$.5M;N)		
CHAR-262-OL	Gas chromatography in the field	H-5-0 (\$.25M;\$50/sample)	H-5-0 (\$.25M;\$50/sample)	H-4-0 (\$.25M;\$50/sample)
CHAR-101-OL	Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	M-4-1 (\$.2M;<\$50/sample)	M-4-1 (\$.2M;<\$50/sample)	M-4-1 (\$.2M;<\$50/sample)
CHAR-90-OL	Direct sampling ion trap mass spectrometry	H-5-2 (\$.2M;\$50/sample)	H-5-2 (\$.2M;\$50/sample)	H-5-2 (\$.2M;\$50/sample)
Organics—laboratory methods				
CHAR-206-OL	Analytical methods for chelators and decon agents	M-3-1 (\$.25M;\$500-\$1000/sample)	H-5-1 (\$.25M;\$500-\$1000/sample)	H-4-1 (\$.25M;\$500-\$1000/sample)
CHAR-207-OL	Capillary zone electrophoresis	M-3-1 (\$.25M;\$300/sample)	M-5-1 (\$.25M;\$300/sample)	M-4-1 (\$.25M;\$300/sample)
CHAR-115-OL	On-line supercritical fluid extraction-multidetector gas chromatography	H-5-1 (\$.25M;\$300/sample)	H-5-1 (\$.25M;\$300/sample)	H-4-1 (\$.25M;\$300/sample)
CHAR-66-OL	Gas chromatography-fourier transform infrared spectroscopy	M-4-2 (\$.5M;\$400/sample)	H-5-2 (\$.5M;\$400/sample)	H-4-2 (\$.5M;\$400/sample)
CHAR-89-OL	Liquid chromatography-mass spectrometry	M-4-1 (\$.3M;\$500/sample)	H-5-1 (\$.34M;\$500/sample)	H-4-1 (\$.3M;\$500/sample)
CHAR-88-OL	Gas chromatography-mass spectrometry	E-5-0 (\$0;\$200-\$800/sample)	E-5-0 (\$0;\$200-\$800/sample)	E-5-0 (\$0;\$200-\$800/sample)
CHAR-101-OL	Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	H-5-1 (\$.2M;\$10/sample)	M-5-1 (\$.2M;\$10/sample)	
CHAR-94-OL	Gas chromatography using a multitude of detectors	H-5-0 (\$0;\$300/sample)	E-5-0 (\$0;\$300/sample)	E-5-0 (\$0;\$300/sample)
CHAR-214-OL	Screening for PCBs in decommissionable structures	H-5-1 (\$0.1M;\$40/sample)		

Table 2.4 (continued)

Data sheet code number	Technology	Ranking ^a		
		D&D	RA	WM
Organics—laboratory methods (continued)				
CHAR-93-OL	Laser ablation organic mass spectrometry	H-5-1 (\$.3M;<\$500/sample)		
CHAR-265-OL	Surface enhanced raman scattering (SERS)	H-4-1 (\$.15M;N)		
CHAR-211-OL	Solid-phase microextraction analytical method		H-5-1 (\$.3M;\$500/sample)	H-4-1 (\$.3M;\$500/sample)
CHAR-258-OL	In situ groundwater flow meter		H-5-0 (\$.4M;\$1-\$3K/sample)	
CHAR-259-OL	Pathogen surveillance		E-5-1 (\$.25M;\$50-\$250/sample)	
Physical—field methods				
CHAR-246-OL	Instrument response models for remote sensing	E-5-2 (\$.6M;\$200Kam)		E-5-2 (\$.6M;\$200Kam)
CHAR-248-OL	Fiber optic systems for measuring multiple physical variables	E-5-3 (\$1M;\$.25/sample event)		E-5-3 (\$1M; \$.25/measurement made)
CHAR-258-OL	In situ groundwater flow meter		H-5-0 (\$.4M;\$1K/well)	
CHAR-259-OL	Groundwater discharge location		H-5-0 (\$0M;\$50K/survey	
Physical—laboratory methods				
CHAR-26-OL	Particle-size analysis	M-4-0 (\$0;\$1000/sample)	M-5-0 (\$0;\$1000/sample)	M-4-0 (\$0;\$1000/sample)
CHAR-32-OL	Optical microscopy	M-4-0 (\$0;\$100-\$800/sample)	H-5-0 (\$0;\$100-\$800/sample)	M-4-0 (\$0;\$100-\$800/sample)
CHAR-58-OL	Magnetic resonance imaging	M-4-0 (\$.2M;N)		
CHAR-46-OL	Holographic imaging	M-4-0 (N;N)		
CHAR-41-OL	Computer tomography			M-4-0 (N;N)
CHAR-39-OL	Inorganic cementitious matrix composites	M-4-0 (N;N)		
CHAR-38-OL	Nondestructive testing for concrete	M-4-0 (N;N)		
CHAR-61-OL	Correlation of host matrix porosity with collection efficiency: standardized methods	H-4-0 (\$.3M;N)		
CHAR-42-OL	Radiation-induced segregation	H-4-2 (\$.5M;N)		
Pathogens—laboratory method				
CHAR-215-OL	Pathogen surveillance		E-5-1 (\$.25M;\$50-\$250/sample)	E-4-1 (\$.25M;N)

Table 2.4 (continued)

Data sheet code number	Technology	Ranking ^a		
		D&D	RA	WM
Building 9203-1, 3517, and 3019 fuel reprocessing or oil D&D, RA, and WM problem areas				
Field methods				
CHAR-85-OL	Infrared absorption (laser based)	M-3-2 (\$.5M;N)		
CHAR-05-OL	Portable volatile-organic compound detector	H-3-0 (\$.25M;\$10/sample)		
CHAR-90-OL	Direct sampling ion trap mass spectrometry	H-3-2 (\$.1M;\$50/sample)		
CHAR-15-OL	Sampling interface system for surface contamination by organics	H-3-3 (\$.775M;N)		
CHAR-262-OL	Gas chromatography in the field	H-3-0 (\$.25M;\$50)		
CHAR-18-OL	Infrared spectroscopy	M-3-1 (\$.5M;\$100/sample)		
CHAR-25-OL	Fiber optic chemical sensors	H-3-1 (\$.1M;\$10/sample)		
Laboratory methods				
CHAR-88-OL	Gas chromatography-mass spectrometry	E-3-0 (\$0;\$200-\$800/sample)		
CHAR-115-OL	On-line supercritical fluid-multidetector gas chromatography	H-3-1 (\$.25M;\$300/sample)		
CHAR-93-OL	Laser ablation organic mass spectrometry	H-3-1 (\$.3M;<\$500/sample)		
CHAR-206-OL	Analytical methods for chelators and decon agents	H-3-1 (\$.25M;\$500-\$1000/sample)		
CHAR-89-OL	Liquid chromatography-mass spectrometry	M-4-1 (\$.3M;\$500/sample)		
Building 9201-3 asbestos piping insulation PCB D&D, RA, and WM problem areas				
Field methods				
CHAR-100-OL	Portable gas chromatograph with electron capture detector for PCB analysis	H-3-0 (\$.25M;\$50/sample)		
CHAR-99-OL	PCB immunoassay kit	H-3-0 (\$.25M;\$80/sample)		
CHAR-90-OL	Direct sampling ion trap mass spectrometry	H-3-2 (\$.2M;\$50/sample)		
CHAR-15-OL	Sampling interface system for surface contamination by organics	H-3-3 (\$.775M;N)		

Table 2.4 (continued)

Data sheet code number	Technology	Ranking ^a		
		D&D	RA	WM
Field methods (continued)				
CHAR-214-OL	Screening for PCBs in decommissionable structures	H-3-1 (\$.1M;\$40/sample)		
Laboratory methods				
CHAR-94-OL	Gas chromatography using a multitude of detectors	H-3-0 (\$0;\$300/sample)		
CHAR-115-OL	On-line supercritical fluid-multidetector gas chromatography	H-3-1 (\$.25M;\$300/sample)		
Buried waste remedial action problem only				
Sample collection and field methods				
CHAR-273-OL	SEAMIST® inverted membrane		H-5-1 (\$.6M;\$15K/survey)	
CHAR-272-OL	Electromagenetic offset log survey		M-5-1 (\$.25M;\$50K/survey)	
CHAR-25-OL	Fiber optic chemical sensors		H-5-1 (\$1M;\$3.3M/survey)	
Hydrofracture remedial action problem only				
Sample collection and field methods				
CHAR-274-OL	Groundwater monitoring		H-1-2 (\$.5M;\$3.3M/analysis)	

^aThe technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as \$M or \$K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology (\$ per ft² or other unit or N for no estimate).

An example of a ranking follows: H-5-5 (\$3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of \$3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

^bKam = thousands of dollars annual maintenance

Table 2.5. Rankings of robotics/automation technologies

Data sheet code number	Technology	Ranking ^a		
		D&D	RA	WM
Mechanical—mobility				
ROBA-1-OL	Wheeled/tracked vehicles	E-5-2 (\$3M;N)	E-5-2 (\$3M;N)	E-5-2 (\$3M;N)
ROBA-5-OL	Internal-duct/pipe crawlers	M-3-2 (\$1M;N)		
ROBA-6-OL	External-duct/pipe crawlers	M-3-4 (\$5M;N)		
ROBA-7-OL	Specialized robotic deployment platforms	M-4-3 (\$5M;N)	M-4-3 (\$5M;N)	
ROBA-8-OL	Bridge-mounted robotic platforms	M-2-1 (\$5M;N)		M-2-1 (\$5M;N)
ROBA-9-OL	Long-arm deployed robotic platforms	M-4-3 (\$5M;N)	M-5-3 (\$5M;N)	
ROBA-10-OL	Power sources for mobile platforms	E-5-1 (\$0.5M;N)	E-5-1 (\$0.5M;N)	E-5-1 (\$0.5M;N)
ROBA-11-OL	Failure recovery systems for mobile platforms	E-5-1 (\$0.5M;N)	E-5-1 (\$0.5M;N)	E-5-1 (\$0.5M;N)
ROBA-12-OL	Transportation systems for mobile platforms	M-3-1 (\$0.5M;N)	M-3-1 (\$0.5M;N)	M-3-1 (\$0.5M;N)
ROBA-13-OL	Data/signal transmission	E-5-1 (\$1M;N)	E-5-1 (\$0.5M;N)	E-5-1 (\$1M;N)
Mechanical—manipulation				
ROBA-14-OL	Long-reach manipulator (light duty)	H-4-2 (\$2M;N)		
ROBA-15-OL	Long-reach manipulator (heavy duty)	M-4-3 (\$5M;N)		
ROBA-16-OL	Dexterous manipulator (single-/dual-arm configuration)	E-5-1 (\$1M;N)	E-5-1 (\$1M;N)	E-5-1 (\$1M;N)
ROBA-19-OL	Compact, high-capacity manipulators	H-5-1 (\$1M;N)	H-5-1 (\$1M;N)	E-5-1 (\$1M;N)
Mechanical—mechanisms				
ROBA-20-OL	Precise programmable motions	H-5-1 (\$0.5M;N)		H-5-1 (\$0.5M;N)
ROBA-21-OL	Tool caddies	H-4-1 (\$0.5M;N)	H-4-1 (\$0.5M;N)	H-4-1 (\$0.5M;N)
ROBA-22-OL	Stabilization/support mechanisms or booms	M-3-1 (\$0.5M;N)	M-3-1 (\$0.5M;N)	M-3-1 (\$0.5M;N)

Table 2.5 (continued)

Data sheet code number	Technology	Ranking ^a		
		D&D	RA	WM
Mechanical—end-of-arm tooling				
ROBA-23-OL	End-effectors/alternatives	E-5-2 (\$1M;N)	E-5-2 (\$1M;N)	E-5-2 (\$1M;N)
ROBA-24-OL	End-effector changeout mechanisms	M-3-1 (\$0.5M;N)	M-3-1 (\$0.5M;N)	M-3-1 (\$0.5M;N)
ROBA-25-OL	General-gripper/tool interface	H-4-1 (\$0.5M;N)	H-4-1 (\$0.5M;N)	H-4-1 (\$0.5M;N)
ROBA-26-OL	Force-limiting/compliant mechanisms	M-3-1 (\$0.5M;N)	M-3-1 (\$0.5M;N)	M-3-1 (\$0.5M;N)
Controls—algorithms				
ROBA-27-OL	Control modes	E-5-N (\$N;N)	E-5-N (\$N;N)	E-5-N (\$N;N)
ROBA-28-OL	Vehicle/mobility (driving)	E-5-1 (\$0.5M;N)	E-5-1 (\$0.5M;N)	E-5-1 (\$0.5M;N)
ROBA-29-OL	Vehicle/mobility (navigation)	M-4-1 (\$0.5M;N)	H-4-1 (\$0.5M;N)	H-4-1 (\$0.5M;N)
ROBA-30-OL	Joint control	H-4-1 (\$0.5M;N)	H-4-1 (\$0.5M;N)	H-4-1 (\$0.5M;N)
ROBA-31-OL	Cartesian control	H-4-1 (\$1M;N)	H-4-1 (\$1M;N)	H-4-1 (\$1M;N)
ROBA-32-OL	Special purpose control	H-4-2 (\$1.5M;N)	H-4-2 (\$1.5M;N)	H-4-2 (\$1.5M;N)
ROBA-33-OL	Redundancy control	M-3-2 (\$2M;N)	M-3-2 (\$2M;N)	M-3-2 (\$2M;N)
ROBA-34-OL	Combined mobility/manipulation	M-2-2 (\$1M;N)	M-2-2 (\$1M;N)	M-2-2 (\$1M;N)
ROBA-35-OL	Safety—collision avoidance	H-4-1 (\$1M;N)	H-4-1 (\$1M;N)	H-4-1 (\$1M;N)
ROBA-36-OL	Safety—load/rate limiting	H-3-1 (\$0.5M;N)	H-3-1 (\$0.5M;N)	H-3-1 (\$0.5M;N)
ROBA-37-OL	Emergency shutdown	E-4-1 (\$0.5M;N)	E-4-1 (\$0.5M;N)	E-4-1 (\$0.5M;N)
Controls—human-machine interface				
ROBA-38-OL	Console-fixed/-mobile suitcase	E-5-1 (\$0.5M;N)	E-5-1 (\$0.5M;N)	E-5-1 (\$0.5M;N)
ROBA-39-OL	Console-data handling methods	M-3-1 (\$1M;N)	M-3-1 (\$1M;N)	H-5-1 (\$1M;N)
ROBA-40-OL	Operator interface—command-input/hand controllers/voice/touch screens	H-3-1 (\$0.5M;N)	H-3-1 (\$0.5M;N)	H-3-1 (\$0.5M;N)

Table 2.5 (continued)

Data sheet code number	Technology	Ranking ^a		
		D&D	RA	WM
Controls—human-machine interface (continued)				
ROBA-41-OL	Operator interface—operator assistance	H-3-2 (\$1.5M;N)	H-3-2 (\$1.5M;N)	H-3-2 (\$1.5M;N)
ROBA-42-OL	Operator interface—status/alert system	E-5-1 (\$0.5M;N)	E-5-1 (\$0.5M;N)	E-5-1 (\$0.5M;N)
Sensors—perception				
ROBA-43-OL	Vision/aural systems	E-5-1 (\$1M;N)	E-5-1 (\$1M;N)	E-5-1 (\$1M;N)
ROBA-44-OL	Range finders	M-3-2 (\$1.5M;N)	M-3-2 (\$1.5M;N)	M-3-2 (\$1.5M;N)
ROBA-45-OL	Proximity probes	M-2-2 (\$1M;N)	M-2-2 (\$1M;N)	M-2-2 (\$1M;N)
ROBA-46-OL	Force/torque sensors	M-2-1 (\$0.5M;N)	M-2-1 (\$0.5M;N)	M-2-1 (\$0.5M;N)
ROBA-47-OL	Integration of detection sensors deployed by robotic vehicles		M-4-1 (\$1M;N)	M-4-1 (\$1M;N)
Sensors—control				
ROBA-48-OL	Position/velocity sensors	E-5-1 (\$0.5M;N)	E-5-1 (\$0.5M;N)	E-5-1 (\$0.5M;N)
ROBA-50-OL	Force/torque	H-3-1 (\$0.5M;N)	H-3-1 (\$0.5M;N)	H-3-1 (\$0.5M;N)
ROBA-51-OL	Proximity	H-3-1 (\$1M;N)	H-3-1 (\$1M;N)	H-3-1 (\$1M;N)
ROBA-52-OL	Tooling sensors	H-3-1 (\$0.5M;N)	H-3-1 (\$0.5M;N)	H-3-1 (\$0.5M;N)
Other technologies				
ROBA-53-OL	Field hardening	M-3-1 (\$0.5M;N)	E-5-1 (\$0.5M;N)	E-5-1 (\$0.5M;N)
ROBA-54-OL	Radiation hardening	E-5-2 (\$2M;N)	M-3-2 (\$2M;N)	M-3-2 (\$2M;N)
ROBA-55-OL	Integrated automated analytical laboratory	E-5-2 (\$3M;N)	E-5-2 (\$3M;N)	E-5-2 (\$3M;N)
ROBA-56-OL	Information management for sample handling	E-5-1 (\$1M;N)	E-5-1 (\$1M;N)	E-5-1 (\$1M;N)
ROBA-57-OL	Sample collection	E-5-1 (\$1.5M;N)	E-5-1 (\$1.5M;N)	E-5-1 (\$1.5M;N)
ROBA-58-OL	Characterization sensor integration	M-3-2 (\$1M;N)	M-5-2 (\$1M;N)	M-3-2 (\$1M;N)

Table 2.5 (continued)

Data sheet code number	Technology	Ranking ^a		
		D&D	RA	WM
Other technologies (continued)				
ROBA-59-OL	Sample preparation	E-5-1 (\$1M;N)	E-5-1 (\$1M;N)	E-5-1 (\$1M;N)

^aThe technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as \$M or \$K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology (\$ per ft² or other unit or N for no estimate).

An example of a ranking follows: H-5-5 (\$3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of \$3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

Table 2.6. Rankings of dismantlement technologies

Data sheet code numbers	Technology	Ranking ^a
Massive containment		
DISM-11-OL	High-pressure abrasive water jet	H-5-5 (\$5.5M;\$10/ft ²)
DISM-12-OL	Diamond wire cutting	M-5-5 (\$3.5M;\$100/ft ²)
DISM-16-OL	Deep microwave demolition	M-5-9 (\$5M;\$6/ft ²)
Reactor pools		
DISM-21-OL	High-pressure abrasive water jet	M-4-7 (\$5.5M;\$15/ft ²)
DISM-25-OL	Demolition compounds	M-4-6 (\$4M;\$90/ft ³)
DISM-28-OL	Microwave demolition	M-4-10 (\$7M;\$60/ft ²)
Buried tanks		
DISM-31-OL	High-pressure abrasive water jet	H-4-7 (\$5.5M;\$80/ft ³)
DISM-33-OL	Explosive cutting	M-4-7 (\$2.5M;\$60/ft ³)
DISM-35-OL	Demolition compounds	M-4-8 (\$4M;\$90/ft ³)
Structural—only concrete		
DISM-48-OL	Grappler	H-2-1 (\$1M;\$8/ft ³)
DISM-42-OL	Diamond wire cutting	H-2-0.5 (\$1.5M;\$10/ft ³)
DISM-44-OL	Conventional (jack hammer, headache ball, etc.)	H-2-0 (\$0M;\$20/ft ³)
DISM-41-OL	High-pressure abrasive water jet	M-2-1 (\$2M;\$10/ft ³)
DISM-46-OL	Demolition compounds	M-2-2 (\$1.5M;\$25/ft ³)
Steel structures—high-level contamination		
DISM-51-OL	Laser cutting	H-4-6 (\$2.5M;\$1000/cut)
DISM-53-OL	Abrasive water jet	H-4-3 (\$750K;\$100/h)
DISM-62-OL	Explosive cutting	H-4-3 (\$1.3M;\$12000/cut)
DISM-56-OL	Plasma arc cutting	M-4-4 (\$1M;\$1300/cut)
DISM-57-OL	Oxygen cutting	E-4-2 (\$200K;\$100/cut)
DISM-61-OL	Grapple and massive mobile shearing	E-4-1.5 (\$250K;\$250/cut)
DISM-60-OL	Conventional disassembly	E-4-2 (\$800K;\$75/bolt & \$600/cut)

Table 2.6 (continued)

Data sheet code numbers	Technology	Ranking ^a
Steel structures—low-level contamination		
DISM-72-OL	Abrasive water jet	H-2-2 (\$250K;\$100/h)
DISM-71-OL	Laser cutting	H-2-4 (\$2.5M;\$900/cut)
DISM-74-OL	Plasma arc cutting	M-2-4 (\$250K;\$600/cut)
DISM-76-OL	Conventional disassembly	E-2-1 (\$200K;\$10/bolt & \$300/cut)
DISM-77-OL	Grapple and other massive tooling	E-2-1 (\$N/A;\$150/cut)
DISM-75-OL	Oxygen cutting	E-2-N/A (\$N/A;\$150/cut)
Asbestos removal		
DISM-82-OL	Conventional/automated with vacuum system	H-3-6 (\$200K;\$30/ft ³)
DISM-84-OL	Laser cutting	H-3-3 (\$3.5M;\$50/ft ³)
DISM-83-OL	CO ₂ blasting	M-3-7 (\$3.5M;\$60/ft ³)
DISM-85-OL	High-pressure abrasive jet	M-3-6 (\$3.5M;\$50/ft ³)
Major equipment removal		
DISM-92-OL	Plasma arc cutting	H-5-4 (\$2–3.5M;\$50/ft ³)
DISM-100-OL	Advanced automatic fixtures, Bug-o, etc.	H-5-3 (\$1.5–2.5M;\$30/ft ³)
DISM-95-OL	Advanced laser cutting	H-5-5 (\$2.5–4M;\$50/ft ³)
DISM-93-OL	High-pressure water jet	H-5-4 (\$2–4M;\$40/ft ³)
DISM-90-OL	Mechanical saws	M-5-1 (\$250K;\$40/ft ³)
Entombment		
DISM-113-OL	Encasement (voids may remain)	H-4-3 (\$0.5M;\$10/ft ³)
DISM-115-OL	Engineered storage for very radioactive items (anticipating future permanent disposal)	H-4-8 (\$7M;\$400/ft ³)
DISM-118-OL	Sensors for entombment integrity	H-4-3 (\$0.8M;\$1K/sensor)
DISM-114-OL	Permanent entombment	H-4-3 (\$1M;\$15/ft ³)
DISM-112-OL	Capping	H-4-3 (\$0.5M;\$3/ft ³)

Table 2.6 (continued)

Data sheet code numbers	Technology	Ranking ^a
Needed enabling technologies		
DISM-191-OL	Computer-based training systems	H-4-1 (\$0.3M;\$100K/yr)
DISM-159-OL	Electronic catalog descriptions and source locations of site historical data	H-4-2 (\$2M;\$150K/yr)
DISM-156-OL	3-D CAD database of buildings and structures	H-4-2 (\$2M;\$300K/yr)
DISM-155-OL	Automated scanning and conversion of engineering drawings	H-4-2 (\$2M;\$300K/yr)
DISM-151-OL	Project information access service	H-4-1 (\$0.5M;\$100K/yr)
DISM-153-OL	Client/server access to standards and regulatory guidelines	H-4-1 (\$0.25M;\$25k/yr)
DISM-172-OL	Computer-aided task analysis and procedure preparation	H-4-1 (\$0.5M;\$150K/yr)
DISM-143-OL	Computer-based D&D information retrieval	H-4-2 (\$0.5M;\$300K/yr)
DISM-171-OL	Simulated walkthru facility	H-4-1 (\$0.3M;\$60K/yr)

^aThe technologies are ranked according to the following criteria:

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- A ranking of the site problem (1-5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as \$M or \$K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology (\$ per ft² or other unit or N for no estimate).

An example of a ranking follows: H-5-5 (\$3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of \$3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

Table 2.7. Rankings of decontamination technologies

Data sheet code number	Technology	Ranking ^a
Bulk decontamination methods		
DCON-1-OL	Solvent extraction	M-2-1 (<\$2M;N)
DCON-2-OL	Incineration	M-2-12 (\$30M;\$10/lb)
DCON-3-OL	Biological	L-2 (\$0;N)
DCON-4-OL	Dry heat (bulk roasting)	L-1-1 (\$2M;N)
DCON-5-OL	Chemical leaching	M-3-2 (\$1M;<\$1/ft ²)
DCON-6-OL	Catalytic extraction process	H-5-4 (\$20M;\$1/lb)
DCON-7-OL	Vacuum (low pressure)	L-1-2 (\$2M;N)
DCON-78-OL	Transmutation	L-1-10 (\$500M;N)
Chemical surface cleaning methods		
DCON-8-OL	Chemical foams	M-4-1 (\$3M;\$0.50-\$2/ft ²)
DCON-9-OL	Chemical gels	M-4-2 (\$3M;N)
DCON-10-OL	Organic acid treatments	H-4-2 (\$2M;N)
DCON-11-OL	Fluoboric acid treatments	H-4-2 (\$2M;N)
DCON-12-OL	Inorganic acid treatments	M-3-0 (\$4M;N)
DCON-13-OL	Caustic detergent treatments	M-4-0 (\$0;>\$1/ft ²)
DCON-14-OL	REDOX treatments	M-4-1 (\$3M;<\$1/ft ²)
DCON-15-OL	Electropolishing	M-4-2 (\$3M;>\$1/ft ²)
DCON-16-OL	Gas phase	M-4-4 (\$5M;<\$0.50/lb)
DCON-17-OL	Biological surface cleaning	L-2-3 (\$1M;~\$1/ft ²)
DCON-19-OL	UV light/ozone	M-4-2 (\$1M;~\$1/ft ²)
DCON-20-OL	Electromigration	M-3-3.5 (\$1.2M;N)
DCON-21-OL	Chelation	M-4-2 (\$1.5M;<\$1/ft ²)

Table 2.7 (continued)

Data sheet code number	Technology	Ranking ^a
Metal refining methods		
DCON-31-OL	Smelt purification	H-3-3 (\$4M;~\$1/lb)
DCON-32-OL	Electrorefining	M-2-5 (\$3M;\$6/lb)
DCON-34-OL	Leach/electrowinning	M-2-5 (\$0.5M;\$3.80/lb)
Mechanical surface removal methods		
DCON-35-OL	Ultrahigh-pressure water	H-5-1 (\$1.7M;\$1/ft ²)
DCON-36-OL	Shot blasting	H-3-0 (<\$0.1M;~\$1/ft ²)
DCON-37-OL	Scabblers/scarifiers	H-4-2 (\$0.5M;\$5/ft ²)
DCON-38-OL	Grit blasting	H-4-0 (<\$0.1M;~\$5/ft ²)
DCON-39-OL	Centrifuge cryogenic CO ₂ blasting	H-5-2 (\$1M;<\$1/ft ²)
DCON-40-OL	Ice blasting	H-5-1 (<\$1M;\$1/ft ²)
DCON-41-OL	Supercritical CO ₂ blasting	H-5-1 (\$0.75+M;>\$1/ft ²)
DCON-42-OL	Plastic pellet blasting	M-4-0 (<\$0.1M;~\$1/ft ²)
DCON-43-OL	Hand grinding, honing, scraping	H-2-0 (<\$0.1M;~\$1/ft ²)
DCON-44-OL	Automated grinding	H-2-1 (~\$1M;N)
DCON-45-OL	Metal milling	M-2-1 (\$0.15M; \$17.50/ft ²)
DCON-47-OL	Concrete milling	M-1-2 (<\$1M;\$0.75/ft ²)
DCON-48-OL	Explosive	L-2-5 (\$4M;\$50/ft ²)
Surface cleaning methods		
DCON-51-OL	Compressed air cryogenic CO ₂ blasting	H-4-1 (\$0.7M;>\$1/ft ²)
DCON-52-OL	High-pressure water	M-3-1 (\$1.3M;<\$1/ft ²)
DCON-53-OL	Superheated water	M-4-1 (\$1.4M;~\$1/ft ²)
DCON-54-OL	Water flushing	M-4-1 (\$1.3M;<\$1/ft ²)
DCON-55-OL	Steam cleaning	M-4-1 (\$1.3M;~\$1/ft ²)
DCON-56-OL	Hand brushing	H-2-0 (\$0;\$1/ft ²)
DCON-57-OL	Automated brushing	M-3-2 (\$1M;\$300/ft)
DCON-58-OL	Sponge blasting	M-3-1 (\$1.3M;\$2/ft ²)
DCON-59-OL	Hot-air stripping	L-1-1 (\$2M;N)

Table 2.7 (continued)

Data sheet code number	Technology	Ranking ^a
Surface cleaning methods (continued)		
DCON-60-OL	Dry heat (roasting)	L-2-3 (\$5M;N)
DCON-61-OL	Solvent washing to remove radiological contamination	M-3-2 (\$1M;N)
DCON-62-OL	Solvent washing to remove organics	H-2-2 (\$0.4M;N)
DCON-63-OL	Strippable coatings	M-3-0 (<\$0.1M;>\$1/ft ²)
DCON-64-OL	Vacuum cleaning	M-4-0 (<\$0.1M;\$1/ft ²)
DCON-65-OL	Ultrasonic cleaning	M-2-1 (\$0.1M;>\$2/ft ²)
Thermal surface removal methods		
DCON-71-OL	Microwave scabbling	H-3-2 (\$2.5+M;>\$1/ft ²)
DCON-72-OL	Plasma torch	H-4-1 (\$0.5M;~\$1/ft ²)
DCON-73-OL	Laser heating	M-4-4 (\$3M;\$1/ft ²)
DCON-74-OL	Laser etching and ablating	M-4-4 (\$3.5M;>\$1/ft ²)
DCON-75-OL	Plasma surface cleaning	H-4-2 (\$1M;>\$1/ft ²)
DCON-76-OL	Plasma etching/fluorination	M-3-3 (\$5M;>\$2/ft ²)
DCON-77-OL	Flashlamp cleaning	H-3-3 (\$2.5M;~\$1/ft ²)

^aThe technologies are ranked according to the following criteria:

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Table 2.8. Rankings of remedial action technologies

Alternative	Data sheet code number	Technology	Ranking ^a
Buried waste group			
Containment/isolation			
Structural stabilization	REMA-1	Dynamic compaction	H-5-1 (\$0.5M;\$1.50/ft ²)
	REMA-81	Horizontal mixed in place	H-5-4 (\$1.5M;\$275/yd ³)
	REMA-96	Structural caps	M-5-1 (\$.5M;\$1M/acre)
	REMA-82	Surcharging	M-5-1 (\$0.25M;\$25/yd ³)
	REMA-5	In situ solidification	M-5-3 (\$0.5M;\$150/yd)
	REMA-97	Thermal set resin impregnation	L-5-10 (>\$1M;<\$50/ton)
Capping	REMA-94	Intruder barriers	H-5-1 (<\$.5M;<\$50/ton)
	REMA-46	Capping overview	H-5-1 (<\$.5M;\$0.5M-\$7M/acre)
Bottom seals	REMA-87	Vibrated plastic tube	L-5-4 (\$0.5M;\$200-\$300/ft ²)
	REMA-86	Microtunneled high-density polyethylene (HDPE) liner	L-5-4 (\$3M;>\$500/ft ²)
	REMA-85	Jet grouting	L-5-1 (\$0.8M;\$150-\$300/ft ²)
Barriers	REMA-58	Cryogenic barriers	L-5-3 (<\$1M;~\$100/ft ²)
Drains	REMA-44	Biopolymer drains	H-5-1 (<\$1M;\$15-\$20/ft ²)
	REMA-43	French drains	H-5-1 (<\$1;\$50-\$100/ft ²)
	REMA-45	Horizontal wells	H-5-1 (<\$1M;\$150/ft)
Walls	REMA-84	Hydromill	M-5-2 (<\$1M;\$40/ft ²)
	REMA-42	Grout curtain	M-5-1 (<\$1M;\$30-\$40/ft ²)
	REMA-40	Slurry walls	M-5-1 (<\$1M;\$15-\$20/ft ²)
	REMA-83	Slurry walls with HDPE	H-5-1 (\$2M-\$3M;~\$40/ft ²)
	REMA-41	Sheet pile walls	M-5-2 (<\$1M;\$30-\$40/ft ²)
	REMA-88	Soil saw	E-5-2 (\$0.8M;\$40/ft ²)
In situ treatment			
Destruction	REMA-99	In situ heating	L-5-8 (>\$1M;<\$50/ton)
	REMA-110	In situ biodegradation	L-5-5 (<\$1M;<\$50/ton)
Fixation	REMA-3	In situ particulate grouting	M-5-2 (>\$1M;\$40-\$60/yd ³)
	REMA-2	In situ chemical grouting	M-5-2 (<\$1M;\$60-\$100/yd ³)
	REMA-100	In situ vitrification	H-5-5 (\$3M;<\$50/ton)
Separation	REMA-89	Fracted air stripping	M-5-4 (\$2M;>\$50/ton)

Table 2.8 (continued)

Alternative	Data sheet code number	Technology	Ranking ^a
Retrieval			
Excavation	REMA-123	Overshot drilling	H-5-4 (\$5M/6 HFIR ^b holes)
	REMA-126	Bulk item exhumation	H-5-2 (≤\$1M; <\$50/ton)
	REMA-125	Wireline basket recovery	H-5-4 (\$8M/6 HFIR holes)
	REMA-101	Vacuum loader	L-5-2 (≤\$1M; <\$50/ton)
	REMA-4	Borehole/solution mining	L-5-3 (≤\$1M; \$50–\$100/yd ³)
	REMA-10	Solidify and mine	L-5-8 (≤\$1M; <\$50/ton)
	REMA-90	Precision excavation	H-5-1 (≤\$.5M; <\$50/ton)
	REMA-122	Modular excavation	M-5-8 (>\$1M; <\$50–\$100/ton)
	REMA-38	Remote excavation	H-5-2 (≤\$.5M; \$203–\$244/ft ³)
Ex situ treatment			
Separation	REMA-93	Shredding/magnetic separation	L-5-1 (\$1M; \$0.2M/yr/system)
	REMA-121	Physical sorting	M-5-1 (N;N)
	REMA-92	Thermal desorption	L-5-3 (≤\$1M; \$35–\$120/ton)
	REMA-91	Freeze purification	L-5-5 (≤\$.5M; <\$50/ton)
	REMA-8	Gravity sorting	L-5-3 (≤\$1M; \$0.35–\$1/lb)
	REMA-55	Soil washing	L-5-3 (≤\$.5M; \$70–\$150/ton)
Fixation	REMA-9	Cementitious solidification	H-5-3 (≤\$.5M; \$200–\$360/yd ³)
	REMA-112	Thermoplastic encapsulation	H-5-3 (≤\$.5M; \$25/ft ³)
	REMA-113	Thermoset encapsulation	H-5-3 (≤\$1M; \$30/ft ³)
	REMA-114	Sulfur polymer cement	H-5-10 (≤\$1M; \$25/yd ³)
	REMA-115	Polymer impregnated concrete	M-5-8 (>\$1M; <\$50/ton)
	REMA-117	Vitrification	M-5-6 (>\$1M; \$400–\$500/ton)
	REMA-116	Ceramic encapsulation	L-5-10 (N;N)
Destruction	REMA-95	Incineration	H-5-1 (≤\$1M; >\$100/ton)
	REMA-98	Calcining/sintering	L-5-10 (>\$1M; <\$50/ton)
	REMA-7	Low-temperature ashing	H-5-6 (>\$1M; <\$50/ton)
Recovery/ conversion	WPRO-111	Reuse metals (smelting)	M-5-1 (\$3M; \$2/lb.)
	REMA-127	Transmutation	M-5-4 (≤\$1M; <\$50–\$100/ton)

Table 2.8 (continued)

Alternative	Data sheet code number	Technology	Ranking ^a
Tanks core group			
Contents removal	REMA-27	Mechanical excavation	H-5-3 (>\$1M;N)
	REMA-28	Pneumatic removal	H-5-0 (\$4M;N)
	REMA-29	Hydraulic removal (sluicing)	H-5-0 (>\$1M;N)
Fixation	REMA-25	In situ cement grouting	M-5-2 (>\$1M;>\$70/m ³)
	REMA-26	In situ silicate-based stabilization	M-5-2 (>\$1M;>\$70/m ³)
	REMA-30	In situ vitrification	M-5-2 (\$3M;<\$50-\$100/ton)
	REMA-32	In situ polymer grouting	M-5-2 (>\$1M;>\$100/m ³)
	REMA-33	In situ thermal plastic encapsulation	L-5-3 (>\$1M;<\$50-\$100/ton)
Physical separation	REMA-31	In situ sorption	M-5-1 (>\$1M;<\$50-\$100/ton)
Pits and trenches			
Containment	REMA-36	Capping barriers	H-3-1 (L, \$0.5-\$7M/acre)
In situ treatment	REMA-35	In situ vitrification	H-3-1 (>\$1M;\$25/ft ³)
	REMA-37	In situ grouting	M-3-2 (<\$1M;\$75/ft ³)
	REMA-39	In situ extraction	L-3-10 (>\$1M;\$244/ft ³)
Retrieval	REMA-38	Remote excavation	M-3-2 (<\$0.5M;\$203-\$244/ft ³)
Soils/sediments			
Containment	REMA-46	Capping	M-4-1 (<\$0.5M;\$0.5-\$1M/acre)
	REMA-58	Cryogenic barriers	M-4-3 (<\$1M;N)
Physical separation	REMA-55	Soil washing	H-4-2 (<\$0.5M;\$70-\$150/ton)
	REMA-13	Low-temperature thermal treatment	M-4-2 (\$1M;\$100-\$800/ton)
	REMA-11	Vapor extraction/RFH ^c	H-2-4 (<\$1M;<\$100/ton)
	REMA-16	Thermal desorption	H-2-2 (<\$1M;\$35-\$120/ton)
	REMA-78	Soil vapor extraction (SVE)	H-2-3 (<\$1M;N)
	REMA-80	Thermally enhanced SVE	H-2-3 (<\$1M;N)
Chemical separation	REMA-119	Solvent extraction	M-2-3 (\$3M-\$5M;\$200-\$300/ton)
	REMA-120	Oxidation/reduction	M-2-3 (\$3M-\$5M;\$100-\$200/ton)
	REMA-19	Electrokinetic removal	L-2-4 (\$1M-\$10M;>\$100/ton)

Table 2.8 (continued)

Alternative	Data sheet code number	Technology	Ranking ^a
Soils/sediments (continued)			
Destruction	REMA-118	Bioremediation	M-2-3 (\$3M-\$5M;\$100-\$200/ton)
	REMA-12	Incineration	M-4-2 (\$1M-\$2M;\$100-\$800/ton)
	REMA-15	Molton glass combustor	M-2-3 (<\$1M;>\$200/ton)
	REMA-20	Chem char process	L-2-4 (\$1M;<\$50-\$100/ton)
	REMA-17	Plasma arc furnace	M-2-3 (\$10M;<\$50-\$100/ton)
	REMA-14	Cement kiln incinerator	M-2-3 (<\$1M;<\$50/ton)
Fixation	REMA-18	In situ vitrification	M-4-3 (<\$5M;\$390/ton)
	REMA-59	Grouting	M-4-2 (<\$1M;\$75/ft ³)
Retrieval	REMA-124	Entombed clamshell	H-4-0 (<\$5M;<\$50/ton)
Pipeline group			
Excavation	REMA-53	Mechanical excavation	H-1-0 (\$0;\$0.25/yd ³)
Fixation	REMA-52	In situ grouting	H-1-1 (\$0;~\$25-\$70/yd ³)
Hydrofracture group			
Containment—well bores	REMA-22	Plug and abandon	H-1-2 (\$0;\$10-\$20M total cost)
Containment—grout sheets	REMA-21	Water proofing cave with hydraulic cage	M-1-5 (\$3M;\$30-\$40M total cost)
	REMA-24	Deep rock drainage curtain	M-1-4 (\$3M;\$30-\$40M total cost)
	REMA-23	Chemical grouting	L-1-2 (\$3M;\$30-\$40M total cost)
Impoundments			
Capping	REMA-46	Capping overview	H-4-1 (<\$5M;\$0.5-\$7M acre)
Drains	REMA-43	French drains	H-4-1 (<\$1M;<\$50/ton)
	REMA-44	Biopolymer drains	H-4-2 (<\$1M;<\$50/ton)
	REMA-45	Horizontal wells	H-4-3 (<\$5M;<\$50/ton)
Walls/barriers	REMA-58	Cryogenic barriers	M-4-3 (<\$1M;<\$50-\$100/ton)
	REMA-42	Grout curtain	M-4-2 (<\$1M;<\$50/ton)
	REMA-40	Slurry walls	M-4-3 (<\$1M;<\$50/ton)

Table 2.8 (continued)

Alternative	Data sheet code number	Technology	Ranking ^a
Impoundments (continued)			
Walls/ barriers (continued)	REMA-41	Sheet pile walls	M-4-2 ($\leq \$1M$; $< \$50/\text{ton}$)
	REMA-60	Clay/bentonite additives	L-4-1 ($\leq \$5M$; $\$0.55/\text{ft}^2$)
Physical separation	REMA-51	Soil washing	M-4-2 ($\leq \$5M$; $\$70-\$150/\text{ton}$)
	REMA-47	In situ soil flushing	M-4-3 ($\leq \$5M$; $< \$50/\text{ton}$)
	REMA-56	Sludge drying	M-4-3 ($\leq \$1M$; $< \$50/\text{ton}$)
Fixation	REMA-57	In situ fixation	H-4-1 ($\leq \$1M$; N)
	REMA-59	In situ vitrification	M-4-3 ($\leq \$5M$; $\$25/\text{yd}^3$)
Excavation	REMA-50	Mechanical excavation	H-4-1 ($\leq \$5M$; $< \$50/\text{ton}$)
	REMA-49	Vacuum loader	H-4-1 ($\leq \$5M$; $< \$50/\text{ton}$)
	REMA-48	Dredging	H-4-1 ($\leq \$5M$; $< \$50/\text{ton}$)
Groundwater/surface water			
Physical separation	REMA-65	Ion exchange	H-5-1 ($\$1M$; $\$5-\$10/1000 \text{ gal}$)
	REMA-34	Precipitation	M-5-1 ($\$1M$; $\$100-\$1000/1000 \text{ gal}$)
	REMA-73	Adsorption on biomedica	M-2-2 ($\$2M$; N)
	REMA-66	Activated carbon	H-2-1 ($\$1M$; $\$5-\$10/1000 \text{ gal}$)
	REMA-76	Air stripping	H-2-0 ($\$0$; $\$6-\$4.10/1000 \text{ gal}$)
Physical separation	REMA-77	Steam stripping	H-2-0 ($\$0$; $\$8/1000 \text{ gal}$)
Destruction	REMA-68	Biological oxidation	H-2-1 ($\$1M$; $\$10/1000 \text{ gal}$)
	REMA-72	Chemical oxidation	M-2-2 ($\$2M$; $\$100/1000 \text{ gal}$)
	REMA-69	Anaerobic dechlorination	L-2-5 ($\$5M$; N)
	REMA-75	Biological denitrification	M-2-1 ($\$1M$; $\$200/1000 \text{ gal}$)
In situ processes			
Physical separation	REMA-64	Ion exchange	L-5-3 ($\$3M$; N)
	REMA-62	Precipitation	L-5-3 ($\$3M$; N)
	REMA-74	Biomedica on adsorption	L-2-3 ($\$3M$; N)
	REMA-67	Activated carbon adsorption	L-2-3 ($\$3M$; N)

Table 2.8 (continued)

Alternative	Data sheet code number	Technology	Ranking ^a
<i>In situ processes (continued)</i>			
Fixation	REMA-63	Artificial wetlands	M-2-3 (\$3M;N)
Destruction	REMA-61	Chemical oxidation	M-2-2 (\$2M; a few\$/1000 gal)
	REMA-71	Anaerobic dechlorination	M-2-5 (\$5M;N)
	REMA-75	Biological denitrification	M-2-3 (\$3M;N)
Containment	REMA-74	Bioremedia adsorption	H-5-2 (\$2M;N)

^a The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1-5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as \$M or \$K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology (\$ per ft² or other unit or N for no estimate).

An example of a ranking follows: H-5-5 (\$3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of \$3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

^b HFIR = High Flux Isotope Reactor

^c RFH = radio frequency heating

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Table 2.9 (continued)

Treatment/ management options	Solid Wastes																		
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos: transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactable debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	NA ^b	Scaled sources	Graphite moderator	Fissile materials	Steam plant ash	
Treatability code ^b	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	NA ^b	NA	NA	NA	NA	
Mixed and/or hazardous waste (continued)																			
Mond process (nickel only)						H-4-1 (\$1M;N)													
NAC ^g process (aluminum only)						M-4-3 (\$4M;N)													
Solvent extraction		M-2-2 (\$1M;N)	M-2-2 (\$2M;N)									M-3-3 (\$2M;N)	M-4-2 (\$1M;N)						
Supercritical fluid extraction	M-2-5 (\$3M;N)	M-2-5 (\$3M;N)	M-2-5 (\$3M;N)	M-2-5 (\$3M;N)	M-1-5 (\$3M;N)		M-3-5 (\$3M;N)	M-3-5 (\$3M;N)		L-3-5 (\$3M;N)	L-1-5 (\$3M;N)	M-3-5 (\$3M;N)							
Calcination/ roasting		M-2-1 (\$1M; \$1/lb)	M-2-1 (\$1M; \$2M/lb)																
Chem char process		M-2-7 (\$4M;N)		M-2-7 (\$4M;N)			M-3-7 (\$4M;N)			L-3-7 (\$4M;N)	M-1-5 (\$4M;N)	L-3-7 (\$4M;N)							
Incineration		H-2-1 (\$1M; \$6/lb)	M-2-2 (\$1M; \$6/lb)			L-4-1 (\$1M; \$6/lb)	H-3-1 (\$1M; \$6/lb)	L-3-1 (\$1M; \$6/lb)	H-1-1 (\$0.5M; \$6/lb)	M-3-2 (\$1M; \$6/lb)	M-1-2 (\$1M; \$6/lb)	L-3-2 (\$1M; \$6/lb)							
Microwave treatment	M-2-3 (\$4M;N)		M-2-3 (\$4M;N)	H-2-5 (\$4M;N)				M-3-5 (\$4M;N)		M-3-5 (\$3M;N)	M-1-5 (\$3M;N)	M-3-5 (\$3M;N)	M-4-3 (\$3M;N)						
Molten glass combustor		M-2-2 (\$2M;N)		M-2-2 (\$2M;N)			M-3-2 (\$2M;N)	M-3-2 (\$2M;N)	L-1-2 (\$2M;N)		M-1-1 (\$1M;N)								

Table 2.9 (continued)

Treatment/ management options	Solid Wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactable debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Scaled sources	Graphite moderator	Missile materials	Steam plant ash
Treatability code ^b	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	NA ^b	NA	NA	NA	NA
Mixed and/or hazardous waste (continued)																		
Molten salt oxidation		L-2-3 (\$2M;N)					M-3-3 (\$2M;N)		L-1-2 (\$2M;N)		L-1-1 (\$2M;N)	M-3-2 (\$2M;N)						
Plasma arc furnace	M-2-3 (\$2M;N)	M-2-3 (\$3M;N)	M-2-5 (\$3M;N)	M-2-5 (\$3M;N)	M-1-5 (\$3M;N)	M-4-5 (\$3M;N)	M-3-5 (\$3M;N)	H-3-5 (\$3M;N)	L-1-5 (\$3M;N)	M-3-1 (\$1M;N)	M-1-5 (\$3M;N)							
Pyrolysis		M-2-1 (\$1M; \$1/lb)									M-1-1 (\$1M; \$1/lb)							
Smelting					H-1-1 (\$3M; \$2/lb)	H-4-1 (\$3M; \$2/lb)												
Thermal desorption	H-2-2 (\$1M; \$1/lb)	H-2-2 (\$1M; \$1/lb)		M-2-2 (\$1M; \$1/lb)	H-1-2 (\$1M; \$1/lb)	H-4-2 (\$1M; \$1/lb)					L-1-1 (\$1M; \$1/lb)	M-3-2 (\$1M; \$1/lb)						
Anaerobic digestion							L-3-1 (\$0.5M;N)											
Biosorption										M-3-1 (\$1M;N)								
Supercompac- tion								H-3-1 (\$0.5M;N)				M-3-1 (\$0.5M;N)						
HF dissolution										M-3-2 (\$1M;N)								

Table 2.9 (continued)

Solid Wastes													
Treatment/ management options	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs
	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100
Mixed and/or hazardous waste (continued)													
Supercritical water oxidation											L-1-3 (\$2M;N)		
												L-3-10 (\$10M;N)	
											M-1-2 (\$2M;N)	L-3-2 (\$2M;N)	
Transmutation													
Wet air oxidation													
Waste containing RAD and/or TRU ^b contaminants only													
Waste stabilization (encapsulation)	H-3-1 (\$0.5M; \$300/R ²)	H-3-1 (\$0.5M; \$400/R ²)	H-3-1 (\$0.5M; \$400/R ²)	H-2-1 (\$0.5M; \$400/R ²)	M-3-1 (\$0.5M; \$0.6/lb)	H-3-1 (\$0.5M; \$0.6/lb)	L-3-1 (\$0.5M; \$300/R ²)	H-3-1 (\$0.5M; \$300/R ²)		H-3-1 (\$0.5M; \$300/R ²)	M-4-1 (\$0.5M; \$300/R ²)	L-3-3 (\$2M; \$300/R ²)	
Sonification					M-3-2 (\$1M;N)	M-3-2 (\$1M;N)							
Acid digestion							M-3-2 (\$1M;N)						
Electrochemical metal removal					H-3-3 (\$2M;N)	H-3-3 (\$2M;N)			L-3-2 (\$1M;N)		L-4-3 (\$2M;N)	L-3-5 (\$3M;N)	
Electropolish- ing/osmosis/ migration	M-3-4 (\$2M;N)		M-3-4 (\$2M;N)										
Steam plant ash													

Table 2.9 (continued)

Solid Wastes																		
Treatment/ management options	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos: transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Scaled sources	Graphite moderator	Fissile materials	Steam plant ash
	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	NA ^d	NA	NA	NA	NA
Waste containing RAD and/or TRU contaminants only (continued)																		
Gas-phase ClF ₃ treatment					L-3-3 (\$2M;N)	L-3-3 (\$2M;N)												
Leaching and stripping	M-3-3 (\$1M;N)	M-3-3 (\$1M;N)		M-2-3 (\$1M;N)		M-3-3 (\$1M;N)	M-3-3 (\$1M;N)	M-3-3 (\$2M;N)		M-3-3 (\$1M;N)	M-4-3 (\$1M;N)	M-3-2 (\$2M;N)						
Mond process (nickel only)						H-3-3 (\$1M;N)												
NAC process (aluminum only)						M-3-3 (\$4M;N)												
Solvent extraction			M-3-2 (\$2M;N)															
Calcination/ roasting			M-3-1 (\$1M;N)															
Chem char process																		
Incineration		H-3-1 (\$1M; \$6/lb)	M-3-2 (\$1M; \$6/lb)			L-3-1 (\$1M; \$6/lb)	H-3-1 (\$1M; \$6/lb)	L-3-1 (\$1M; \$6/lb)	H-3-1 (\$0.5M; \$6/lb)	M-3-1 (\$1M; \$6/lb)	M-4-1 (\$1M; \$6/lb)	M-3-2 (\$1M; \$6/lb)				H-2-1 (\$1M; \$6/lb)		
Microwave treatment	M-3-3 (\$4M;N)		M-3-3 (\$4M;N)	H-2-5 (\$4M;N)				M-3-5 (\$4M;N)		L-3-4 (\$4M;N)		L-3-5 (\$4M;N)						

Table 2.9 (continued)

Treatment/ management options	Solid Wastes													
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components
Treatability code ^b	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	NA ^b
Waste containing RAD and/or TRU contaminants only (continued)														
Molten glass combustor		M-3-2 (\$2M;N)		M-2-2 (\$2M;N)			M-3-2 (\$2M;N)	M-3-2 (\$2M;N)	L-3-2 (\$2M;N)	M-3-2 (\$2M;N)	M-4-2 (\$2M;N)	M-3-2 (\$2M;N)		M-2-2 (\$2M;N)
Molten salt oxidation							M-3-3 (\$2M;N)		L-3-2 (\$2M;N)	M-3-2 (\$3M;N)	M-4-2 (\$2M;N)			M-2-2 (\$2M;N)
Plasma arc furnace	M-3-3 (\$2M;N)	M-3-3 (\$3M;N)	M-3-5 (\$3M;N)	M-2-5 (\$3M;N)	M-3-5 (\$3M;N)		M-3-5 (\$3M;N)	M-3-5 (\$3M;N)	L-3-5 (\$3M;N)					M-2-5 (\$3M;N)
Pyrolysis														
Smelting					H-3-1 (\$3M; \$2/lb)	H-3-1 (\$3M; \$2/lb)								
Thermal desorption	H-3-2 (\$1M; \$1/lb)													
Anaerobic digestion							L-3-1 (\$0.5M;N)							
Biosorption							L-3-5 (\$2M;N)			M-3-1 (\$1M;N)				
Package to WIPP ¹ WAC/ TRU waste only)	E-3-5 (\$5M;N)	E-3-5 (\$5M;N)	E-3-5 (\$5M;N)	E-2-5 (\$5M;N)	E-3-5 (\$5M;N)	E-3-5 (\$5M;N)	E-3-5 (\$5M;N)	E-3-5 (\$5M;N)		E-3-5 (\$5M;N)	E-4-5 (\$5M;N)	E-3-5 (\$5M;N)		

Table 2.9 (continued)

Treatment/ management options	Solid Wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactable debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Missile materials	Steam plant ash
Treatability code ^b	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	NA ^b	NA	NA	NA	NA
Waste containing RAD and/or TRU contaminants only (continued)																		
Supercompac- tion								H-3-1 (\$0.5M;N)		M-3-1 (\$0.5M;N)		M-3-1 (\$0.5M;N)						
HF dissolution										M-3-2 (\$1M;N)								
Supercritical water oxidation											L-4-3 (\$2M;N)							
Transmutation												L-3-10 (\$10M;N)			L-2-10 (\$10M;N)		L-3-10 (\$10M;N)	
Dry storage														M-4-2 (\$2M;N)				
Pool storage														M-4-2 (\$2M;N)				
Cask to Savannah River Site for storage														M-4-3 (\$3M;N)				
Reprocessing														L-4-3 (\$3M;N)				
Safe storage for eventual disposal															H-2-1 (\$1M;N)			

Table 2.9 (continued)

Treatment/ management options	Solid Wastes																	
	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
Treatability code ^b	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	NA ^b	NA	NA	NA	NA
Uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants)																		
Landfill disposal	H-1-1 (\$0.5M; \$30/yd ³)	H-1-1 (\$0.5M; \$30/yd ³)	E-1-1 (\$0.5M; \$30/yd ³)	H-1-1 (\$0.5M; \$30/yd ³)	M-1-1 (\$0.5M; \$30/yd ³)		L-2-1 (\$0.5M; \$30/yd ³)		M-3-1 (\$0.5M; \$30/yd ³)			H-3-1 (\$1M; \$30/yd ³)						
Landfill disposal (exc. As, Ag, Ba, Cd, Cr, Hg, Pb, Se)						M-1-1 (\$0.5M; \$30/yd ³)												
Recycle/reuse	H-1-1 (\$0.5M;N)	H-1-1 (\$0.5M;N)		H-1-1 (\$0.5M;N)	H-1-1 (\$0.5M;N)	H-1-1 (\$0.5M; N)	H-2-1 (\$0.5M;N)	H-2-1 (\$0.5M;N)		H-2-1 (\$0.5M;N)		H-3-1 (\$0.5M;N)	H-4-1 (\$0.5M;N)		H-2-1 (\$0.5M; N)			
Sell as scrap					H-1-1 (\$0.5M;N)	H-1-1 (\$0.5M; N)	H-2-1 (\$0.5M;N)	H-2-1 (\$0.5M;N)										
Incineration							H-2-1 (\$0.5M; \$6/lb)		E-3-1 (\$0.5M; \$6/lb)			M-3-2 (\$1M; \$6/lb)	E-4-1 (\$0.5M; \$6/lb)					
Microwave treatment				M-1-3 (\$4M;N)														
Molten glass combustor				M-1-2 (\$2M;N)									M-4-2 (\$2M;N)					
Molten salt oxidation									L-3-2 (\$2M;N)									

Table 2.9 (continued)

Treatment/ management options		Solid Wastes																	
		Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactible debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Fissile materials	Steam plant ash
Treatability code ^b		5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	NA ^b	NA	NA	NA	NA
Uncontaminated waste (continued)																			
Plasma arc furnace					M-1-3 (\$3M/N)					L-3-5 (\$3M/N)				M-4-3 (\$3M/N)					
Sell for salvage value													H-3-1 (\$0.5M/N)						H-2-1 (\$0.5M/N)
Solar evaporation																			H-2-1 (\$0.2M/N)
Shallow land burial																			H-2-1 (\$0.2M/N)
Leaching and stripping													M-3-2 (\$2M/N)	M-4-1 (\$1M/N)					
Thermal desorption													M-3-2 (\$1M/\$1/1 b)						
Solvent extraction														M-4-2 (\$1M/N)					

Table 2.9 (continued)

Treatment/ management options	Solid Wastes																		
	Treatability code ^b	Concrete rubble and gravel	Asphalt, building materials	Discarded asbestos; transite	Fiberglass insulation	Scrap ferrous metals	Scrap nonferrous metals	Combustible debris	Compactable debris	Biological wastes	Discarded filters	Spent ion exchange media	Other heterogeneous debris	Lab packs	Irradiated and spent fuel elements and components	Sealed sources	Graphite moderator	Missile materials	Steam plant ash
	5210	5210	5290	5220	5110	5190	5300	5400	5350/ 5360	5410	3115	5490	6100	NA ^b	NA	NA	NA	NA	NA

The technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1-5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as \$M or \$K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology (\$ per ft³ or other unit or N for no estimate).

An example of a ranking follows: H-5-5 (\$3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of \$3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

^b Treatability code from Mixed Waste Treatment Project

^c NA = not applicable

^d RAD = radioactive

^e RCRA = Resource Conservation and Recovery Act

^f TSCA = Toxic Substances Control Act

^g NAC = nitrate-ammonia-ceramic

^h TRU = transuranic

ⁱ WIPP = Waste Isolation Pilot Plant

^j WAC = waste acceptance criteria

Table 2.10. Rankings^a of waste management options for solid-liquid wastes

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA ^b hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
Treatability code ^c	3120	6390	1100/ 1200	5420	2200	8900	NA ^d	NA
Mixed and/or hazardous waste (RAD^e and RCRA/TSCA^f)								
Waste stabilization (encapsulation)	M-2-1 (\$0.5M; \$500/ft ³) ^g							
Adsorption				M-3-2 (\$1M:N)	L-4-2 (\$1M:N)			
Filtration				M-3-2 (\$2M:N)				
HGMS ^h				L-3-4 (\$2M:N)				
Inorganic microporous filters			L-4-8 (\$4M:N)	L-3-8 (\$4M:N)				
Reverse osmosis			M-4-2 (\$1M:N)	M-3-2 (\$1M:N)				
Acid digestion					M-4-2 (\$1M:N)			
Catalytic destruction		H-5-2 (\$1M:N)				M-3-2 (\$1M:N)		
Chemical oxidation/ reduction		M-5-2 (\$2M:N)				M-3-2 (\$2M:N)		
Chemical precipitation			M-4-1 (\$0.5M:N)	H-3-2 (\$1M:N)				
Enviro CP process				M-3-5 (\$2M:N)				
Gamma radiolysis					L-4-5 (\$2M:N)	L-3-5 (\$2M:N)		
Ion exchange			M-4-2 (\$1M:N)	H-3-2 (\$1.5M:N)				

Table 2.10 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA ^b hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
Treatability code ^c	3120	6390	1100/ 1200	5420	2200	8900	NA ^d	NA
Mixed and/or hazardous waste (continued)								
Leaching and stripping	M-2-3 (\$2M;N)	M-5-3 (\$1M;N)			M-4-1 (\$1M;N)			
Neutralization			H-4-1 (\$0.5M;N)					
Solvent extraction	M-2-3 (\$2M;N)	M-5-3 (\$2M;N)		M-3-2 (\$1M;N)				
Supercritical fluid extraction	M-2-5 (\$3M;N)	M-5-5 (\$3M;N)						
Supercritical water oxidation		H-5-3 (\$3M;N)			M-4-3 (\$3M;N)	M-3-3 (\$3M;N)		
Wet air oxidation	M-2-2 (\$2M;N)					M-3-2 (\$2M;N)		
Distillation					H-4-2 (\$2M;N)			
Evaporation			H-4-1 (\$0.5M;N)	H-3-1 (\$0.5M;N)				
Incineration	M-2-1 (\$1M; \$6/lb)	H-5-1 (\$0.5M; \$6/lb)		L-3-1 (\$0.5M; \$6/lb)	E-4-1 (\$0.5M; \$6/lb)	H-3-1 (\$0.5M; \$6/lb)		
Microwave treatment	M-2-3 (\$3M;N)							
Molten glass combustor	M-2-2 (\$2M;N)	M-5-2 (\$2M;N)			M-4-2 (\$3M;N)	M-3-2 (\$2M;N)		
Molten salt oxidation		H-5-3 (\$2M;N)		L-3-2 (\$2M;N)	H-4-2 (\$2M;N)	M-3-3 (\$2M;N)		
Plasma arc furnace	M-2-5 (\$3M;N)	M-5-5 (\$3M;N)		L-3-5 (\$3M;N)	M-4-3 (\$3M;N)	M-3-3 (\$3M;N)		
Thermal desorption	M-2-2 (\$1M; \$1/lb)							

Table 2.10 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA ^b hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
Treatability code ^c	3120	6390	1100/ 1200	5420	2200	8900	NA ^d	NA
Mixed and/or hazardous waste (continued)								
Aerobic/ anaerobic digestion					M-4-3 (\$2M;N)	M-3-3 (\$3M;N)		
Biodegradation	M-2-3 (\$2M;N)	L-5-2 (\$2M;N)						
Biosorption				L-3-5 (\$2M;N)				
Waste containing RAD and/or TRUⁱ contaminants only								
Waste stabilization (encapsulation)	M-4 ^j -1 (\$0.5M; \$500/ft ³)							
Acid digestion								M-3-1 (\$0.5M;N)
Gamma radiolysis								M-3-2 (\$2M;N)
Ion exchange			M-4-2 (\$1.5M;N)					
Leaching and stripping	M-4-3 (\$2M;N)							
Neutralization			H-4-1 (\$0.5M;N)					
Solvent extraction	M-4-3 (\$2M;N)							
Evaporation	H-4-1 (\$1M;N)							
Incineration	M-4-1 (\$1M; \$6/lb)							H-3-1 (\$0.5M; \$6/lb)
Microwave treatment	M-4-3 (\$3M;N)							

Table 2.10 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA ^b hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
Treatability code ^c	3120	6390	1100/ 1200	5420	2200	8900	NA ^d	NA
Waste containing RAD and/or TRUⁱ contaminants only (continued)								
Molten glass combustor	M-4-2 (\$2M;N)							M-3-2 (\$2M;N)
Molten salt oxidation								M-3-3 (\$2M;N)
Plasma arc furnace	M-4-5 (\$3M;N)							M-3-3 (\$3M;N)
Biosorption	L-4-5 (\$2M;N)							
Package to WIPP ^k WAC ^l (TRU waste only)	E-4-5 (\$5M;N)							
Autoclaving								E-3-1 (\$0.5M;N)
Uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants)								
Encapsulation		M-2-1 (\$0.5M; \$500/ft ³)						
Inorganic microporous filter			L-3-8 (\$4M;N)					
Reverse osmosis			M-3-2 (\$1M;N)					
Recycle/ reuse	L-3-3 (\$2M;N)	L-2-2 (\$1M;N)	L-3-2 (\$1M;N)				M-1-1 (\$0.5M;N)	
Sell as scrap (if permitted)		L-2-1 (\$0.2M;N)						
Shallow land burial							H-1-1 (\$0.2M;N)	

Table 2.10 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA ^b hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
Treatability code ^c	3120	6390	1100/ 1200	5420	2200	8900	NA ^d	NA
Uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants) (continued)								
Acid digestion								M-3-1 (\$0.5M;N)
Chemical oxidation/ reduction	M-3-2 (\$2M;N)							
Chemical precipitation		M-2-1 (\$1M;N)						
Gamma radiolysis								M-3-2 (\$2M;N)
Ion exchange			M-3-2 (\$1.5M;N)					
Leaching and stripping		M-2-3 (\$1M;N)						
Neutralization			H-3-1 (\$0.5M;N)					
Solvent extraction		M-2-3 (\$2M;N)						
Supercritical fluid extraction		M-2-5 (\$3M;N)						
Supercritical water oxidation		H-2-3 (\$3M;N)						
Autoclaving								E-3-1 (\$0.5M;N)
Evaporation			H-3-1 (\$0.5M;N)					
Incineration	M-3-3 (\$3M;N)	H-2-1 (\$0.5M; \$6/lb)						E-3-1 (\$0.5M; \$6/lb)
Microwave treatment	M-3-1 (\$0.5M; \$6/lb))							

Table 2.10 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA ^b hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
Treatability code ^c	3120	6390	1100/ 1200	5420	2200	8900	NA ^d	NA
Uncontaminated waste (no RAD, TRU, or RCRA/TSCA contaminants) (continued)								
Molten glass combustor		M-2-2 (\$2M;N)						M-3-2 (\$2M;N)
Molten salt oxidation		H-2-3 (\$2M;N)						M-3-3 (\$2M;N)
Plasma arc furnace		M-2-5 (\$3M;N)						M-3-5 (\$3M;N)
Thermal desorption	M-3-2 (\$1M; \$1/lb)							
Aerobic/ anaerobic digestion								
Biodegradation	M-3-3 (\$2M;N)	L-2-2 (\$2M;N)						

Table 2.10 (continued)

Treatment/ management options	Solid-liquid wastes							
	Waste processing sludges	Ignitable and reactive wastes	Corrosive wastes	Toxic metal wastes	Toxic organic wastes	Other RCRA ^b hazardous wastes	Coal yard run-off sludge	Infectious medical wastes
Treatability code ^c	3120	6390	1100/ 1200	5420	2200	8900	NA ^d	NA

^aThe technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1-5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as \$M or \$K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology (\$ per ft² or other unit or N for no estimate).

An example of a ranking follows: H-5-5 (\$3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of \$3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

^b RCRA = Resource Conservation and Recovery Act

^c Treatability code for Mixed Waste Treatment Project

^d NA = not applicable

• RAD = Radioactive

^f TSCA = Toxic Substances Control Act

^g For Melton Valley Storage Tanks (MVST), this ranking is M-4-1 (\$0.5M;\$500/ft³)

^h HGMS = high-gradient magnetic separation

ⁱ TRU = transuranic

^j The ranking shown is the ranking for the MVST sludges. This criteria is ranked "3" for the Process Waste Treatment Plant (PWTP) and the Nonradiological Wastewater Treatment Plant (NRWTP) sludges.

^k WIPP = Waste Isolation Pilot Plant

^l WAC = waste acceptance criteria

Table 2.11. Rankings^a of waste management options for liquid wastes

Treatment/ management options	Liquid wastes						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC ^b caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/Industrial waste water
Treatability code ^c	2210	2220	1000	1200	1100	2900	1900
Mixed and/or hazardous waste (radioactive and RCRA^d/TSCA^e contaminants)							
Adsorption	L-4-2 (\$1M;N)	L-4-2 (\$1M;N)				M-4-3 (\$2M;N)	
Air stripping		M-4-1 (\$0.5M;N)					
Filtration				L-5-1 (\$1M;N)	L-4-1 (\$1M;N)		
HGMS ^f							
Inorganic microporous filters				L-5-8 (\$4M;N)	L-4-8 (\$4M;N)		
Reverse osmosis				L-5-2 (\$1M;N)	L-4-2 (\$1M;N)		
Bradtec process				M-5-3 (\$4M;N)	M-4-2 (\$4M;N)		
Bucky ball chemistry						L-4-10 (\$10M;N)	
Chemical dechlorination	L-4-5 (\$2M;N)						
Catalytic destruction	M-4-2 (\$1M;N)	H-4-2 (\$1M;N)					
Chemical oxidation/reduction				M-5-2 (\$2M;N)	M-4-2 (\$2M;N)	L-4-2 (\$2M;N)	
Chemical precipitation				M-5-2 (\$2M;N)	M-4-2 (\$2M;N)	M-4-2 (\$2M;N)	
Electrochemical metal removal							
Electrolysis				M-5-4 (\$3M;N)	M-4-4 (\$3M;N)		

Table 2.11 (continued)

Treatment/ management options	Liquid waste						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC ^b caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/Industrial waste water
Treatability code ^c	2210	2220	1000	1200	1100	2900	1900
Mixed and/or hazardous waste (continued)							
Gamma radiolysis	L-4-5 (\$2M;N)						
Ion exchange				M-5-2 (\$2M; \$0.20/gal)	M-4-2 (\$2M; \$0.20/gal)		
Leaching and stripping	M-4-2 (\$2M;N)						
Neutralization				H-5-1 (\$0.5M;N)	H-4-1 (\$0.5M;N)		
Nitrate-ammonia-ceramic process				M-5-3 (\$4M;N)	M-5-3 (\$4M;N)		
Ozonation photolysis	M-4-2 (\$1M;N)	M-4-2 (\$2M;N)		M-5-3 (\$3M;N)	M-4-3 (\$3M;N)		
Solvent extraction	L-4-2 (\$1M;N)	M-4-2 (\$1M;N)		M-5-3 (\$2M;N)	M-4-3 (\$2M;N)	M-4-3 (\$2M;N)	
Supercritical fluid extraction						M-4-5 (\$3M;N)	
Supercritical water oxidation	M-4-3 (\$3M;N)	M-4-3 (\$3M;N)					
Wet air oxidation	L-4-2 (\$2M;N)	M-4-2 (\$2M;N)				M-4-3 (\$3M;N)	
Advanced electric thermolysis						L-4-5 (\$4M;N)	
Chem char process		M-4-5 (\$4M;N)				M-4-5 (\$4M;N)	
Distillation	H-4-1 (\$1M;N)	H-4-1 (\$1M;N)				H-4-2 (\$1M;N)	
Evaporation				H-5-1 (\$1M;N)	H-4-1 (\$1M;N)		

Table 2.11 (continued)

Treatment/ management options	Liquid wastes						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC ^a caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
Treatability code	2210	2220	1000	1200	1100	2900	1900
Mixed and/or hazardous waste (continued)							
Incineration	E-4-1 (\$0.5M; \$6/lb)	E-4-1 (\$0.5M; \$6/lb)				M-4-1 (\$1M; \$6/lb)	
Low-temperature separation		M-4-2 (\$1M;N)					
Microwave treatment				M-5-3 (\$4M;N)	M-4-3 (\$4M;N)		
Molten glass combustor		H-4-2 (\$2M;N)				M-4-2 (\$2M;N)	
Molten salt oxidation	L-4-2 (\$2M;N)	H-4-3 (\$2M;N)				M-4-3 (\$2M;N)	
Plasma arc furnace	L-4-3 (\$3M;N)					M-4-5 (\$3M;N)	
Aerobic/ anaerobic digestion		M-4-1 (\$1M;N)				L-4-2 (\$2M;N)	
Biodegradation				M-5-2 (\$1M;N)	M-4-2 (\$1M;N)		
Microbial dechlorination	L-4-8 (\$4M;N)						
Waste containing radioactive and/or transuranic contaminants only							
Adsorption			M-5-3 (\$2M;N)			M-4-3 (\$2M;N)	M-4-2 (\$2M;N)
Air stripping							
Filtration			H-5-1 (\$1M;N)	L-5-1 (\$1M;N)	L-5-1 (\$1M;N)	L-4-1 (\$1M;N)	H-4-1 (\$1M;N)
HGMS			L-5-4 (\$2M;N)				

Table 2.11 (continued)

Treatment/ management options	Liquid waste						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC ^b caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
Treatability code ^c	2210	2220	1000	1200	1100	2900	1900
Waste containing radioactive and/or transuranic contaminants only (continued)							
Inorganic microporous filters			L-5-8 (\$4M;N)	L-5-8 (\$4M;N)	L-5-8 (\$4M;N)	L-4-8 (\$4M;N)	M-4-8 (\$4M;N)
Reverse osmosis			M-5-2 (\$1M;N)	M-5-2 (\$1M;N)	L-5-2 (\$1M;N)		H-4-2 (\$1M;N)
Bradtec process				M-5-3 (\$4M;N)	M-5-3 (\$4M;N)		
Bucky ball chemistry						L-4-10 (\$5M;N)	
Chemical dechlorination							
Catalytic destruction							
Chemical oxidation/reduction			M-5-2 (\$2M;N)	M-5-2 (\$2M;N)	M-5-2 (\$2M;N)	L-4-2 (\$2M;N)	
Chemical precipitation			H-5-2 (\$2M;N)	M-5-2 (\$2M;N)	M-5-2 (\$2M;N)	M-4-2 (\$2M;N)	
Electrochemical metal removal			M-5-3 (\$2M;N)	M-5-3 (\$2M;N)	M-5-3 (\$2M;N)		
Electrolysis			M-5-4 (\$3M;N)	M-5-4 (\$3M;N)	M-5-4 (\$3M;N)		
Gamma radiolysis							M-4-3 (\$2M;N)
Ion exchange			H-5-4 (\$2M; \$0.2/gal)	M-5-2 (\$2M; \$0.2/gal)	M-5-2 (\$2M; \$0.2/gal)		
Leaching and stripping							

Table 2.11 (continued)

Treatment/ management options	Liquid wastes						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC ^a caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
Treatability code	2210	2220	1000	1200	1100	2900	1900
Waste containing radioactive and/or transuranic contaminants only (continued)							
Neutralization				H-5-1 (\$0.5M:N)	H-5-1 (\$0.5M:N)		
Nitrate-ammonia-ceramic processes				M-5-3 (\$4M:N)	M-5-3 (\$4M:N)		
Ozonation photolysis			M-5-3 (\$3M:N)	M-5-3 (\$3M:N)	M-5-3 (\$3M:N)		
Solvent extraction			M-5-3 (\$2M:N)	M-5-3 (\$2M:N)	M-5-3 (\$2M:N)	M-4-3 (\$2M:N)	M-4-3 (\$2M:N)
Supercritical fluid extraction						M-4-5 (\$3M:N)	
Supercritical water oxidation							M-4-3 (\$3M:N)
Wet air oxidation							M-4-3 (\$3M:N)
Advanced electric thermolysis						L-4-5 (\$4M:N)	
Chem char process						M-4-5 (\$4M:N)	
Distillation						H-4-2 (\$1M:N)	
Evaporation			H-5-1 (\$0.5M:N)	H-5-1 (\$1M:N)	H-5-1 (\$1M:N)		H-4-1 (\$1M:N)
Incineration						M-4-1 (\$1M; \$6/lb)	
Low-temperature separation							
Microwave treatment				M-5-3 (\$4M:N)	M-5-3 (\$4M:N)		

Table 2.11 (continued)

Treatment/ management options	Liquid waste						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC ^b caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
Treatability code ^c	2210	2220	1000	1200	1100	2900	1900
Waste containing radioactive and/or transuranic contaminants only (continued)							
Molten glass combustor						M-4-2 (\$2M;N)	
Molten salt oxidation						M-4-3 (\$2M;N)	
Plasma arc furnace						M-4-5 (\$3M;N)	
Aerobic/ anaerobic digestion						L-4-2 (\$2M;N)	E-4-1 (\$0.5M; \$0.5)
Biodenitrification				M-5-2 (\$1M;N)	M-5-2 (\$1M;N)		
Biosorption			L-5-5 (\$2M;N)				
Uncontaminated waste (no radioactive, transuranic, or RCRA/TSCA contaminants)							
Recycle/reuse		H-4-1 (\$0.5M;N)					
Adsorption		L-4-2 (\$1M;N)					
Air stripping		M-4-1 (\$0.5M;N)					
Catalytic destruction		H-4-2 (\$0.5M;N)					
Ozonation photolysis		M-4-2 (\$2M;N)					
Solvent extraction		M-4-2 (\$1M;N)					
Supercritical water oxidation		M-4-3 (\$3M;N)					

Table 2.11 (continued)

Treatment/ management options	Liquid wastes						
	Listed halogenated solvents	Listed nonhalogenated solvents	Process/dilute liquid low-level wastes	Melton Valley and REDC ^a caustic aqueous wastes	REDC acidic aqueous wastes	REDC liquid organic wastes	Sanitary/industrial waste water
Treatability code	2210	2220	1000	1200	1100	2900	1900
Uncontaminated waste (continued)							
Wet air oxidation		M-4-2 (\$2M;N)					
Chem char process		M-4-5 (\$4M;N)					
Distillation		H-4-1 (\$1M;N)					
Incineration		E-4-1 (\$0.5M; \$6/lb)					
Low-temperature separation		M-4-2 (\$1M;N)					
Molten glass combustor		H-4-2 (\$2M;N)					
Molten salt oxidation		H-4-3 (\$2M;N)					
Aerobic/anaerobic digestion		M-4-1 (\$1M;N)					

^a The technologies are ranked according to the following criteria:

- Overall assessment of the technology's usefulness (E—essential, H—high, M—medium, and L—low).
- Ranking of site problem (1–5 is the scale of lowest significance to highest significance).
- Time required to bring to commercial or mature state from its current state (expressed in number of years).
- Cost to bring technology to large-scale commercial use (presented as \$M or \$K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology (\$ per ft² or other unit or N for no estimate).

An example of a ranking follows: H-5-5 (\$3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of \$3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

^b REDC = Radiochemical Engineering Development Center

^e TSCA = Toxic Substances Control Act

^c Treatability Code for Mixed Waste Treatment Project

^f HGMS = high-gradient magnetic separation

^d RCRA = Resource Conservation and Recovery Act

Table 2.12. Rankings^a of waste management options for gaseous waste

Treatment/ management options	Gaseous wastes										
	Volatile organic compounds in gases	Semi-volatile organic compounds in gases	Particulates in gases	Inorganics in gases	RAD ^b in gases	Adsorbable RAD in gases	Nonadsorbable RAD in gases	Sulfur oxides in gases	Nitrogen oxides in gases	Entrained vapors/acids in gases	Orphan gas cylinders
Treatability code ^c	NA ^d	NA	NA	NA	NA	NA	NA	NA	NA	NA	6400
Mixed and/or hazardous waste (RAD and RCRA^d/TSCA^e contaminants)											
Adsorption	M-4-2 (\$1M;N)	M-4-2 (\$1M;N)	M-2-2 (\$1M;N)	H-2-2 (\$1M;N)						H-2-1 (\$1M;N)	
Cyclone separation			H-2-1 (\$1M;N)								
Filtration			E-2-1 (\$1M;N)	E-2-1 (\$1M;N)							
High-gradient magnetic separation			L-2-4 (\$2M;N)	L-2-4 (\$2M;N)							
Inorganic membrane separation	M-4-5 (\$4M;N)	M-4-5 (\$4M;N)	M-2-5 (\$4M;N)	M-2-5 (\$4M;N)						M-2-5 (\$4M;N)	
Recharacterization and disposal											H-1-1 (\$2M;N)
Scrubbers	H-4-1 (\$5M;N)	H-4-1 (\$5M;N)	H-2-1 (\$1M;N)	H-2-1 (\$1M;N)							
Catalytic destruction	H-4-1 (\$1M;N)	H-4-1 (\$1M;N)									
DeNO _x processes									E-2-1 (\$1M; \$700/ton)		

Table 2.12 (continued)

[illegible]

Table 2.12 (continued)

Treatment/ management options	Gaseous waste										
	Volatile organic compounds in gases	Semi-volatile organic compounds in gases	Particulates in gases	Inorganics in gases	RAD ^b in gases	Adsorbable RAD in gases	Nonadsorbable RAD in gases	Sulfur oxides in gases	Nitrogen oxides in gases	Entrained vapors/acids in gases	Orphan gas cylinders
Treatability code ^c	NA ^d	NA	NA	NA	NA	NA	NA	NA	NA	NA	6400
Uncontaminated waste (continued)											
Cyclone separation			H-2-1 (\$1M;N)								
Filtration			E-2-1 (\$1M;N)	E-2-1 (\$1M;N)							
High-gradient magnetic separation			L-2-4 (\$2M;N)	L-2-4 (\$2M;N)							
Inorganic membrane separation			M-3-5 (\$4M;N)	M-2-5 (\$4M;N)						M-2-5 (\$4M;N)	
Scrubbers		H-4-1 (\$1M;N)	H-3-1 (\$1M;N)								H-1-1 (\$1.2M;N)
Recharacterization and disposal											
DeNO _x processes									E-2-1 (\$1M; \$700/ton)		
Flue gas desulfurization processes								E-2-1 (\$1M; \$900/ton)			
Leaching and stripping				M-2-2 (\$1M;N)						M-2-2 (\$1.2M;N)	M-1-2 (\$1.3M;N)

Table 2.12 (continued)

Treatment/ management options	Gaseous waste										
	Volatile organic compounds in gases	Semi-volatile organic compounds in gases	Particulates in gases	Inorganics in gases	RAD ^b in gases	Adsorbable RAD in gases	Nonadsorbable RAD in gases	Sulfur oxides in gases	Nitrogen oxides in gases	Entrained vapors/acids in gases	Orphan gas cylinders
Treatability code ^c	NA ^d	NA	NA	NA	NA	NA	NA	NA	NA	NA	6400
Uncontaminated waste (continued)											
Incineration								H-2-1 (\$5M; \$6/lb)	H-2-1 (\$5M; \$6/lb)		
Low-temperature separation				M-2-2 (\$2M;N)							
Molten salt oxidation			M-3-2 (\$2M;N)					M-2-2 (\$2M;N)	M-2-2 (\$2M;N)		

^aThe technologies are ranked according to the following criteria:

- Overall assessment of the usefulness of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for low usefulness).
- A ranking of the site problem (1-5 is the scale of lowest significance to highest significance).
- Time required to bring the technology to an acceptable state for application at large scale (commercial or mature state) at the site (this is expressed in number of years and depends on the current state of its development).
- The cost for bringing the technology from its present state to large-scale commercial use (the costs are presented as \$M or \$K, which indicate the number of millions or thousands of dollars without escalation).
- Projected unit processing cost for mature technology (\$ per ft² or other unit or N for no estimate).

An example of a ranking follows: H-5-5 (\$3.5M;N). This means that this technology has a high overall usefulness; the problem is of highest significance to the site; the technology is estimated to take 5 years before it is ready for application at the site; an approximate expenditure of \$3.5 million will be required to bring the technology to this state of readiness; and the unit processing cost cannot be projected at the present time.

^b RAD = radioactive

^c Treatability code for Mixed Waste Treatment Project

^d NA = not applicable

^e RCRA = Resource Conservation and Recovery Act

^f TSCA = Toxic Substances Control Act

2.5 REGULATORY OVERVIEW

The regulatory aspects of EM are addressed for each of the EM areas: D&D, RA, and WM. Topics listed below are evaluated in more detail in the regulatory compliance chapters.

2.5.1 Vol. 1, Pt. A (D&D), Overview

- RCRA
 - Closure and postclosure care
 - Federal and state regulations applicable to D&D activities at ORNL
 - Treatment of structural components: contaminated debris; miscellaneous treatment units; chemical, physical, biological, or thermal treatment
 - Corrective action management units
- Clean Water Act
 - Direct discharge to surface water bodies
 - Storm water discharges
- Clean Air Act
 - Process emissions
 - Fugitive dust emissions
 - Asbestos emissions
- National Environmental Policy Act
 - Wetlands and floodplains
 - Aquatic resources
 - Rare, threatened, or endangered species
 - Historic sites and archaeological findings
- Occupational Safety and Health Administration
- Radiation protection standards
 - DOE orders
 - Generic below regulatory concern (BRC) levels for radioactive wastes

2.5.2 Vol. 1, Pt. B (RA), Overview

- Overview of environmental laws affecting RA activities
- Chemical-specific regulations
 - Groundwater and surface water: RCRA, Safe Drinking Water Act, Clean Water Act, air, soil, and nonregulatory guidance
- Radiation protection standards
 - Generic BRC levels for radioactive wastes
 - Federal agreements and legislation
 - U.S. Environmental Protection Agency regulations
 - U.S. Department of Transportation regulations
 - DOE orders
- Action-specific regulations
 - Comprehensive Environmental Response, Compensation, and Liability Act
 - RCRA: Subtitle C regulations, land disposal restrictions, corrective action requirements, Subtitle I regulations, and Subtitle D regulations
 - Clean Air Act

- Clean Water Act
- Safe Drinking Water Act
- Toxic Substances Control Act
- Federal Insecticide, Fungicide, and Rodenticide Act
- Occupational Safety and Health Administration
- Federal and state regulations
- Location-specific regulations
 - Caves, salt-dome formations, salt-bed formations, and underground mines
 - Faults
 - Wetlands and floodplains
 - Wilderness areas, wildlife refuges, wildlife resources, and scenic rivers
 - Rare, threatened, or endangered species

2.5.3 Vol. 1, Pt. C (WM), Overview

- Types of wastes
- Solid- and hazardous-waste management
 - RCRA: Subtitles A-J
 - Tennessee regulations
 - Solid waste
 - Hazardous-waste management: characteristic, listed, hazardous constituents regulated under RCRA and hazardous waste constituents, wastes excluded from Subtitle C regulation, delisting petitions, waste mixtures (mixture rule, derived from rule, contained-in policy, mixed waste), generator requirements under RCRA Subtitle C, Transporter requirements under RCRA Subtitle C, Treatment, Storage, or Disposal facilities requirements under RCRA Subtitle C (permitting requirements under RCRA), corrective action requirements, RCRA land disposal restrictions, and underground storage tanks under Subtitle I
- Radioactive-waste management
 - General requirements: DOE orders and Clean Air Act and Tennessee Air Quality laws
 - Regulation of radioactive waste: transuranic waste, high-level radioactive waste, low-level radioactive waste, special-case waste, spent nuclear fuel, and mixed waste
- Asbestos
 - Clean Air Act
 - Occupational Safety and Health Administration
 - State regulations
 - DOE orders
- Waste minimization
- Clean Water Act
- Toxic Substances Control Act
- Federal Insecticide, Fungicide, and Rodenticide Act
- Transportation off-site
- National Environmental Policy Act
- Occupational Safety Health Administration Requirements

2.6 REFERENCES

1. *Oak Ridge National Laboratory Waste Management Plan*, ORNL/TM-11433/R2, Office of Waste Management and Remedial Actions, Oak Ridge Nat'l Lab., December 1992.