**Oak Ridge National Laboratory
Technology Logic Diagram**

**Volume 1
Technology Evaluation**

**Part A
Decontamination and Decommissioning**

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ACRONYMS AND INITIALISMS

ACM	asbestos-containing material
ALARA	as low as reasonably achievable
ARAR	applicable or relevant and appropriate requirement
BRC	below regulatory concern
CAA	Clean Air Act
CAMU	Corrective Action Management Unit
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CWA	Clean Water Act
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EM	environmental management
EPA	U.S. Environmental Protection Agency
ER	environmental restoration
ER/WM	environmental restoration/waste management
ES&H	Environmental, Safety, and Health
FFA	Federal Facility Agreement
FWCA	Fish and Wildlife Conservation Act
HSWA	Hazardous and Solid Waste Amendments
LDR	land disposal restriction
LLLW	liquid low-level waste
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NPDES	National Pollutant Discharge Elimination System
NRC	Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OSHA	Occupational Safety and Health Administration
PCB	polychlorinated biphenyl
R&D	research and development
RA	remedial action
RACM	regulated asbestos-containing material
RCRA	Resource Conservation and Recovery Act
TCA	Tennessee Code Annotated
TDEC	Tennessee Department of Environment and Conservation
TLD	Technology Logic Diagram
TRU	transuranic
TTP	Technical Task Plan
USC	United States Code
WM	waste management

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. It is essential that follow-on engineering studies be conducted to build on the output of this project. These studies will begin by selecting the most promising technologies identified in the TLD and finding an optimum mix of technologies that will provide a socially acceptable balance between cost and risk.

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. Part B of Vols. 1 and 2 focuses on RA of contaminated facilities. 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 responsibilities, a review of identified technologies, and the rankings of remedial technologies. Volume 2 (Pts. A, B, and C) contains the 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 logic paths from Vol. 2.

The focus of Vol. 1, Pt. A, is D&D, and it has been divided into seven chapters. The first chapter is an introduction, which defines problems specific to the D&D Program for ORNL. Chapter 2 provides a general overview of the TLD. Chapters 3 through 6 are the categories which together make up D&D activities: characterization, dismantlement/disassembly, decontamination, and robotics and automation. The final chapter contains regulatory compliance information concerning D&D.

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. Introduction

1. INTRODUCTION

1.1 OAK RIDGE NATIONAL LABORATORY

The Oak Ridge National Laboratory (ORNL) was built in 1943 as part of the World War II Manhattan Project. Its original mission was to produce and chemically separate the first gram quantities of plutonium as part of the national effort to produce the atomic bomb. The peacetime history of the laboratory first began in the late 1940s. Through 1973, ORNL was concerned with the development of nuclear technology for electrical power generation. From 1973 to 1980, ORNL was largely devoted to finding solutions for the energy crisis. The primary missions since 1980 have been to conduct applied research and engineering development in support of U.S. Department of Energy (DOE) programs in fusion, fission, conservation, fossil, and other energy technologies and to perform basic scientific research in selected areas of the physical and life sciences. The Laboratory also operates "user facilities" for the benefit of university and industry researchers and supplies radioactive isotopes that are not otherwise commercially available.

1.2 ORNL MISSION

The mission statement that follows was reproduced from the *ORNL Institutional Plan FY 1993–FY 1998*.¹ ORNL, which is managed by Martin Marietta Energy Systems, Inc., for DOE, is one of the nation's premier research institutions (see Fig. 1.1 for aerial view of ORNL). The primary mission of the Laboratory is to perform leading-edge research and development (R&D) in support of the nonweapons roles of DOE. Significant elements of ORNL's mission are to perform basic and applied research that is of importance to the nation; to provide the scientific and technical community with unique national user facilities; to improve the nation's competitiveness through technology development and transfer by partnering universities and industry; and to improve science and math education through contributions to the national initiative.

ORNL will accomplish the mission through its core competencies:

- energy production, conservation, and utilization technologies;
- materials sciences and engineering;
- physical, chemical, and engineering sciences;
- biological and life sciences;
- environmental sciences and technologies;
- computational sciences; and
- manufacturing sciences and technologies.

The principal sponsor of ORNL's work is DOE, but, in a larger sense, the Laboratory serves many national—even international—customers. ORNL staff are involved in research on global energy and environmental problems and in the development of technologies that will improve U.S. competitiveness in international markets. The Laboratory's more fundamental scientific research, much of which is done in collaboration with researchers from around the world, contributes to the storehouse of human knowledge; this work, therefore, has a very broad customer base. In the conception, construction, and operation of national research facilities, the Laboratory's customers are drawn from major segments of the scientific and technical community. Much of the applied research and technology development work at ORNL is expected to provide services for other government agencies and private companies.

Fig. 1.1.1. Aerial view of the Oak Ridge National Laboratory.

1.3 ORNL DECONTAMINATION AND DECOMMISSIONING PROBLEM DEFINITION

Past R&D, isotope production, and waste management (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 identified in Sect. 1.3.1. In addition, there are 16 isotope facilities described in Sect. 1.3.2 that are undergoing safe shutdown before being accepted by and turned over to the decontamination and decommissioning (D&D) program. Section 1.3.3 describes two additional facilities that will require D&D and are also part of the "official" list of ORNL D&D problems.²

1.3.1 ORNL Facilities Already in D&D Program

This section briefly describes the facilities that have already been accepted into the ORNL D&D Program. Figure 1.2 shows the Bethel Valley reactor area with the Metal Recovery Facility, Fission Product Pilot Plant, and Waste Evaporator Facility in the background. The Fission Product Development Laboratory, Waste Evaporator Facility, and Fission Product Pilot Plant are shown in Fig. 1.3. The Homogeneous Reactor Experiment and the Molten Salt Reactor Experiment are seen in Fig. 1.4.

Building 3001 ORNL Graphite Reactor (see Fig. 1.2) was the first reactor constructed at ORNL, being placed in service in 1943 at a 1-MW power level. It was an air-cooled, graphite-moderated and -reflected, heterogeneous, natural-uranium-fueled reactor. The support facilities for Graphite Reactor include the Graphite Reactor Filter House (3002), the Graphite Reactor Fan House (3003), and the Graphite Reactor Exhaust Stack (3018).

Building 3005 Low-Intensity Test Reactor was a water-moderated and -cooled reactor, using enriched uranium as fuel and beryllium as a reflector for the purpose of supplying a variety of irradiation facilities for ORNL and other research groups. The reactor was originally designed for a 500-kW power level but was converted to a 3-MW testing reactor prior to permanent shutdown in 1968. The Low-Intensity Test Reactor is supported by an air cooler (3077).

Building 3042 Oak Ridge Research Reactor (see Fig. 1.2) was a 20-MW materials testing reactor built in 1958. It was used for neutron beam experiments, isotope production, and materials irradiation. It was shut down in 1987, and all fuel was removed. The Oak Ridge Research Reactor is supported by a pool cooling tower and annex (3086), the cooling tower (3103), the heat exchanger pit (3102), the demineralizer (3004), and the pump house (3085).

Building 3087 Oak Ridge Research Reactor Heat Exchanger—This water-to-air heat exchanger was the original heat dissipation system for the Oak Ridge Research Reactor. When the reactor power level was increased from 20 MW to 30 MW in 1960, the radiators were replaced by a water-to-water heat exchanger and cooling tower heat dissipation system.

Building 3505 Metal Recovery Facility was a pilot- and small-scale production nuclear fuel reprocessing plant used for the processing of various waste-solution, scrap, and miscellaneous fuel elements for the recovery of uranium, plutonium, neptunium, and americium.

Fig. 1.2. Bethel Valley Reactor Area.

Fig. 1.3. Fission Product Development Laboratory, Waste Evaporation Facility, and Fission Product Pilot Plant.

Fig. 1.4. Homogeneous Reactor Experiment and Molten Salt Reactor Experiment.

Building 3506 Waste Evaporator Facility received the liquid low-level waste (LLLW) streams from ORNL laboratories and other processing areas during the 1950s for concentration prior to final disposition by shale fracture techniques.

Building 3515 Fission Product Pilot Plant was used in the fission product recovery development program for the separation of curie quantities of various radionuclides from LLLW streams. It was abandoned in 1958 when it was replaced by the FPD.

Building 3517 Fission Product Development Laboratory Inactive Cells went on line in 1958 to separate kilocurie quantities of fission products from Redox- and Purex-type waste streams. In 1975, the chemical processing cells were shut down and maintained in protective storage. Some initial decontamination was performed, but subsequent funding restrictions limited the scope of this effort.

Building 4507 High-Level Chemical Development Laboratory was designed and operated as a laboratory and small-scale pilot plant for development studies of reactor-fuel processing, separation and recovery of transuranic (TRU) materials, and separation of fission products from aqueous wastes.

Building 7500 Homogeneous Reactor Experiment housed two experimental aqueous homogeneous reactors that were developed for nuclear power application analyses. The Homogeneous Reactor Experiment is supported by the waste evaporator (7502), the cooling tower (7554), the charcoal absorber pit (7557), the waste evaporator loading pit (7558), the charcoal absorber valve pit (7559), and the decontamination pad (7561).

Building 7503 Molten Salt Reactor Experiment was a single-region, unclad graphite-moderated, homogeneous-fueled reactor built to investigate the practicality of the molten salt reactor concept for central power station applications. The circulating fuel solution was a mixture of lithium-, beryllium-, and zirconium-fluoride salts, containing uranium fluoride as the fuel. The Molten Salt Reactor Experiment is supported by the filter pit (7511), the exhaust stack (7512), the cooling tower (7513), the supply air filter house (7514), and the diesel generator house (7555). Figure 1.5 shows the elevation layout; the reactor cell can be seen in Fig. 1.6.

Building 7852 Old Hydrofracture Facility was an experimental and operational plant for the injection of waste grout into a fractured shale formation. The experimental design was tested in 1964-1965 using dilute and concentrated waste solutions. Beginning in 1966, operational injections of concentrated liquid waste from the ORNL LLLW system were routinely made until facility shutdown in 1980. A pump house and four bulk storage bins comprise the Old Hydrofracture Facility ancillary facilities. Figure 1.7 is a photograph of the facility.

Building 9201-3 Mezzanine Storage Tank (Y-12) is a 3000-gal storage tank that was used from 1958 to 1969. Until recently it was believed that this tank was used as a reservoir for machine shop cutting oil during development of molten salt reactor technology. However, recent information suggests that this tank held cleaning solution for the decontamination facility.^{3,4} The tank shown in Fig. 1.8 is contaminated with uranium,⁴ thorium, molten salt, and an oil residue.

Building 9201-3 Coolant Salt Technology Facility (Tritium Test Loop) was built in 1958 and 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.

Building 9201-3 Molten Salt Corrosion Loop was built in 1958 for the preparation and handling of fuel for molten salt reactor technology development and the Molten Salt Corrosion Loop.

Fig. 1.5. Molten Salt Reactor Experiment layout.

Fig. 1.6. Molten Salt Reactor containment cell (prior to start-up).

Building 9419-1 Decontamination Facility was used to decontaminate equipment and materials associated with the development of molten salt reactor technology from 1958 to 1969.

Shielded Transfer Tanks were used to ship ^{137}Cs -loaded ion exchange resins for processing from Richland, Washington, to ORNL.

1.3.2 Isotope Facilities Scheduled for D&D Program

The following facilities are scheduled for acceptance into the D&D program.

Building 3026-C Krypton-85 Enrichment Facility was constructed in 1943 and was used for about five years to develop methods of isolating fission products. After the war, the effort shifted to processing radioisotopes for research and medical purposes.

Building 3028 Alpha Powder Facility was constructed in 1950 and originally housed the Short-Lived Fission Product Cells and the separation facility, which was a four-story ion-exchange column. The facility was converted to manipulator cells in the early 1960s and expanded to the Short-Lived Fission Product Facility.

Building 3029 Source Development Laboratory was constructed in 1952 and originally contained a system of remotely operated barricades and a small manipulator cell that is now called Cell 4. Cell 1 was used for ^{60}Co -source fabrication, and Cell 3 was built for ^{137}Cs -source fabrication. Cell 2 was built by enclosing the space between Cells 1 and 3 and was used for waste handling and as a pass-through between the cells.

Building 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.

Building 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.

Building 3033 Radioactive Gas Processing Facility houses the tritium and krypton production facility. The facility was constructed in the late 1940s and was used to process gaseous isotopes.

Building 3033-A Actinide Fabrication Facility was constructed in about 1960 and was used to house and contain the facilities for the production, loading, welding, and decontamination of neutron dosimeter materials, as well as the weighing and packaging of milligram-to-gram quantities of actinide materials for research applications. The building has been used almost exclusively for the preparation and distribution of highly purified actinide isotopes for the Isotopes Program.

Building 3038 Isotope Research Materials Laboratory was constructed to house all the radioisotope shipping activities for ORNL. The building has been in operation since 1949. Originally, the entire facility was dedicated to radioisotope shipping as follows: the east portion (3038-E) contained the analytical chemistry laboratory, which performed analyses of short-lived radioisotopes prior to shipment; the middle section (3038-M) housed the radioisotope handling and transfer barricade; and the west section housed the packaging, inspection, and shipping activities. In 1968, the west portion of the shipping area was converted into the Alpha Handling Facility area by adding water-shielded hot cells and glove boxes for fabrication of targets.

Fig. 1.7. The Old Hydrofracture Facility (foreground).

Fig. 1.8. The 3000-gal Storage Tank.

Building 3047 Radioisotope Development Laboratory was constructed in about 1962 as part of the isotopes program. The facility housed four high-level beta/gamma cells, one alpha hot cell, seven laboratories for handling low-level materials, a decontamination room, offices, and service areas. During operations, isotopes handled within the facility included ^{60}Co , ^{152}Eu , ^{154}Eu , ^{153}Gd , ^{14}C , and other alpha and beta/gamma isotopes specifically identified individually. All process operations in the building have been shut down.

Building 3093 Storage Cubicle for Krypton was constructed in the late 1940s and was used to support the gaseous isotopes processes. The permanent storage cubicle in Building 3093 contains four charcoal-filled storage tanks. It consists of a nonventilated reinforced-concrete enclosure.

Building 3099 Storage Pad is a concrete pad used for temporary storage of prepackaged shipments, casks, and other materials. All radioactive materials located on the pad are stored in accordance with U.S. Department of Transportation (DOT) or equivalent regulations for shipment of radioactive materials contained in a minimum double containment designed to prevent leaks and spills.

Building 3118 Radioisotope Production Laboratory-H is basically a shed covering the rear-entry doors to the hot cells in Bldgs. 3030 and 3031. It may be used for forklift storage and as a waste staging area during shutdown activities.

Building 3517 Fission Products Development Laboratory went on line in 1958 to separate kilocurie quantities of fission products from Redox- and Purex-type waste streams. Following the shutdown of the chemical processing cells in 1975, radioisotope processing continued in the manipulator cells at a reduced level until April 1989, when the building was placed in standby.

Building 7025 Tritium Target Facility was installed in the late 1960s to house a tritium target fabrication system. The facility was used to produce titanium tritide accelerator targets for the Lawrence Livermore National Laboratory. The system has also been used to prepare metallurgical samples for helium embrittlement studies related to fusion energy materials research. In later years, the ThO_2/UO_2 evaporator was moved to Bldg. 7025 and was used to prepare hundreds of oxide-thin films for a variety of customers.

1.3.3 ORNL Special-Case Facilities

The D&D project intends to perform D&D of Bldgs. 3019-A and -B together.

Building 3019-A Radiochemical Development Facility is used for dispensing and storing fissile material and for radiochemical process experimentation and development. This project is currently funded by Defense Programs and will remain funded for several more years.

Building 3019-B High-Level-Radiation Analytical Facility was built in 1955 and was used for separating, processing, and analyzing highly radioactive samples from many ongoing ORNL programs. These samples included fission and activation products, and uranium, plutonium, and other TRU materials. No project claims ownership of this facility.

1.3.4 Summary of Contaminants

Outstanding characteristics of the contaminants in a selection of these facilities are summarized in Table 1.1.

Table 1.1. Outstanding characteristics of contaminants

Facility	Highest contamination	Location	Contaminants
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
Low-Intensity Test Reactor	200-300 R/h	Interior surfaces of reactor tank and primary water piping	Corrosion products and long-lived fission products
Oak Ridge Research Reactor	>50,000 R/h	Surfaces, reactor core, process piping, and equipment	Primarily ^{60}Co , ^{137}Cs , and ^{90}Sr
Metal Recovery Facility	600 mrad/h 2,500,000 dpm/100 cm ²	Cell walls and floors	Most likely ^{137}Cs and ^{239}Pu
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
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
Fission product 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
High-Level Chemical Development Laboratory	250,000,000 dpm/100 cm ²	Cell surfaces and equipment	Transuranic materials and fission products
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 1.1 (continued)

Facility	Highest contamination	Location	Contaminants
Molten Salt Reactor Experiment	2200 R/h	Reactor vessel, fuel storage cells, process piping, and equipment	Primarily ^{60}Co and other fission products
Old Hydrofracture Facility	8 R/h (max)	Surfaces, equipment, and piping	Fission products, ^{137}Cs , ^{90}Sr , and ^{60}Co
Coolant Salt Technology Facility	1,000,000 dpm/100 cm ² (max) 1,000 dpm/100 cm ² transferable 3,500 dpm/100 cm ² transferable	Interior of flow system (pumps, tanks, valves, and piping)	Tritium
Molten Salt Corrosion Loop	50,000 dpm/100 cm ² (max) 1,200 dpm/100 cm ² transferable 3,500 dpm/100 cm ² transferable	Interior of fuel handling cell and support equipment	^{233}U , ^{228}Th , and low levels of transferable Be
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 9201-3	4,000 dpm/100 cm ²	Surface	U, Th, Oil

1.4 ORNL ROADMAP

1.4.1 Introduction

The *Strategic Roadmap for the Oak Ridge Reservation* is a generalized planning document that identifies broad categories of issues that keep ORNL outside full compliance with the law and other legally binding agreements.⁵ The *Strategic Roadmap for the Oak Ridge Reservation* identifies possible generic paths to compliance, issues, and the schedule for resolution of the issues. The role of the *Oak Ridge National Laboratory Technology Logic Diagram* (TLD) is then to identify specific site issues (problems), identify specific technologies that can be brought to bear on the issues, and assess the current status and readiness of these remediation technologies within the constraints of the schedule commitment.

Regulatory requirements and commitments contained in the *Strategic Roadmap for the Oak Ridge Reservation* are also included in the TLD as constraints to the application of immature technological solutions. Some otherwise attractive technological solutions may not be employed because they may not be deployable on the schedule enumerated in the regulatory agreements. Conversely, negotiators in the process of defining regulatory agreements may fruitfully take cognizance of the TLD assessments in order to schedule remediation milestones that allow the use of cheaper, faster, better, or safer technologies.

The roadmap for ORNL includes a list of 46 comprehensive logic diagrams for WM of low-level, radioactive-mixed, hazardous, sanitary and industrial, and TRU waste. The roadmapping process gives comparisons of the installation as it exists to the way the installation should exist under full compliance. The identification of the issues is the goal of roadmapping. This allows accurate and timely formulation of activities. The following information is excerpted from the *Strategic Roadmap for the Oak Ridge Reservation*.

1.4.2 Roadmapping Methodology

The roadmapping methodology is divided into nine steps and covers three phases—assessment, analysis, and issue resolution.

The *assessment phase* identifies the current status and background of the installation. This phase is accomplished in four steps: (1) identifying installation assumptions that provide for the conduct of environmental management (EM) activities; (2) identifying regulations and codes of federal, state, and local levels, DOE Orders, and other agreements that DOE is responsible to comply with; (3) describing those DOE commitments, which include Inter-Agency Agreements and Federal Facility Agreements (FFAs); and (4) preparing a schedule that includes all commitments with all currently budgeted and forecast activities.

The *analysis phase* identifies key issues and actions needed for resolution. This phase is accomplished in four steps: (1) identification of issues that prevent the installation from accomplishing EM objectives; (2) analysis of issues to determine the root causes; (3) conversion of issues to needs for the resolution of issues and the identification of activities that satisfy those needs; and (4) preparation of the schedule for the desired activities.

The *issue-resolution phase* merges the issue resolution activities with ongoing and planned activities as the ninth and final step. Specific recommendations for modifications, additions, or deletions to current plans are formulated and captured in Activity Data Sheets or are forwarded to DOE Headquarters for resolution.

1.4.3 Summary of Major Committed Milestones

Although the FFA for the Oak Ridge Reservation (ORR) does not address D&D directly, it does contain major committed milestones for ORNL which may impact the D&D process and technology development indirectly in the form of time, resource and budget constraints and directly in that D&D sites determined to have newly identified releases of hazardous substances to the environment will be incorporated into the FFA Appendix E list of sites requiring remedial action (RA). Likewise, although the ORNL roadmap does not impose any requirement or constraints on the technologies that may be developed for use in D&D of ORNL facilities, several major environmental regulations are addressed which could place constraints of the application of immature technological solutions. Therefore, this document provides a discussion of regulatory drivers for D&D activities and technologies in Chap. 7.

1.5 REFERENCES

1. *Oak Ridge National Laboratory Institutional Plan FY 1993-FY 1998*, ORNL/PPA-92/3, U.S. DOE and Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., November 1992.
2. T. W. Burwinkle, Decontamination and Decommissioning workshop, Oak Ridge Natl. Lab., October 29, 1992.
3. R. Montgomery, personal communication to R. D. Bundy (Notebook 11888, p. 66), Oak Ridge, Tenn., February 26, 1993.
4. R. Montgomery and S. M. Anderson, personal communication to R. D. Bundy (Notebook 11888, p. 68), Oak Ridge, Tenn., March 2, 1993.
5. *Strategic Roadmap for the Oak Ridge Reservation, March 1992*, U.S. DOE Field Office—Oak Ridge and Martin Marietta Energy Systems, Inc., Oak Ridge Natl. Lab., March 26, 1992.

2. Description of the Technology Logic Diagram

2. DESCRIPTION OF THE TECHNOLOGY LOGIC DIAGRAM

2.1 PURPOSE AND SCOPE

The purpose of the TLD is to provide a planning document for DOE, DOE operating contractors, and private industry that relates the environmental restoration/waste management (ER/WM) problems at ORNL to the technologies that can be used to remediate these problems. In doing so, the status of each potential remediation technology is evaluated. This is a significant focus of the diagram preparation.

Several important aspects impacting implementation of each technology are folded into the evaluation so that the appropriateness of each technology can be evaluated:

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 WM required for the technology—what wastes are generated as a result of the use of the technology?

The TLD addresses the enforceable compliance and cleanup agreements that have designated timetables for ameliorating the specific site problems. 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.

Because of enforceable compliance agreements, DOE is bound by Executive Order 12088, which requires the Secretary of the Department of Energy to submit a plan and request sufficient funding each year to comply with federal pollution control standards. This document will aid in the annual planning and budget submittals.

This document will address all current D&D problems that have been identified at ORNL. The technology listings in the diagrams were judged to be reasonably applicable to D&D at ORNL.

The TLD provides several benefits to the DOE community. The diagram identifies technologies that can be used for EM programs. It serves as a vehicle to identify the deficiencies in technologies that otherwise have potential to (1) foster faster remediation; (2) allow safer project activities; (3) result in better remediation efforts; and (4) allow these projects to be accomplished at a lower cost to DOE and the United States. Improving existing technologies, demonstrating the applicability of promising technologies, developing immature technologies, and supporting fundamental technology investigations are options that DOE can pursue to deploy technologies necessary for successful EM of DOE facilities. The diagram will highlight areas for private industry and university involvement in EM.

2.2 STAFFING FOR THE TLD

The formulation of the ORNL TLD was led by many of the same professional staff that formulated and published the *Oak Ridge K-25 Site Technology Logic Diagram*, with participation from across ORR. Although a number of ORNL personnel were involved, about half of the team was selected from other Energy Systems organizations in Oak Ridge, such as the K-25 Site, the Y-12 Plant, Central Engineering, and other DOE contractors. The personnel from these organizations represent input to the TLD from programs under the DOE Deputy Assistant Secretaries of Waste Management (EM-30), Environmental Restoration (EM-40), and Technology Development (EM-50), as well as professionals not associated with these programs. Figure 2.1 shows a staffing plan for the ORNL TLD Team.

Specialists worked as members of each team formed for the *subelement* categories shown. Representatives from each team served on a coordinating committee, which functioned as a common communication forum for the TLD. More than 100 specialists were involved in this effort. The teams (1) compiled the site problems in terms that were applicable to each team; (2) identified and evaluated technologies that could be applied to remediate the problems; (3) furnished, through the technology evaluation, information on the opportunities that were evident for development and improvement in each technology; and (4) furnished the requirements for deployment of these developed and improved technologies.

Technology evaluation was a significant component of the TLD effort. Team members identified potential technologies, but it was not necessary for the technology evaluation experts to become familiar with the concepts of the TLD before their evaluations. The data sheets allowed the evaluations to be performed on a systematic basis. The data sheets (Vol. 3, Pts. A, B, and C) provide detailed information and the basis upon which the diagram (Vol. 2, Pts. A, B, and C) was devised.

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Fig. 2.1. The ORNL Technology Logic Diagram Team.

2.3 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) → Reference Requirements → Subelement → Alternative (Generic Technology) → Technology → Technology Status → Science/Technology Need → Implementation Need.

Three different levels of information are provided. First, the technologies are evaluated and ranked in Vol. 1, Pts. A, B, and C. Second, more detailed diagrams are provided in Vol. 2, Pts. A, B, and C. Although each large sheet contains the entire logic path, several sheets are necessary to describe each evaluation area. Finally, each single logic path is published as a technology data sheet. These sheets are the most detailed source of information about each technology and are provided in Vol. 3, Pts. A, B, and C.

The information found under each logic element is described below.

EM Goal has three components: cleanup legacy, prevent future insult, and develop environmental stewardship. These problems are shared by all elements of the DOE complex to varying extents.

EM Problem contains problem areas agreed upon by EM/DOE: such as decommissioning of facilities (D&D); cleanup of soils, ground water, 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, environmental restoration (ER), and WM staff. The magnitudes of the site problems will be indicated in terms of floor areas, estimated metal tonnages, etc.

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

Reference Requirements refers the reader to the final chapters of Vol. 1, Pts. A, B, and C. Requirements can only be determined after consideration of detailed site-, waste-, and technology-specific characteristics.

Subelement specifies the different components that must be addressed to solve the problem. All D&D activities have been categorized into the following subelement groups: characterization, decontamination, dismantlement, robotics/automation, materials disposition, and regulatory compliance.¹ The subelements for RA are characterization; treatment and fixation; retrieval; robotics/automation; materials disposition; and regulatory compliance. The subelements for WM are waste retrieval; characterization; processing; stabilization; minimization; packaging, handling, and transportation; disposal; and regulatory compliance. Table 2.1 lists the various subelements for D&D, RA, and WM.

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

Table 2.1. Subelement categories in the Technology Logic Diagram

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

Technology identifies specific technologies that may be applied to remediate the problem.

Status provides information on the status of the technologies identified in the previous column using the standard categories.

Some accepted technologies are *fully developed* or *commercially available* and if so are noted. These terms are used to denote slightly different meanings. *Fully developed* means that both the basis of the technology and the methods for designing remediation equipment or operations using the method are well known and covered in public literature. *Commercially available* means that the technology is offered by one or more commercial firms, but the data, design methods, or experience needed to assess the technology are not fully available to the public. The only difference in these two categories is that the public's ability to assess the performance and reliability of the technology is restricted for commercial technology. It suggests an unknown degree of risk in the commercially available technologies that cannot be fully evaluated with generally available information (even though the amount of risk may be negligible).

- *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 of the technology exists.

These classifications should provide indirect, 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*—the 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; the analysis time and lower 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.

Science and Technology Needs are perceived needs, 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 that will lead to a technology. Technology improvement needs suggest improvements that will make a current technology more economical to apply, safer, and more effective or efficient. The demonstration of a technology on a site-specific problem is classified as a technology improvement need.

If scientific needs are specified, it should be understood that the needs of scientific technology development or improvement are 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 number, or other reference number. Other work related to the technology area may also be referenced.

Most new 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 or facility from functioning as it was designed and that the equipment can last an acceptable lifetime. Demonstrations are intended to provide final tests of all aspects of a technology. If, however, particular questions remain about the technology, these are specifically mentioned on the diagram.

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. An estimate of the cost of the process and any potential cost payback are also given. 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 reasons for payback, such as reducing the waste volume compared to a reference process, the sale of useable products, and the reduction of labor compared to a reference technology.

When standard laboratory facilities are sufficient, facility needs are not identified. Since the facilities on ORR are relatively extensive—including the K-25 Site, ORNL, and the Y-12 Plant—the diagram does not address needs for standard facilities but focuses on unique facility needs.

However, additional conventional facilities may be needed to meet the technology needs for RA at ORNL because the available facilities may not provide adequate capacity for testing the various technologies. To assess the availability of standard facilities for these programs, it will be necessary to know (1) the rate at which technology development in Oak Ridge will proceed and (2) the extent at which other programs will compete for the facilities.

2.4 TECHNOLOGY RANKINGS

Throughout the technology evaluation a method of conveying information about the ranking and status of each technology and its application is used to communicate separate information about the following:

- Overall assessment of the applicability of the technology (E, H, M, and L, where E is for essential, H for high, M for medium, and L for usefulness.)
- Significance of site problem to which the technology is applied (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 a level acceptable for commercial or large-scale use. The costs are presented as \$M or \$K, which indicates 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). 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 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 Overall Assessment

Following are the criteria used to determine the overall assessment of a technology and its application.

- *Waste Generation Reduction*—ability of the technology to minimize additional waste generation (1-no confidence, 5-complete confidence).
- *Compliance with Requirements [Applicable or Relevant and Appropriate Requirements (ARARs)]*—confidence that the technology will comply with applicable, relevant, and appropriate requirements (1-no confidence, 5-complete).
- *Environmental, Safety, and Health (ES&H)*—ability of the technology to meet the requirements of ES&H (1-no confidence, 5-complete).
- *Versatility*—ability of the technology to meet a wide range of requirements and to adapt to changes in requirements (1-no confidence, 5-complete).
- *Complexity*—ability of the technology to be deployed without requirements for extraordinary levels of expertise, training, and oversight (1-very high level of requirements, 5-low level of requirements).
- *Technical Risk*—confidence that the technology will work at the site(s) being evaluated (1-no confidence, 5-complete confidence).
- *Technical Maturity*—readiness of the technology for deployment at large (commercial) scale (1-very immature-idea for research, 5-ready for commercial application).
- *Development Required*—relative amount of time required to bring the technology to commercial application (1-all research, development, and demonstration steps required, 5-now commercial/no tests required).

- *Development Cost*—relative cost of bringing the technology to commercial application (1—highest cost for development of a technology within a technical area, 5—no costs, not even field testing).
- *Process Cost*—relative cost of process in terms of unit production costs in application (1—prohibitively expensive relative to other methods, 5—very inexpensive compared with other methods).

After scoring the criteria, the scores were averaged and the overall assessment rating was determined by the scale in Table 2.2.

Table 2.2. Scale for overall assessment rating

Assessment code	Code meaning	Score	Meaning
E	Essential		No other processes or technology available for essential requirement
H	High	3.67 to 5	High potential for application
M	Medium	2.33 to <3.67	Medium potential for application
L	Low	<2.33	Low potential for application

2.4.2 Status of Technology

The development state for technology was assessed using the scale provided in Table 2.3.

Table 2.3. Scale for status of technology

State of Technology	Score
Accepted	5
Demonstration needed	4
Predemonstration—evolving	3
Conceptual	2
Preconceptual	1

2.4.3 Estimates for Time to Maturity

Definitions for progress of development and time periods, which were used as guidelines for estimating the total period required to bring technology to the state of large scale application (state of acceptance), are provided in Table 2.4.

Table 2.4. Definitions for progress of development and time periods

Step in development	Definition of step	Years
New technology		
Applied research	Work required to define scientific feasibility	1-3
Development	Bench or engineering scale to define scaling of the technology	2-3
Pilot	Integrated test of process or technology at less than full scale	3-4
Prototype demonstration	Integrated demonstration at full scale	3-5
Commercialization or mature application	Application of the technology at large scale	1-2
Adaptation of existing technology (existing at mature state)		
Synthesis demonstration	Combining existing technologies to meet requirement—demonstrate at pilot scale	2-3
Field test	Testing on the exact site problems and configuration	1-3

These stages of development correspond to the state of the technology and are shown in Table 2.5.

Table 2.5. Correspondence of terms for state of the technology

Status of technology	Score	Development period expressed by time	Development stages
Accepted	5	Available	Mature
Demonstration	4	Short range	Field test
Predemonstration	3	Medium range	Development, pilot, prototype, or synthesis of technology
Evolving—conceptual	2	Long range	Development
Evolving—preconceptual	1	Unknown	Applied research

2.5 REFERENCES

1. T. W. Burwinkle, Decontamination and Decommissioning workshop, Oak Ridge National Laboratory, October 29, 1992.

3. CHARACTERIZATION

3.1 INTRODUCTION

D&D problem areas require characterization to answer the following questions:

1. What contaminants are present?
2. How concentrated are the contaminants?
3. Where are they?
4. How far have they spread?

Identification of the chemical form of the contaminant may also be important, in some cases, for designing treatment schemes. Characterization is needed to locate and quantify contamination and to define contaminant boundaries in or on tanks, pipes, pavement, concrete, plaster, metal structures, insulation, and equipment in buildings. It is required to meet regulatory requirements, to permit risk assessment, and to guide decontamination and dismantling. The technologies involve, for the most part, analyses in the field, although laboratory analyses may also be required. The main contaminant groups of concern are radioactive elements and heavy metals. Organic compounds are of minor importance except for oils, polychlorinated biphenyls (PCBs), and reprocessing chemicals, such as normal hydrocarbons and tributyl phosphate.

This chapter presents the characterization technologies required to support D&D at ORNL; brief overviews of the science/technology needs to bring the technologies to a useable level; implementation needs to deploy these technologies; and rankings of these technologies for D&D.

3.2 TECHNOLOGY OPTIONS

3.2.1 Characterization Technology Options

Characterization technology options for D&D at ORNL are listed in Table 3.1 of Sect. 3.5, along with their rankings. All technologies are not required for each problem; many of the technologies for a given constituent are optional. Many of these technologies are broadly applicable to a variety of constituents and D&D problem areas, and they are listed in Vol. 2 under a "general" problem category. This reflects the applicability of a technology to more than one group of constituents (e.g., radioactive elements and metals) and to more than one problem area (e.g., pipes and tanks). Under this general heading, the technologies are grouped as the following alternatives: sampling design, sample collection, sample preparation, detection/measurement—field methods, and detection/measurement—laboratory methods. Technologies specific to a group of constituents are then listed in Vol. 2 under a specific alternative: radioactive elements (which includes both specific radionuclides and radioactivity), inorganic constituents (cations, anions, and elemental metals such as mercury), organic constituents, physical characteristics, and pathogens. These constituent-specific technologies are subdivided by their deployment in the field or laboratory. Technologies for in situ and ex situ determinations are included in the field and laboratory classifications. Simple and common characterization technologies such as for pH measurements are omitted for simplicity in this compilation. Following "general" listings are specific ORNL problems for which certain technologies are particularly needed.

3.2.1.1 Sampling Design

The main technologies needed under this alternative are statistical designs or approaches for planning sample collection. Although these technologies are not as critical to D&D as they are in remediation of large areas (e.g., burial grounds), they still may be useful in designing sampling strategies for areas such as concrete or asphalt pads and building walls.

3.2.1.2 Sample Collection

Sample collection methods exist for most of the D&D problems at ORNL, but many are inadequate or expensive, and technology improvements are needed. An example is the sampling of surfaces for contamination. Refinements are needed in laser and flashlamp surface desorption methods for organics and other contaminants. Sample coring methodologies are particularly important to determine contaminant depth penetration (as in concrete pads). Because sample collection may have to be conducted in high-radiation fields, the DOE as low as reasonably achievable (ALARA) principle is important in the adaptation and development of such technologies.

Concerns about sample collection are most relevant to ex situ methods of analysis in which samples are collected for transport to the analytical instrumentation.

3.2.1.3 Sample Preparation

One of the largest technology needs is the adaptation of conventional sample preparation methods to the special requirements of radioactive samples, where

containment in a radiochemical hood (low activities of alpha, beta, or gamma-emitting samples) or glove box (primarily for samples with alpha activities of 10^6 disintegrations per minute and greater) or shielding in a hot cell (generally, samples with beta/gamma radiation fields of 500 mR/h or greater) may be required. This includes upgrading organic and inorganic preparation methods and also regulatory leaching procedures. Current methodologies have not been able to meet regulatory requirements in some applications. High-pressure ashing is an example of a critically needed technology for preparing samples for inorganic and radiochemical analyses.

3.2.1.4 Detection/Measurement—Field Methods

These are very important technologies for D&D. Field measurement technologies are needed to define areas and boundaries of contamination. They can also screen samples in the field such that only those with significant contamination are returned to the laboratory for more extensive and expensive characterization. Field-method technologies are also discussed under specific contaminant group alternatives. In this general alternative, major needs are for field measurement technologies for determining radionuclide and heavy metal contamination and, to a lesser extent, certain organics. Deployment of these measurement technologies with robotics and automation is an important crosscutting area that promises to streamline and reduce costs of such surveys. Please refer to the robotics and automation chapter (Chap. 6) of this volume.

3.2.1.5 Detection/Measurement—Laboratory Methods

Laboratory-based technologies capable of multianalyte (e.g., inorganic and organic components) determinations are listed under the "general" alternative, while constituent group-specific technologies are presented under the specific alternatives. A technology need general to laboratory measurements is contamination control of the analytical equipment. This need goes hand-in-hand with adaptation of the sample preparation technologies for radioactive samples.

3.2.1.6 Data Analysis/Management

A wide range of information management and data analysis technologies will be needed, perhaps in some cases required, to support the level of tracking and accounting necessary to assure compliance with environmental laws and guidelines for conduct of activities. Configuration management support will be needed to meet the demands of working in a highly regulated environment, especially in dealing with hazardous materials. Decision aids, including simulation models, databases, full text information retrieval applications, and expert systems will be needed to assist with planning. Statistical analysis, graphical display, and geographical information system support will be needed to assist with analysis and interpretation of data. Large amounts of information and data will need to be transferred between the various groups of people working on the various aspects of the ER effort. Quick, reliable access to data or information distributed among many different organizations will be needed. All of these areas of support are best taken care of using computer networks. Network communications support then becomes yet another area of technology that must be included. The demands on project management and support made by environmental legislation, requirements for safe handling and processing of very hazardous materials,

and having adequate resources to deal with problems on the large scales that are involved make use of automation and networked computing capabilities essential or highly important.

3.2.1.7 Radioactive Elements—Field Methods

Fieldable technologies are needed to define areas of radiological contamination and to quantify radionuclides or radiation fields. They can reduce the sample load (and thus costs) for laboratory analyses and ensure that only the most important contaminated samples are sent to the laboratory for detailed analysis. Technologies for detecting surface contamination are particularly important to D&D.

3.2.1.8 Radioactive Elements—Laboratory Methods

A general technology need is the upgrading of radiochemical laboratory procedures and equipment to make them more rapid and efficient, and to reduce the generation of secondary laboratory wastes. This is important in view of the greatly increased sample load anticipated from WM and the need to minimize costs and wastes. A particularly important technology need is the development and validation of inductively coupled plasma-mass spectrometry methods for determining long-lived, low-specific activity radionuclides. Traditional chemical separation and counting methods are labor intensive and require long counting periods to meet sensitivity requirements. The inductively coupled plasma-mass spectrometry methods also can determine nonradioactive metals.

3.2.1.9 Inorganics—Field Methods

Technologies for determining inorganic composition, particularly on surfaces, are needed for the same reasons as described above for fieldable methods for radioactive elements. Promising technologies include X-ray fluorescence, which is especially useful for quickly measuring surface contamination by heavy metals.

3.2.1.10 Inorganics—Laboratory Methods

There are many established, accepted laboratory methods for inorganic analyses. Adaptation and upgrading these technologies to meet the special requirements of radioactive samples is required. A particularly useful technology is inductively coupled plasma-mass spectrometry methods.

3.2.1.11 Organics—Field Methods

Fieldable methods for organic compounds will be required for numerous deployments in large numbers. The technologies require development to make them more rugged and reliable in the field, simpler to operate so that the technical expertise required to use them is reduced. Fieldable gas chromatography and immunoassay-based field test kits for selected organic compounds or mixtures such as PCBs are high-priority technologies.

Fieldable methods for determining surface contamination by PCBs, oils, and fuel reprocessing chemicals (mainly tributyl phosphate and hydrocarbon residues) will be especially important to specific applications in D&D.

3.2.1.12 Organics—Laboratory Methods

Technologies that determine regulated and DOE-unique compounds (e.g., chelators or chelated radionuclides) are required. Improvements that will reduce secondary waste generation, and increase analytical speed and efficiency are needed in these technologies. Supercritical fluid extraction as a virtually waste-free preparation method and liquid chromatography-mass spectroscopy for nonvolatile analytes are examples of technologies that would greatly support D&D if developed and deployed.

3.2.1.13 Physical—Field Methods

Remote sensing of physical properties is needed to assist decontamination tasks. Fiber-optic systems for measuring multiple physical variables are important fieldable technologies.

3.2.1.14 Physical—Laboratory Methods

Characterization of contaminated materials and objects testing of structures are important technology needs.

3.2.2 Crosscutting Technologies

An important area of technology crosscutting is robotics and automation. This is particularly relevant in two areas of characterization: sample collection or field surveys in situations too hazardous or remote for direct human participation (as during the decontamination of highly radioactive hot cells or equipment) and preparation of highly radioactive samples for analysis (as for highly radioactive samples of scabbled concrete). These crosscutting technologies are discussed in Chap. 6 of this volume.

3.3 SCIENCE AND TECHNOLOGY NEEDS

The basic R&D needs for characterization technologies range from none to considerable. Many characterization technologies are already mature and available on site. Examples of such technologies are gas chromatography-mass spectrometry, for identification and quantification of regulated organic compounds, and inductively coupled plasma-emission spectroscopy, for metals. Some development is required for fieldable-chromatographic instrumentation to determine surface contamination by organic compounds.

Other technologies will require basic research or development. The specific needs are explained in the *Technology Evaluation Data Sheets*, which are included in Vol. 3, Pt. A. Important examples are the surface contamination sampling technologies, such as surface heating by laser and direct interfacing to ion trap mass spectrometry. Development of advanced radiation sensors for field surveys of radiation fields and surface radionuclide contamination is another good example.

3.4 IMPLEMENTATION NEEDS

Implementation needs, like science and technology needs, range from none to considerable. Instruments and U.S. Environmental Protection Agency (EPA) protocols already exist for determining many regulated organics and inorganics. These technologies have essentially no implementation needs and are ready as is for samples that contain no significant radioactive components. Other mature technologies are available on site, but some work is needed to deploy them. This work may entail calibration for the specific constituents and/or sample matrices or adaptation for deployment in certain locations, such as fieldable-gas chromatography or radiation sensors. Performance validation for method quality assurance is included in the implementation costs. Other technologies are not available on site, and it will require greater effort to obtain them and implement them at ORNL.

Some facility upgrades at ORNL are also required to handle the anticipated sample load. This is particularly true for radioactive samples that require shielding or containment and for which current facilities are inadequate.

3.5 TECHNOLOGY RANKINGS

The priorities assigned to the characterization technologies for D&D at ORNL are included in the last column of Table 3.1. The ranking system is essentially the same as that explained in Chap. 2, Sect. 2.3, in this volume.

Table 3.1. Rankings of characterization technologies for D&D

Alternative	Data sheet code number	Technology	Ranking ^a
Generally applicable to all D&D problem areas			
Sampling design	CHAR-252-OL	Sequential sampling plans	M-3-.5 (\$.1M;\$.5Kam ^b)
	CHAR-71-OL	Optimization of sampling designs	H-5-.5 (\$.1M;N)
	CHAR-228-OL	Sampling program configuration management system	E-5-1 (\$.5M;\$.50Kam)
Sample collection	CHAR-20-OL	Ultrasonic extraction	M-4-1 (\$.2M;\$.400/sample)
	CHAR-62-OL	In situ solvent extraction	M-4-2 (\$.4M;N)
	CHAR-81-OL	Sampling and mixing methods	E-5-1 (\$.2M;N)
	CHAR-82-OL	Punch cores	H-5-1 (\$.3M;N)
	CHAR-67-OL	Metallographic sectioning and sample preparation	H-4-0 (\$0M;<\$500/sample)
	CHAR-64-OL	Multiangle drilling for depth profiling of containments	H-4-1 (\$.2M;N)
	CHAR-271-OL	Sampling interface system for surface contamination by organics	H-4-3 (\$.775M;N)
	CHAR-87-OL	Flashlamp heating to release or desorb surface and subsurface contaminants	H-4-2 (\$.5M;N)
	CHAR-86-OL	Laser ablation for sample collection	H-4-2 (\$.5M;N)
Sample preparation	CHAR-205-OL	Radioactive sample preparation	H-4-1 (\$.1M;N)
	CHAR-208-OL	Supercritical fluid extraction of organics	H-4-1 (\$.33M;\$100/sample)
	CHAR-201-OL	Supercritical fluid extraction of inorganics	M-3-2 (\$.2M;N)
	CHAR-209-OL	Adaptation of the EPA ^c toxicity characteristic leaching process for use with radioactive samples	H-5-1 (\$.45M;N)
	CHAR-19-OL	Microwave digestion	H-5-1 (\$.2M;\$100/sample)
	CHAR-203-OL	High-pressure ashing for sample preparation	H-4-1 (\$.1M;N)
Detection/ measurement—field methods	CHAR-25-OL	Fiber-optic chemical sensors	H-5-1 (\$.1M;\$10/sample)
	CHAR-264-OL	Ion mobility mass spectrometry	M-5-2 (\$.1M;\$50/sample)

Table 3.1. (continued)

Alternative	Data sheet code number	Technology	Ranking ^a
Detection/ measurement—field methods (continued)	CHAR-23-OL	Immunoassay detection	H-5-3 (\$1M;\$50/sample)
	CHAR-84-OL	Portable Raman spectrometer	M-5-2 (\$1M;\$10/sample)
	CHAR-27-OL	Optical absorption spectroscopy	H-5-1 (\$.6M;\$50/sample)
	CHAR-59-OL	Air monitoring	H-5-0 (\$.25M;\$500/sample)
	CHAR-18-OL	Infrared spectroscopy (wavelength dispersion)	M-5-1 (\$.5M;\$100/sample)
	CHAR-52-OL	Personnel monitoring	H-5-1 (\$.2M;N)
	CHAR-10-OL	Electrochemical methods	M-4-2 (\$.5M;\$100/sample)
	CHAR-15-OL	Laser photoacoustic spectroscopy	M-5-2 (\$.4M;N)
	CHAR-92-OL	Portable luminescence detection	M-5-1 (\$.5M;\$10/sample)
Detection/ measurement—lab methods	CHAR-204-OL	Contamination control—analytical equipment	H-5-2 (\$.5M;N)
	CHAR-8-OL	Fourier transform infrared spectroscopy	M-4-1 (\$.2M;\$100–500/sample)
	CHAR-48-OL	Isotopic dilution mass spectroscopy	H-4-0 (\$0M;\$100–1000/sample)
	CHAR-11-OL	Nuclear magnetic resonance	M-4-0 (\$0M;\$200–500/sample)
	CHAR-3-OL	Secondary ion mass spectrometry	H-4-0 (\$0M;\$50–400/sample)
	CHAR-9-OL	Ultraviolet/visible spectroscopy	H-5-0 (\$.1M;\$50–200/sample)
	CHAR-4-OL	Laser ionization mass spectrometry	M-4-0 (\$0M;\$100/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)
	CHAR-233-OL	Hazard analysis expert system	E-5-2 (\$.5M;\$150Kam)
	CHAR-234-OL	Application of approximate reasoning to data analysis/evaluation	E-5-2 (\$.5M;\$150Kam)
	CHAR-253-OL	Spatial sample and data analysis plans	H-3-0.5 (\$.1M;\$5Kam)

Table 3.1. (continued)

Alternative	Data sheet code number	Technology	Ranking ^a
Data analysis/ management (continued)	CHAR-251-OL	Statistical methods for the analysis of large data sets	M-3-3 (\$.5M;\$.5Kam)
	CHAR-250-OL	Quality control for measurement processes	E-4-.25 (\$.05M;\$.5Kam)
	CHAR-249-OL	Analysis of censored data	H-4-.25 (\$.05M;\$.5Kam)
	CHAR-44-OL	Criticality indices	L-2-1 (\$.25M;N)
	CHAR-53-OL	Modeling of volatile organic compounds migration in porous materials	M-4-1 (\$.2M;N)
	CHAR-241-OL	Task scheduling aids	M-4-1 (\$.05M;N)
	CHAR-225-OL	Fractals used to select models for material transport in porous media	M-2-2 (\$.5M;\$.20Kam)
	DISM-151-OL	Project information access services (needed enabling technologies)	E-5-1 (\$.5M;\$.100Kam)
	DISM-153-OL	Client/server access to standards and regulatory guidelines (needed enabling technologies)	E-5-0.5 (\$.25M;\$.25Kam)
	DISM-154-OL	Data access services (needed enabling technologies)	E-5-1 (\$.5M;\$.200Kam)
	DISM-181-OL	Geographic information system for DOE sites (needed enabling technologies)	E-5-1 (\$1M;\$.200Kam)
	DISM-155-OL	Automated scanning and conversion of engineering drawings (needed enabling technologies)	E-5-2 (\$2M;\$.300Kam)
	DISM-171-OL	Simulated walk-through facility for robotics task sequence analysis (needed enabling technologies)	E-5-1 (\$.3M;\$.60Kam)
	DISM-191-OL	Computer-based training systems (needed enabling technologies)	E-5-1 (\$.3M;\$.100Kam)
	DISM-172-OL	Computer-aided task analysis and procedure preparation (needed enabling technologies)	E-5-1 (\$.5M;\$.150Kam)
	DISM-157-OL	Client/server architecture for data-base access (needed enabling technologies)	E-5-1 (\$.5M;\$.200Kam)

Table 3.1. (continued)

Alternative	Data sheet code number	Technology	Ranking ^a
Data analysis/ management (continued)	DISM-158-OL	Hypertext information systems (needed enabling technologies)	E-5-1 (\$.3M;\$150Kam)
	CHAR-240-OL	Fiber-optic detection and monitoring system (intelligent materials)	M-4-3 (\$.3M;\$1K/container)
	DISM-156-OL	3-D CAD data base of buildings and structures (needed enabling technologies)	E-5-2 (\$.2M;\$300Kam)
	DISM-173-OL	Generalized object-oriented simulation software (needed enabling technologies)	E-3-2 (\$.5M;\$200Kam)
	DISM-174-OL	Automated engineering system life cycle planning (needed enabling technologies)	E-5-1 (\$.3M;\$60Kam)
	DISM-175-OL	Automated system reliability and safety analysis (needed enabling technologies)	E-5-2 (\$.5M;\$150Kam)
Radioactive elements—field methods	CHAR-108-OL	Proportional counter for alpha and beta activity	H-5-0 (\$.1M;\$100/sample)
	CHAR-102-OL	Passive monitors for weak beta radionuclides	M-4-2 (\$.6M;\$20/sample)
	CHAR-103-OL	Thermoluminescence dosimeter array for spatial characterization of alpha contamination	M-4-3 (\$.6M;\$20/sample)
	CHAR-65-OL	Long-range alpha detector	M-4-1 (\$.4M;\$100/sample)
	CHAR-263-OL	Portable gamma-ray scintillometers	H-4-0 (\$0M;\$100/sample)
	CHAR-269-OL	Advanced radiation monitors	M-4-2 (\$.4M;\$50/sample)
	CHAR-216-OL	Bubble dosimeters for neutron flux	M-4-1 (\$.2M;\$15/sample)
	CHAR-105-OL	Tritium/beta/gamma floor scanner	H-4-0 (\$0M;N)
	CHAR-95-OL	Electret passive surface alpha monitor	H-4-1 (\$.3M;\$15/sample)
	CHAR-96-OL	Alpha track etch detectors for surface alpha contamination	H-4-1 (\$.4M;\$10/sample)
Radioactive elements—laboratory methods	CHAR-107 and 266-OL	Neutron activation	H-4-1 (\$.2M;\$300/sample)
	CHAR-106-OL	Sodium iodide-germanium gamma spectroscopy	H-4-0 (\$0M;N)

Table 3.1. (continued)

Alternative	Data sheet code number	Technology	Ranking ^a
Radioactive elements—laboratory methods (continued)	CHAR-202-OL	Radioanalytical procedures	H-4-2 (\$1M;N)
	CHAR-108-OL	Proportional counter for alpha and beta activity	H-5-0 (\$.1M;\$100/sample)
	CHAR-97-OL	Photon electron rejecting alpha liquid scintillation	H-4-0 (\$0M;N)
	CHAR-268-OL	Gamma-ray spectrometry	H-5-0 (\$.1M;\$100/sample)
	CHAR-267-OL	Liquid scintillation counting	H-5-0 (\$.1M;\$100/sample)
	CHAR-40-OL	Radiographic imaging	M-4-1 (N;N)
Inorganics—field methods	CHAR-76-OL	Atomic emission spectroscopy	M-4-1 (\$.2M;N)
	CHAR-6 and CHAR-219-OL	Portable X-ray fluorescence	H-5-1 (\$.2M;\$25/sample)
	CHAR-111-OL	Laser ablation; inductively coupled plasma; atomic emission spectroscopy	H-5-3 (\$1M;N)
Inorganics—laboratory methods	CHAR-78-OL	Inductively coupled plasma—mass spectroscopy	H-4-2 (\$1M;\$200/sample)
	CHAR-77-OL	Inductively coupled plasma spectroscopy	H-4-0 (\$.1M;\$200/sample)
	CHAR-76-OL	Atomic emission spectroscopy	H-4-0 (\$.1M;\$200/sample)
	CHAR-50-OL	Ion chromatography	H-4-0 (\$0.1M;\$100/sample)
	CHAR-37-OL	Electron diffraction	M-4-0 (\$0M;\$100/sample)
	CHAR-36-OL	Wavelength dispersive X-ray spectroscopy	M-4-0 (\$0M;\$100/sample)
	CHAR-35-OL	Energy dispersive X-ray spectroscopy	M-4-0 (\$0M;\$100/sample)
	CHAR-34-OL	Transmission electron microscopy	M-4-0 (\$0M;\$100/sample)
	CHAR-33-OL	Scanning electron microscopy	M-4-0 (\$0M;\$100/sample)
	CHAR-17-OL	Particle-induced X-ray emission	M-4-0 (\$0M;\$100/sample)
	CHAR-24-OL	Cold-vapor (mercury) analysis	H-4-0 (\$0M;\$100/sample)
	CHAR-266-OL	Neutron activation analysis	H-4-1 (\$.2M;\$200/sample)

Table 3.1. (continued)

Alternative	Data sheet code number	Technology	Ranking ^a
Inorganics—laboratory methods (continued)	CHAR-31-OL	Powder X-ray diffraction	M-4-0 (\$0M;>\$100/sample)
	CHAR-1-OL	Electron spectroscopy for chemical analysis	M-4-0 (\$0M;\$200-\$600/sample)
	CHAR-2-OL	Auger electron spectroscopy	M-4-0 (\$0M;\$300-\$800/sample)
	CHAR-56-OL	Glow discharge ionization mass spectroscopy	H-4-1 (\$.5M;N)
Organics—field methods	CHAR-100-OL	Portable gas chromatograph/electron capture detection for analyzing PCBs ^d	H-4-0 (\$.25M;\$50/sample)
	CHAR-5-OL	Portable volatile organic compound detectors	H-5-0 (\$.25M;\$10/sample)
	CHAR-110-OL	Fluorescence diagnosis of contaminated surfaces	M-3-2 (\$1M;\$10/sample)
	CHAR-85-OL	Infrared absorption (laser-based source)	M-4-2 (\$.5M;N)
	CHAR-262-OL	Gas chromatography in the field	H-5-0 (\$.25M;\$50/sample)
	CHAR-101-OL	Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	M-4-1 (\$.2M;<\$50/sample)
	CHAR-90-OL	Direct sampling ion trap mass spectrometry	H-5-2 (\$.2M;\$50/sample)
Organics—laboratory methods	CHAR-206-OL	Analytical methods for chelators and decontamination agents	M-3-1 (\$.25M;\$500-\$1000/sample)
	CHAR-207-OL	Capillary zone electrophoresis	M-3-1 (\$.25M;\$300/sample)
	CHAR-115-OL	On-line supercritical fluid extraction—multidetector gas chromatography	H-5-1 (\$.25M;\$300/sample)
	CHAR-66-OL	Gas chromatography—fourier transform infrared spectroscopy	M-4-2 (\$.5M;\$400/sample)
	CHAR-89-OL	Liquid chromatography—mass spectrometry	M-4-1 (\$.3M;\$500/sample)
	CHAR-88-OL	Gas chromatography—mass spectrometry	E-5-0 (\$0M;\$200-\$800/sample)
	CHAR-101-OL	Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	H-5-1 (\$.2M;\$10/sample)

Table 3.1. (continued)

Alternative	Data sheet code number	Technology	Ranking ^a
Organics— laboratory methods (continued)	CHAR-94-OL	Gas chromatography	H-5-0 (\$0M;\$300/sample)
	CHAR-93-OL	Laser ablation organic mass spectrometry	H-5-1 (\$.3M;<\$500/sample)
	CHAR-265-OL	Surface-enhanced Raman scattering	H-4-1 (\$.15M;N)
Physical—field methods	CHAR-246-OL	Instrument response models for remote sensing	E-5-2 (\$0.6M;\$200Kam)
	CHAR-248-OL	Fiber-optic systems for measuring multiple physical variables	E-5-3 (\$1M;\$.25/sample event)
Physical— laboratory methods	CHAR-26-OL	Particle size analysis	M-4-0 (\$0M;\$1000/sample)
	CHAR-32-OL	Optical microscopy	M-4-0 (\$0M;\$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-39-OL	Inorganic cementitious matrix composites model	M-4-0 (N;N)
	CHAR-38-OL	Nondestructive testing for concrete	M-4-0 (N;N)
	CHAR-61-OL	Modeling of heterogeneous materials sampling	H-4-0 (\$.3M;N)
	CHAR-42-OL	Radiation-induced segregation model	H-4-2 (\$.5M;N)
Building 9203-1, 3517, and 3019 fuel reprocessing or oil D&D problem areas			
Field methods	CHAR-85-OL	Infrared absorption (laser-based source)	M-3-2 (\$.5M;N)
	CHAR-05-OL	Portable volatile organic compound detectors	H-3-0 (\$.25M;\$10/sample)
	CHAR-90-OL	Direct sampling ion trap mass spectrometry	H-3-2 (\$1M;\$50/sample)
	CHAR-15-OL	Laser photoacoustic spectroscopy	H-3-3 (\$.775M;N)
	CHAR-262-OL	Gas chromatography in the field	H-3-0 (\$.25M;\$50/sample)
	CHAR-18-OL	Infrared spectroscopy (wavelength dispersion)	M-3-1 (\$.5M;\$100/sample)
	CHAR-25-OL	Fiber-optic chemical sensors	H-3-1 (\$1M;\$10/sample)

Table 3.1. (continued)

Alternative	Data sheet code number	Technology	Ranking ^a
Laboratory methods	CHAR-88-OL	Gas chromatography—mass spectrometry	E-3-0 (\$0M;\$200–\$800/sample)
	CHAR-115-OL	On-line supercritical fluid extraction—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 decontamination 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 problem area			
Field methods	CHAR-100-OL	Portable gas chromatograph/electron capture detection for analyzing PCBs	H-3-0 (\$.25M;\$50/sample)
	CHAR-90-OL	Direct sampling ion trap mass spectrometry	H-3-2 (\$.2M;\$50/sample)
	CHAR-15-OL	Laser photoacoustic spectroscopy	H-3-3 (\$.775M;N)
Laboratory methods	CHAR-94-OL	Gas chromatography	H-3-0 (\$0M;\$300/sample)
	CHAR-115-OL	On-line supercritical fluid extraction—multidetector gas chromatography	H-3-1 (\$.25M;\$300/sample)

^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 Kam = Thousands of dollars annual maintenance.

^c EPA = Environmental Protection Agency

^d PCBs = polychlorinated biphenyls

3.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE

DOE is currently developing technologies that could contribute to solving environmental and waste recycling problems at the different DOE sites. Some of these projects may have relevant and beneficial elements with respect to the characterization technologies listed in Table 3.1. Table 3.2 gives the results of a search of available information on programs funded in FY 1992 and FY 1993 and identifies possible matches with the complete set of characterization technologies listed in the TLD, Vol. 1, Pts. A, B, and C. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding characterization technology code by TTP number. When no FY 1993 matches were found and the searcher (based solely on personal knowledge) knew of valid FY 1992 matches, these were entered in the 1993 TTP column. Characterization technologies for which no matches were found are omitted from the table. When many matches were found, specific TTPs may or may not be cited, but it is noted that many exist. The relevance column indicates the degree of overlap between the technologies listed in Vol. 1, Pts. A, B, and C, and active TTP projects. The TTPs comprising the search data base are listed in the appendix.

Table 3.2. Characterization technologies under development by DOE

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Auger electron spectroscopy (AES)	CHAR-2-OL	OR121115	M	Uses EDX ^c for U analysis
Laser ionization mass spectroscopy	CHAR-4-OL	CH101101		Laser-ablated inductively coupled plasma (ICP)
Portable volatile organic compound detectors	CHAR-5-OL	CH101104	H	Portable volatile organic compound (VOC) analyzer
Portable X-ray fluorescence	CHAR-6-OL	RL321114	H	Field-portable XRF
		RL321113	H	Develop field-portable XRF
Fourier transform infrared spectroscopy	CHAR-8-OL	AL221108	M	Uses Fourier transform infrared (FTIR) for chromium
		AL239002	L	Uses in-package tests
		CH111203	M	Integration demo: sensors, monitoring
		CH131001	H	FTIR analysis of waste
Ultraviolet/visible spectroscopy	CHAR-9-OL	OR121101	H	In situ fiber-optic probe development
		OR101101	H	In situ fiber-optic derivative ultraviolet (UV) spectroscopy
		CH101101	H	Mobile ICP atomic emission spectroscopy
		AL213204	M	Robotics to include AES
		AL221108	M	Uses AES for chromium
		CH114101	M	CATD ^d and TIP ^e : sensors, monitors
Electrochemical methods	CHAR-10-OL	RL321112	H	Stripping voltametry
Nuclear magnetic resonance	CHAR-11-OL	RL132002	M	Using technique on polymers
Laser photoacoustic spectroscopy	CHAR-15-OL	AL113101	M	Technology studies
		AL121122	M	Use on Fernald soil samples
		CH101104	M	Portable VOC analyzer
		CH131001	M	Photoacoustic spectroscopy
Infrared spectroscopy (wavelength dispersion)	CHAR-18-OL	CH101104	L	FTIR (but not atmospheric)
Microwave digestion	CHAR-19-OL	AL132006	H	Microwave detoxification of mixed waste
		OR123101	H	Lead lab for EPA SW-846 mixed waste adaptation
Ultrasonic extraction	CHAR-20-OL	AL123101	H	EPA SW-846 for mixed waste
		RF121204	L	Ultrasonic cleaning at RFP ^f

Table 3.2 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Fiber-optic chemical sensors	CHAR-25-OL	OR101101	H	Fiber-optic derivative UV spectrometry
		ID111701	M	Innovative technology development
		SF211203	H	Fiber-optic Raman system development
		SR132003	H	Infrared fiber-optic spectrophotometer
		Many more		Widely pursued technology
Optical absorption spectroscopy	CHAR-27-OL	OR101101	M	Fiber-optic version
		SF211203	H	Fiber-optic differential absorption spectrometer
Scanning electron microscopy	CHAR-33-OL	OR121115 Many More	M	One example of widely used technology
Transmission electron microscopy	CHAR-34-OL	OR121115	M	Example. Mature technology; needs careful sample preparation
Energy dispersive X-ray spectroscopy	CHAR-35-OL	AL221108	M	Using on Cr mobility study
Electron diffraction	CHAR-37-OL	AL121120	H	Site geochemistry characterization use
		AL121122	H	Site geochemistry characterization use
		AL221108	H	Cr mobility studies
		OR121115	H	U solubility in soil study
Inorganic cementitious matrix composites model	CHAR-39-OL	CH331001	L	Cement matrix grout development and application
Computer tomography	CHAR-41-OL	AL221123	M	Electromagnetic tomography (especially water) of underground sites
		SF223203	H	Developing CT for waste drum inspection
Subsurface complexation model	CHAR-45-OL	AL931102	L	Geochemistry: Monticello, Utah
		ID111701	L	Chelation: lanthanides, actinides
		RL331002	L	Chemical barriers in-ground
Ion chromatography	CHAR-50-OL	Many		Accepted and widely used
Modeling of volatile organic compounds migration in porous materials	CHAR-53-OL	None except soil		Much work directed at soil
Membranes for sample collection and concentration	CHAR-55-OL	OR111204	M	HEPA ^g filter
		AL131007	M	VOC in air sampling
		AL221107	L	Borehole membrane liner
		SR121106	L	Membrane use
Glow discharge ionization mass spectroscopy	CHAR-56-OL	AL131007	M	Membrane sampling ion trap mass spectrometry

Table 3.2 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Magnetic resonance imaging	CHAR-58-OL	RL132002	M	Using technique on polymers
Air monitoring	CHAR-59-OL	Many		Widely used. Tailor to application need
Tomographic seismic monitoring	CHAR-60-OL	AL201101	H	Seismic tomography development, use SRID ^h
		AL221123	M	Underground imaging (resistance)
		CH221101	M	Seismic wave measurement of clay at Savannah River
		SF121101	H	High-resolution seismic imaging
		SF121102	M	Underground imaging (resistance)
		AL921102	M	Seismic survey and analysis
Modeling of heterogeneous materials sampling	CHAR-61-OL	SR132003	L	Chemometric models tank waste spectrophotometry
In situ solvent extraction	CHAR-62-OL	SR121107	L	Vacuum extraction of VOC from soil at SRID
		Many more	L	
Long-range alpha detector	CHAR-65-OL	AL131002	H	LRAD developed, used at Fernald
Atomic emission spectroscopy	CHAR-76-OL	Many		Widely used technique
Inductively coupled plasma spectroscopy	CHAR-77-OL	CH101101	H	Mobile ICP-AES development
		Many		Widely used technology
Inductively coupled plasma—mass spectroscopy	CHAR-78-OL	OR111105	M	Direct sampling ion-trap mass spectrometer (ITMS)
		AL113101	M	Covered in field screening project
Sampling and mixing methods	CHAR-81-OL	AL131003	H	Use on Fernald soil
		NV031001	H	Use on Nevada Test Site soil
Portable Raman spectrometer	CHAR-84-OL	OR121101	H	Fiber-optic raman sensor development
		OR101101	H	Employ sensor on aromatic hydrocarbons (HCs)
		RL401206	M	Use raman sensing in hot cell
		SF211203	H	Development raman sensor for RL401206
Infrared absorption (laser-based source)	CHAR-85-OL	RL401206	M	Near IR absorption
		SF211203	H	Near IR raman with diode laser
Laser ablation for sample collection	CHAR-86-OL	CH101101	H	Laser ablation ICP development
Gas chromatography—mass spectrometry	CHAR-88-OL	Many		Widely used

Table 3.2 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Liquid chromatography—mass spectrometry	CHAR-89-OL	AL113101	M	Considered in field screening
		ID101301	H	Used on hydrophobic organic compounds (HOCs)
		SR132002	H	Used on cesium extraction project
Direct sampling ion-trap mass spectrometer	CHAR-90-OL	OR101102	H	Development
		OR101103	H	Development and application
		OR101105	H	Use with army toxic materials
		OR121103	H	Use at SRIDP ⁱ
		Others		
Portable luminescence detection	CHAR-92-OL	OR121201	H	Luminescence spot test for PCBs
Laser ablation organic mass spectrometry	CHAR-93-OL	CH101101	H	Laser ablation ICP
Gas chromatography	CHAR-94-OL	Many		Widely used
Photon electron rejecting alpha liquid scintillation	CHAR-97-OL	ORNL-DOSAR Facility	H	Evaluate uranium resuspension at Weldon Springs cleanup
Portable gas chromatograph/electron capture detection for analyzing PCBs	CHAR-100-OL	RL321101	M	HOC monitoring off-gas treatment project VOC-nonarid
Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	CHAR-101-OL	OR121101	H	In situ fiber-optic probe development
Sodium iodide-germanium gamma spectroscopy	CHAR-106-OL	AL131004	M	Gamma detector used in project
		AL931001	M	Gamma detector used in project
Neutron activation	CHAR-107-OL	AL911201	M	Neutron activated fission for detection of uranium
		AL921101	M	Prompt fission neutron logging
		AL931001	M	Neutron activated fission
Fluorescence diagnosis of contaminated surfaces	CHAR-110-OL	OR121101	M	In situ fiber-optic probe development
Laser ablation; inductively coupled plasma; atomic emission spectroscopy	CHAR-111-OL	CH101101	H	Laser ablation ICP
		CH501301	H	Field test, Fernald
On-line supercritical fluid extraction—multidetector gas chromatography	CHAR-115-OL	AL123101	M	Use for SW-846 methods
		ID4231010	M	Use for SW-846 methods
Ground-penetrating radar	CHAR-124-OL	AL921102	H	Used on mixed waste landfill
		NV001102	M	Airborne tests
		RL313203	H	Tested on landfill

Table 3.2 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Electrical and electromagnetic detection of ground and geologic features	CHAR-125-OL	SF121102	H	Underground imaging (resistance)
Seismic methods (refraction, profiling, reflection)	CHAR-126-OL	AL201101	H	Seismic tomography development, use SRID
		CH221101	M	Seismic wave measurement of clay at Savannah River
		SF121101	H	High-resolution seismic imaging
		AL921102	M	Seismic survey and analysis
Magnetics	CHAR-128-OL	AL911201	H	Tensor magnetic gradiometer
		AL921102	M	Landfill characterization
		ID132003	H	Use for site characterization
Supercritical fluid extraction of inorganics	CHAR-201-OL	ID111701	H	Lanthanides and actinides with lariat crown ethers
Radioanalytical procedures	CHAR-202-OL	CH013102	L	EM/ analytical laboratories performance evaluation
Contamination control—analytical equipment	CHAR-204-OL	AL213203	L	Characterization automation
Radioactive sample preparation	CHAR-205-OL	OR123101	M	Adapted SW-486 methods for radioactive mixed waste analysis
Analytical methods for chelators and decontamination agents	CHAR-206-OL	AL132002	M	Polymers for Pu and Am concentration for wastewater
Capillary zone electrophoresis	CHAR-207-OL	SF213203	M	Robotic cross cutting advanced technology
Supercritical fluid extraction of organics	CHAR-208-OL	ID111701	L	Lanthanides and actinides with lariat crown ethers
Adaptation of the EPA toxicity characteristic leaching process for use with radioactive samples	CHAR-209-OL	RF101205	L	Incineration alternatives
Fissile material locator/profiler	CHAR-212-OL	NV021701	H	Associated particle imaging
		AL931001	L	Multispectral neutron logging
X-ray fluorescence for in situ monitoring of toxic heavy metals	CHAR-219-OL	RL321114	H	Field-portable XRF
		RL321113	H	Field-portable XRF development
Sampling program configuration management system	CHAR-228-OL	Many	H	Used at many other sites
Configuration management system	CHAR-229-OL	Many	H	Used at many other sites

Table 3.2 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Fiber-optic systems for measuring multiple physical variables	CHAR-248-OL	SF213203	H	Microsensor systems development
Quality control for measurement processes	CHAR-250-OL	CH013101	H	Analytical management—quality assessment program (EML ^h)
Sequential sampling plans	CHAR-252-OL	Many	H	Accepted and widely used
Spatial sample and data analysis plans	CHAR-253-OL	Many	H	Accepted and widely used
Solid sorbent sampling for airborne organics	CHAR-254-OL	AL113101	M	Field screening study
Soil/sediment sampling for volatile organics analysis	CHAR-256-OL	Many	H	Widely found
In situ ground-water flow meter	CHAR-258-OL	OR121104	H	Colloidal borescope
Ground-water discharge location	CHAR-259-OL	Many	H	Accepted and widely used
Waste drum gamma activity monitor	CHAR-261-OL	SF223203 SR113201	H H	Waste facilities operation & sorting technology Savannah River robotics, waste facilities operations
Gas chromatography in the field	CHAR-262-OL	ALTIPMSA	M	Mobile sample analysis laboratory
Portable gamma-ray scintillometers	CHAR-263-OL	AL112101 SF223203	L M	Field screening studies Used in waste facilities operations
Surface-enhanced Raman scattering	CHAR-265-OL	OR121101 SF211203	H M	Spectroelectrochemical sensors Advanced fiber-optic spectroscopy for inorganic contaminants
Neutron activation analysis	CHAR-266-OL	AL131004 AL931001	M H	Multispectral neutron logging Multispectral neutron logging
Liquid scintillation counting	CHAR-267-OL	AL931102 ORNL-DOSAR Facility	L H	Chemical barriers demonstration U resuspension evaluation
Gamma-ray spectrometry	CHAR-268-OL	RL132002	M	Polymer concentration of U and Pu (gamma technique)
Advanced radiation monitors	CHAR-269-OL	AL121218 ID111701 ID121210	M M M	Real time emission monitor Fiber-optic thermoluminescence dosimeter monitor development BWID contamination control

Table 3.2 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Sampling of heterogeneous wastes	CHAR-270-OL	AL123101	M	Adapted SW-846 methods for mixed waste analysis
Sampling interface system for surface contamination by organics	CHAR-271-OL	CH101101	H	Laser ablated ICP mass spectrometer
SEAMIST inverted membrane	CHAR-273-OL	AL221107	H	Landfill characterization system
Hydrofracture ground-water monitoring	CHAR-274-OL	Many	H	Accepted and widely used
Sediment sampling	CHAR-276-OL	OR113203	H	Robotics advanced technologies

^aTTP = Technical Task Plan Identifier.

^bThe relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagrams* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need;
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

^cEDX = energy-dispersive X-ray analysis

^dCATD = Center for Advanced Technology Development

^eTIP = Technology Information Program

^fRFP = Rocky Flats Plant

^gHEPA = high-efficiency particulate air

^hSRID = Savannah River integrated demonstration

ⁱSRIDP = Savannah River Integrated Demonstration Project

^jEM = environmental management

^kEML = Environmental Measurements Laboratory

4. DISMANTLEMENT/DISASSEMBLY

4.1 INTRODUCTION

The dismantlement section of the TLD addresses site-specific problems and needed technologies that appear to offer the most promise for remediation. Figure 4.1, the D&D Sequence Chart, was prepared as a potential process for identifying steps by the dismantlement team. Please note that all steps in the sequence highlighted by the bold, outlined boxes are considered dismantlement tasks.

Figures 4.2–4.6 show typical facilities at ORNL that are included in the D&D Program. Of specific interest is Fig. 4.5. The Molten Salt Reactor Experiment facility still contains the highly radioactive fuel shown in the tanks in Fig. 4.5. The Molten Salt Reactor Experiment was a single-region, unclad-graphite-moderated, homogeneous-fueled reactor built for investigation of the practicality of the molten salt reactor concept for power station applications. The circulating molten fuel was a mixture of lithium, beryllium, and zirconium-fluoride salts, containing uranium fluoride as a fuel (^{233}U). Figure 4.6 is a layout of the Homogeneous Reactor Experiment. The Homogeneous Reactor Experiment facility housed two experimental reactors that were developed for nuclear power applications analysis. The fuel in these reactors was an aqueous liquid and has been removed from the facilities.

Fig. 4.1. Decontamination and Decommissioning sequence chart.

Fig. 4.2. Typical operating face of mechanical processing cell.

Fig. 4.3. Typical chemical processing hot cell with roof plug removed.

Fig. 4.4. Conventional manual dismantlement technique in low-radiation areas.

Fig. 4.5. Drain tank cell for Molten Salt Reactor Experiment during construction.

Fig. 4.6. Homogeneous Reactor Experiment Facility Schematic.

4.1.1 Problem Area/Constituents for Dismantlement at ORNL

4.1.1.1 Massive Containment

These technologies will address problems associated with the removal of mechanical and chemical hot-cell structures, which is primarily heavily reinforced concrete contaminated with ^{60}Co , ^{137}Cs , ^{90}Sr , and other fission products. Radiation fields may exceed 2,500 R/h. An example of this is the fuel storage cell in the Molten Salt Reactor Facility.

4.1.1.2 Reactor Pools

These technologies will address problems associated with the removal of pool-type structures such as the Oak Ridge Research Reactor. These structures may be contaminated with ^{60}Co , ^{90}Sr , ^{137}Cs , ^{14}C , ^{55}Fe , and other fission products. Technologies here are similar to those listed under Massive Containment except emphasis is placed on under water applications. Radiation fields on surfaces may exceed 50,000 R/h. An example of this problem is the Oak Ridge Research Reactor Pool.

4.1.1.3 Buried Tanks

These technologies are selected for their applicability to buried tanks such as the Gunitite Tanks. Also in this category would be buried vaults housing tanks or housing underground process equipment. These structures are typically contaminated with all possible contaminants listed in Sect. 4.1.1.1.

4.1.1.4 Structural-Only Concrete

This problem category addresses technologies typical for nonnuclear deconstruction.

4.1.1.5 Steel Structures—High-Level Contamination

These technologies are directed toward removal of steel structural materials that are possibly heavily contaminated with ^{137}Cs , ^{90}Sr , Ce, and Ru. Radiation levels may be 10–100 R/h. An example of this is secondary containment structure of the Homogeneous Reactor Experiment.

4.1.1.6 Steel Structures—Low-Level Contamination

These technologies are directed toward removal of steel structural materials that are contaminated with trace quantities of fission products, plutonium, ^{14}C , ^{55}Fe , ^{137}Cs , ^{90}Sr , and ^{60}Co . An example of this problem is the roof structure of the Oak Ridge Graphite Reactor.

4.1.1.7 Asbestos Removal

These technologies address the removal of asbestos materials contaminated with trace amounts of fission products, ^{137}Cs , ^{239}Pu , ^{233}U , and ^{228}Th . An example of this problem is the Molten Salt Corrosion Loop. Maximum radiation levels are 3500 dpm/100 cm², transferable.

4.1.1.8 Major Equipment Removal

These technologies are applicable to equipment removal, size reduction, and packaging of items contaminated with minor to very significant amounts of radioactive isotopes, including fission products, ^{60}Co , ^{137}Cs , ^{90}Sr , and TRU materials. Examples of this problem are the fuel storage tanks and piping in the fuel storage cells in the Molten Salt Reactor Facility and the process piping and equipment in the experimental cells of the Oak Ridge Research Reactor.

4.1.1.9 Entombment

These technologies are the last step of dismantlement, used after other D&D steps have been completed. They are applicable to either temporary or permanent isolation of the remaining facilities. An example of this would be filling the basement structures with an impermeable material (concrete) to affix the remaining contamination.

4.1.1.10 Retrieval

These technologies are applicable to the exhumation of equipment previously buried or stored in ways currently deemed unacceptable. An example of this would be the removal of highly contaminated pieces of equipment buried in a solid waste burial ground that are contributing significantly to underground waste plumes or other RA problems.

4.1.1.11 Equipment Pre-disposal Staging

This function will address the predisposition of dismantled equipment. Examples of these would be shredding of equipment for size reduction and/or packaging of such items. All technologies in the dismantlement tasks are applicable here if properly integrated.

4.1.1.12 Enabling Technologies

Dismantlement activities will almost always be conducted in a highly regulated environment covering conduct of operations, handling of hazardous materials, transportation of materials and equipment, equipment calibration and maintenance, and disposal of many kinds of wastes. Large amounts of different kinds of information and data must be accessible for planning, training workers, and assuring high quality of operations. The most cost-effective and reliable way to meet such requirements is to make extensive use of computing technology. Data bases are needed to store maps, locations of engineered structures, waste storage areas, locations of contamination, drawings of as-built structures, properties of hazardous materials, and much more. In some cases additional mapping of structures will be required, especially for problem areas in which remote manipulation or robotic systems must be used. Convenient and reliable access to information must be provided through the use of networks and graphical displays. Automated planning tools will be essential to keeping up with constantly evolving regulatory requirements. Robust and reliable tagging systems will be needed for tracking materials. The wide range of computing technologies identified for this area will have to be integrated according to an overall system plan or architecture that constitutes a Network Information System so that these technologies can work together effectively.

4.2 TECHNOLOGY OPTIONS

4.2.1 Massive Containment, Reactor Pools, Buried Tanks, and Structural Concrete

Seven technologies were identified for these problem constituents. See Table 4.1 in Sect. 4.5.2 for the most favored technologies. Successful application of these technologies to concrete in D&D of ORNL will depend on how well they can be integrated with robotics and/or automatic systems. All the technologies have been used at nuclear facilities with varying success. Also, more efficient application will depend on improved protective systems for operators and maintenance personnel.

4.2.2 Steel Structures—High-Level and Low-Level Contamination

Removal of steel structures, as seen in Fig. 4.1, will be a process varying from remote removal to conventional removal, depending upon the contamination level. Twelve technologies were identified that are potentially useful in dismantlement of structural steel. See Table 4.1 for the most favored technologies. For highly contaminated structures, successful application will depend on the technology's effective integration with remote delivery systems. Also, success will depend on limiting the spread of contamination during D&D operations.

4.2.3 Asbestos Materials

Six technologies were identified for the removal of asbestos materials. The generic categories are either to cut the asbestos loose or strip it away. Both scenarios will require packaging of loose asbestos materials and reduction and/or collection of airborne asbestos. The focus these activities is to keep the asbestos from becoming more contaminated so that the resulting materials can be disposed of at minimum cost. Also, containment of any contaminated asbestos or matrix-materials dust must be achieved during removal.

4.2.4 Major Equipment Removal

Sixteen technologies were identified for removing equipment from ORNL facilities. Twelve technologies involve some form of cutting. All of the technologies are commercially available. The major task in applying these systems will be to cut and remove the contaminated equipment while containing the contamination. It is important to provide safety for workers by maintaining the proper engineering of the containment systems. A combination of dismantlement and robotics will remove the worker from the actual cutting site and automation of the repetitive tasks will provide maximum benefits.

Figures 4.7 and 4.8 depict concepts that were considered during the technology identification stage. The concepts shown are for remote removal of equipment from a typical reactor process cell.

4.2.5 Entombment

Entombment was identified as a problem area/constituent after discussions with knowledgeable personnel at other DOE sites, as well as ORNL D&D personnel planning future activities. Most facilities at ORNL will require some form of entombment activity

Fig. 4.7. Integrated, heavily shielded facility (dismantlement concept).

Fig. 4.8. Potential dismantlement end effectors. Many others are possible for characterization, decontamination, and dismantlement.

before completing D&D processing and reaching the end state. Entombment includes all technologies that result in isolation of contaminated materials from the biosphere for a long period of time. Technologies included under "dismantlement" address those entombment activities that will isolate large pieces of equipment either removed from facilities, retrieved from past burial operations, or left in a facility and isolated in place. Eleven technologies were identified as applicable to entombment.

4.2.6 Retrieval

Dismantlement includes some tasks that are included as retrieval tasks under RA. Mechanical exhumation of equipment items and packaged items that, if removed today, should have been handled as dismantlement tasks. These items will be retrieved from burial grounds and handled in the "dismantlement flow" shown in Fig. 4.1.

Six technologies were identified and are included in the RA volumes. The data sheets are in Vol. 3, Pt. B. The Logic Flow Diagram in Vol. 2, Pt. B, includes these technologies relative to the specific site problems, and Vol. 1, Pt. B includes a description of their ranking for the RA-site problems.

4.2.7 Predisposal Staging

After equipment is removed for dismantlement, a decision is required as to the ultimate disposal options. Technologies will be required to inspect, reduce size, package, and temporarily hold items prior to transfer to the selected disposition activity areas. At ORNL this will most likely mean establishing a staging facility with capacity to remotely process equipment items. The Oak Ridge Research Reactor with its currently functional pool, may serve as a possible handling facility for such tasks. Two specific technologies were identified, but virtually all dismantlement technologies would be useful in this conceptual facility.

4.2.8 Needed Enabling Technologies

Twenty-four technologies were identified in this area. These technologies will, if properly engineered into the overall D&D ORNL facilities, provide benefits to dismantlement as well as other tasks. Current as-built information does not provide detailed descriptions of what is in the contaminated facilities. Process equipment has been removed, modifications have been made, and items have been stored in the facilities without accurately updating the engineering information.

Examples of benefits from enabling technologies include:

- updated engineering drawings for the facilities to be dismantled,
- accurate 3-dimensional inventories of materials,
- reasonably accurate location of equipment to permit positioning of automatic dismantlement tooling,
- dismantlement tooling utilization planning to aid the scheduling of equipment and manpower,
- real-time status feedback to deconstruction schedules and progress reports,
- continual waste and recycle materials inventories and tracking,
- query capability for investigation of alternative approaches and processes,

- accessible data for establishing a common mission and goal, plan, and
- conceptual 3-dimensional modeling capability for studying other technologies without actual procurement of equipment.

All of the technologies identified under "Enabling Technologies" are intended to enhance or improve the available engineering data bases. Computer-based data bases that would provide accurate 3-dimensional models can be generated. This data could be used to record characterization information, decontamination data, equipment locations, and related technologies by specific location in the facilities. Then this data could be used to guide automated tooling and/or robotics during the dismantlement process, while providing a real-time, automatic, updated data base.

Any demonstration of state-of-the-art technologies would provide guidance in the future on these D&D efforts. In fact, the ORNL facilities could be viewed as potential candidates for Integrated Demonstrations and/or test beds to serve as surrogates for facilities at other sites where remote equipment and tooling are needed. Therefore, the study group recommends including these technologies into any future D&D development effort or demonstration.

Two enabling technologies were identified under the alternative of Dismantlement Support. These are an automation technique for directing cutting called "point and direct" and "updated designs for protective clothing."

The studies to the time of this document have put emphasis on the use of currently demonstrated technologies. Among the high-cost items included in this analysis is their dependency on labor intensive techniques and the necessary protective clothing. Experience indicates that 30-50% of the cost can be attributed to reduced crew efficiency due to protective clothing and equipment required. This cost can be offset by automated dismantlement tooling and sophisticated delivery systems, thereby reducing manual labor and improving protection to D&D workers.

Some manner of manual work will always be required regardless of the degree of automation used in the dismantlement tasks. To this degree the development of improved (cheaper, recyclable, lighter, more convenient, etc.) protective equipment is certainly justified.

New, more efficient, versions of clothing and protective equipment have the potential of saving vast sums of money and labor. Respirators, face masks, air packs, cloth suits, air-tight suits, gloves, shoe covers, laboratory coats, air-conditioned and filtered-equipment cabs, etc., need improved designs to reduce cost in a massive dismantlement project such as a diffusion plant and its support facilities.

4.3 SCIENCE AND TECHNOLOGY NEEDS

An extensive search has been made of potential dismantlement technologies that are applicable to ORNL facilities scheduled for D&D. Of the 100 technologies identified, all are existing in the commercial sector or have been used at other sites for D&D tasks. The primary science needs are in the areas of reduction of secondary contamination and adaptation of robotics delivery systems. The rankings given in Table 4.1 depend, to significant degree, on reduction of secondary-waste volume and spread to secondary volumes.

The other significant science and technology needs are the development of information systems. Dismantlement activities will almost always be conducted in a highly regulated environment covering conduct of operations, handling of hazardous materials, transportation of materials and equipment, equipment calibration and maintenance, and disposal of many kinds of wastes. Large amounts of different kinds of information and data must be accessible for planning, training workers, and assuring high quality of operations. The most cost effective and reliable way to meet such requirements is to make extensive use of computing technology. Data bases are needed to store maps, locations of engineered structures, waste storage areas, location of contamination, drawings of as-built structures, properties of hazardous materials, and much more. In some cases, additional mapping of structures will be required, especially for problem areas in which remote manipulation or robotic systems must be used. Convenient and reliable access to information must be provided through the use of networks and graphical displays. Automated planning tools will be essential to keeping up with constantly evolving regulatory requirements. Robust and reliable tagging systems will be needed for tracking materials. The wide range of computing technologies identified for this area will have to be integrated according to an overall system plan or architecture that constitutes a Network Information System so that these technologies can work together effectively.

4.4 IMPLEMENTATION NEEDS

All of the dismantlement technologies identified require some demonstration to become accepted at the ORNL Site. Implementing even basic technologies, such as torch cutting, will require robotic delivery systems. Implementation of a technology at ORNL centers around timely, adequate demonstration in an integrated system.

An integrated demonstration of dismantlement technologies is needed and recommended so that proper conceptual engineering information can be generated and evaluated. From this information, well-conceived specifications could be prepared for the eventual large-scale dismantlement equipment. This would avoid the need for conservative selection of currently proven processes.

In this dismantlement study, technologies have been investigated individually. Integration of multiple new technologies would magnify the potential benefits. Significant cost and safety benefits would likely result from the cascading effect in an integrated demonstration. The integrated demonstration needed would require selection of areas within ORNL to be dismantled under very controlled conditions. In these areas of the buildings, each of 20-30 technologies would be applied under controlled conditions and evaluated for efficiency of operation. The technologies could then be integrated either through computer modeling techniques or actual demonstrations.

4.5 TECHNOLOGY RANKINGS

4.5.1 Introduction

Selection of technologies for development and use in the D&D facilities at ORNL is a very difficult task. Multidimensional trade-offs are required relative to the availability, complexity, and cost of technologies that appear applicable but have not been demonstrated and/or accepted at ORNL. Also, the variety of facilities makes selection of generic technologies difficult. For example, technologies applicable to hot cells may have limited usefulness for reactor pools. This section reports the evaluation of technologies in a systematic way and recommends those showing the most potential for future use and development.

This development should occur through inclusion in future demonstrations or in ongoing development activities at appropriate installations. The data show that directed R&D of the recommended candidate technologies will significantly reduce the cost of D&D at ORNL facilities. Also, benefits can be further magnified if candidate systems spin off benefits to other DOE sites through the sharing of engineering documentation or actual hardware transfer. Table 4.1 shows rankings of the most favored technologies.

All technologies were ranked against the criteria as described in detail in Sect. 2.1. In some cases the criteria may have been interpreted differently by teams, depending upon the problem being addressed. For example, "versatility" for dismantlement is almost exclusively interpreted as "applicability to robotic tooling," but other teams may take "versatility" as "application to a variety of problems."

The general ranking scheme is described in detail in Sect. 2.1.

4.5.2 Rankings

After ranking the technologies, the more promising technologies are apparent. Throughout the TLD exercise, it can be shown that the most advantageous application of any dismantlement technology requires its incorporation into a dismantlement system. When designed, these systems would include not only dismantlement technologies but possibly all of the teams' needs merged into one or more systems for example, decontamination and characterization technologies may use the same delivery system. If inclusive systems are designed, they will magnify the potential benefits.

All of the technologies in Table 4.1 will require a timely and adequate demonstration in an integrated demonstration, and proper specifications must be prepared by Engineering based on data from integrated demonstrations.

Dismantlement technologies are grouped by the ORNL Problem for dismantlement. The rankings of the technologies are based on perceived benefits, assuming that they are adequately addressed in an integrated demonstration and proper specifications are prepared by Engineering based upon development and engineering data available.

4.5.3 Conclusions and Recommendations

All of the technologies addressed are applicable to the dismantlement of typical ORNL facilities. Each technology has an area that it would benefit if applied. An integrated demonstration of dismantlement technologies is needed and recommended (see Sect. 4.4).

A carefully integrated systems approach to the dismantlement of ORNL facilities will show the need for much off-site support. Some problems at ORNL, such as the

Table 4.1. Rankings of dismantlement technologies for D&D

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 4.1 (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 massive mobile shearing	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 water 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—subsurface waste storage with void reduction	H-4-3 (\$0.5M;\$10/ft ³)
DISM-115-OL	Engineered storage—for very “hot” items, future disposal	H-4-8 (\$7M;\$400/ft ³)
DISM-118-OL	Sensors for monitoring 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—aboveground environmental barrier	H-4-3 (\$0.5M;\$3/ft ³)

Table 4.1 (continued)

Data sheet code numbers	Technology	Ranking ^a
Needed enabling technologies		
DISM-191-OL	Computer-based training systems	H-4-1 (\$.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 data base 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 services	H-4-1 (\$0.5M;100K/yr)
DISM-153-OL	Client/server access to standards and regulatory guidelines	H-4-0.5 (\$.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 system	H-4-2 (\$0.5M;300K/yr)
DISM-171-OL	Simulated walk-through facility for robotics task sequence analysis	H-4-1 (\$.3M;60K/yr)

^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.

disposition of the Molten Salt Reactor Experiment's fuel storage tanks, are beyond the capabilities of even the most advanced, conceived technologies. Therefore, engineered-storage facilities are a key element of any major D&D of ORNL facilities. By carrying the integration of D&D technologies one step further, an interesting scenario develops within the Oak Ridge area.

Facilities exist in Oak Ridge, such as the expansive diffusion facilities at the K-25 Site, that may make ideal storage facilities for cask and safe containers containing items not considered for ultimate disposal. Therefore, integration of D&D efforts at ORNL and the K-25 Site should be considered.

Several advantages would be realized from an integration of D&D at the K-25 Site and ORNL:

1. Empty diffusion buildings, especially K-33 and K-31, are in excellent structural condition with heavy-duty concrete floors, large cranes, and handling capability already in place. If a use can be made of these structures, then disposal of a large amount of transite and low-level contaminated structural material can be avoided.
2. Removal, safe packaging, and storage at the K-25 Site of the high-level items will not increase the contamination level of the diffusion buildings.
3. Well-engineered, safe packaging of the high-level items will not increase the contamination level of the diffusion buildings.
4. Shipment of properly packaged high-level items from the K-25 Site to the ultimate disposal facilities—such as Yucca Mountain or a salt repository—will be simple, relative to the handling and transport required if special individual casks were constructed now.

A typical reactor-type facility should be selected at ORNL as the target facility that will demonstrate the selected technologies from this study. A systems approach must be taken to integrate the selected technologies, not only for dismantlement but for all teams, so that the problems at the target facility are addressed. In addition to this system, a much larger "Mega System" should be considered to integrate the K-25 Site D&D efforts with ORNL's. Such action will take advantage of all resources in the D&D arena—such as the massive buildings at the K-25 Site—and will reduce or eliminate all problems at both sites.

It is further recommended that this effort commence as soon as possible in order to take advantage of the vast technical experience still existing in Oak Ridge. Many technical personnel are still available, either still employed or retired, who worked hands-on with the facilities scheduled for D&D at both sites. The value of this resource cannot be overstated. The following are factors currently available at ORNL:

- partial, but well-cataloged, on-site engineering data bases for as-built condition;
- existing designs for dismantlement tooling (for past maintenance and process);
- on-site engineering personnel and other technical personnel, as part of a skilled three-plant organization, that will have extensive experience in many areas, including
 - hot-cell operations,
 - technology development,
 - remote handling and maintenance,
 - glove box design and operation,
 - special tooling design,
 - weapons dismantlement,
 - nuclear materials production and packaging,
 - RA, and
 - WM; and
- project management expertise in all of the above.

Also available and specific to ORNL are the following:

- radiation hazard-experienced personnel;
- development facilities for laboratory testing;
- integrated staff of health physics, maintenance, and other support groups;
- immediate access to Y-12 and K-25 personnel with readily available, related skills;
- minimum hazards to the public because of the isolated location of the facilities; and
- experience in dealing with all nuclear isotopes.

4.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE

DOE is currently developing technologies that could contribute to solving environmental and waste recycling problems at the different DOE sites. Some of these projects may have relevant and beneficial elements with respect to the dismantlement technologies listed in Table 4.1. Table 4.2 gives the results of a search of available information on programs funded in FY 1992 and FY 1993 and identifies possible matches with this list of dismantlement technologies. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding dismantlement technology code by TTP number. When no FY 1993 matches were found and the searchers (based solely on personal knowledge) knew of valid FY 1992 matches, these were entered in the 1993 TTP column. Dismantlement technologies for which no matches were found are omitted from the table. When many matches were found, only one or two were cited. The relevance column indicates the degree of overlap between the listed dismantlement technologies and active TTP projects. The TTPs comprising the search data base are listed in the appendix.

Table 4.2. Dismantlement technologies under development by DOE

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
High-pressure abrasive water jet (massive containment)	DISM-11-OL	AL221205	M	Hanford tank use
		AL221302	M	Weapons Disposal Integrated Demonstration use
		RL332003	L	End-effector development
Microwave demolition (massive containment)	DISM-16-OL	OR101204	H	Microwave concrete decontamination development
High-pressure abrasive water jet (reactor pools)	DISM-21-OL	AL221205	M	Hanford tank use
		AL221302	M	Weapons Disposal Integrated Demonstration use
		RL332003	L	End-effector development
Microwave demolition (reactor pools)	DISM-28-OL	OR101204	H	Microwave concrete decontamination development
High-pressure abrasive water jet (buried tanks)	DISM-31-OL	AL221205	M	Hanford tank use
		AL221302	M	Weapons Disposal Integrated Demonstration use
		RL332003	L	End-effector development
Microwave demolition (buried tanks)	DISM-38-OL	OR101204	H	Microwave concrete decontamination development
High-pressure abrasive water jet (structural-only concrete)	DISM-41-OL	AL221205	M	Hanford tank use
		AL221302	M	Weapons Disposal Integrated Demonstration use
		RL332003	L	End-effector development
Microwave demolition (structural-only concrete)	DISM-47-OL	OR101204	H	Microwave concrete decontamination development
Grappler (structural-only concrete)	DISM-48-OL	AL221205	L	Small-scale shear
Abrasive water jet (steel structures, highly contaminated)	DISM-53-OL	AL221205	M	Hanford tank use
		AL221302	M	Weapons Disposal Integrated Demonstration use
		RL332003	L	End-effector development
Plasma arc cutting (steel structures, highly contaminated)	DISM-56-OL	ID413200	H	Robot plasma arc cutting in tanks
		SR113201	M	Drum opening robot development
Plasma arc saw (steel structures, highly contaminated)	DISM-58-OL	ID413200	H	Robot plasma arc cutting in tanks
		SR113201	M	Drum opening robot development
Thermal arc water jet (steel structures, highly contaminated)	DISM-59-OL	ID413200	H	Robot plasma arc cutting in tanks
		SR113201	M	Drum opening robot development

Table 4.2 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Grapple and massive mobile shearing (steel structures, highly contaminated)	DISM-61-OL	AL221205	L	Small-scale shear
Abrasive water jet (structural steel, mild contaminants)	DISM-72-OL	AL221205	M	Hanford tank use
		AL221302	M	Weapons Disposal Integrated Demonstration use
		RL332003	L	End-effector development
Plasma arc cutting (structural steel, mild contaminants)	DISM-74-OL	ID413200	H	Robot plasma arc cutting in tanks
		SR113201	M	Drum opening robot development
Grapple and massive mobile shearing (structural steel, mild contaminants)	DISM-77-OL	AL221205	L	Small-scale shear
High-pressure abrasive water jet (asbestos)	DISM-85-OL	AL221205	L	Hanford tank use
		AL221302	M	Weapons Disposal Integrated Demonstration use
		RL332003	L	End-effector development
Plasma arc cutting (major equipment removal)	DISM-92-OL	ID413200	H	Plasma arc cutting
		SR113201	H	Plasma arc cutting
High-pressure water jet (major equipment removal)	DISM-93-OL	RL332003	M	Water jet
High-pressure abrasive water jet (major equipment removal)	DISM-97-OL	AL221205	H	Robot-mounted abrasive water jet
		AL221302	M	
		RL332003	L	
Plasma arc saw cutting (major equipment removal)	DISM-98-OL	ID413200	H	Plasma arc cutting
		SR113201	H	Plasma arc cutting
Thermal arc water jet cutting (major equipment removal)	DISM-99-OL	ID413200	M	Plasma arc cutting
		SR113201	M	Plasma arc cutting
Advanced automatic fixtures, bug-o, etc. (major equipment removal)	DISM-100-OL	AL221205	L	Robot-mounted shear and abrasive water jet
Grapppler/gross shearing and lifting (major equipment removal)	DISM-103-OL	AL221205	L	Small-scale shear
Thermoset polymer/thermal plastic stabilization (entombment)	DISM-109-OL	CH321201	H	Polymer solidification of sludge
		RF111203	H	Polymer encapsulation
Ground-water diversion (entombment)	DISM-110-OL	CH331001	L	Study of waste migration control
Temporary entombment/clay fill (entombment)	DISM-111-OL	CH331001	L	Study of waste migration control
		CH321101	M	In situ containment

Table 4.2 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Capping—aboveground environmental barrier (entombment)	DISM-112-OL	CH321101	H	In situ containment
		AL221111	H	Capping and stabilization
Encasement—subsurface waste storage with void reduction (entombment)	DISM-113-OL	CH321101	H	In situ containment
		AL221111	M	Capping and stabilization
Permanent entombment (entombment)	DISM-114-OL	CH321101	M	Grout solidification
		CH321201	L	Polymer solidification of sludge
		RF111203	L	Polymer encapsulation
Engineered storage—for very "hot" items, future disposal (entombment)	DISM-115-OL	RL438005	M	Spent fuel casks use for liquids
Hydraulic isolation (entombment)	DISM-116-OL	AL221111	M	Landfill-site capping
		AL931102	L	Ground-water treatment
Sensors for monitoring entombment integrity (entombment)	DISM-118-OL	RL421103	M	Horizontal drilling development
		SF221102	M	Electrical resistance tomography
		SR121101	L	Directional drilling use
Modular entombment—with provisions for future removal (entombment)	DISM-119-OL	ID132006	M	Burial Waste Integrated Demonstration waste form integration and limits
Shredding, sorting, compaction (equipment predisposal staging)	DISM-131-OL	SF223203	L	Waste facility operation
Generalized object-oriented simulation software (needed enabling technologies)	DISM-173-OL	RL321104	L	Engineering simulator software
Geographic information systems for DOE sites (needed enabling technologies)	DISM-181-OL	SR121102	L	Info system at Savannah River Site Idaho

^a TTP = Technical Task Plan Identifier.

^b The relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagrams* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need;
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

4.7 REFERENCES

1. T. W. Burwinkle, Decontamination and Decommissioning workshop, Oak Ridge National Laboratory, October 29, 1992.

5. Decontamination

5. DECONTAMINATION

5.1 INTRODUCTION

In general, decontamination is accomplished either by removing the contaminants from surfaces with little damage or by intentionally removing a layer of the contaminated surface along with the embedded contaminant. The energy needed to remove the surface layer may be either mechanical, chemical, or thermal. Bulk decontamination requires entirely different techniques, such as incineration, smelting, or leaching. Removal of contaminants from surfaces is based upon cleaning techniques that have been used for decades. Many procedures and reagents used in decontaminating equipment and facilities in the nuclear industry were first developed and used for cleaning conventional nonnuclear plants.¹ Decontamination procedures were developed to provide high-decontamination efficiencies and moderate-corrosion attack on the surface. Additional criteria to be met were prompt availability of equipment, simple operation and control, acceptable time requirements, satisfactory safety aspects, acceptable costs of application, planned future use of facility, and minimal amounts of wastes. The choice of a decontamination procedure for a particular application will depend upon the importance and priorities assigned to the various criteria, the characteristics of the system to be decontaminated, and the specific capabilities at the facility. The requirements for moderate-corrosion attack and for prompt availability of equipment have little weight for D&D compared to that for decontamination for maintenance and reuse of existing equipment in operating plants.

To develop the decontamination section of the TLD, the first step was to list the decontamination technologies that are in use, under development, or being proposed. For the Problem Area/Constituent logic element of the diagram, a list of problems specific to decontamination and traceable directly to ORNL problems was developed. This list consisted of the various contaminated substrates (e.g., concrete, equipment, structural steel, etc.) and the particular hazardous contaminants that can be found residing on or throughout each substrate (i.e., surface or bulk contamination). For each problem, technologies were identified that could potentially be used for decontamination.

The development of the list of problems for ORNL involved (1) interviews with personnel familiar with the history of the facility or facilities of interest, (2) review of documents describing the contamination problems at the various facilities, and (3) tours of the facilities by the decontamination team members. Based on the results of these activities, a detailed list of ORNL decontamination problems was generated and is presented in Table 5.1. Table 5.1 specifies the types of substrates that are contaminated, the types of contaminants present on each substrate, the radiation levels existing as a result of the contamination, and examples of the particular situations (i.e., the facility and the equipment or surfaces that are contaminated) that exhibit the listed combinations of substrate, contaminants, and radiation levels. While Table 5.1 is as complete as possible, the particular situations that are listed should be regarded as examples of the contaminated equipment and surfaces, not as an exhaustive list.

Table 5.1. ORNL decontamination problems

Substrate	Contaminant	Radiation level ^a	Example
Stainless steel pipe interior	Uranyl sulfate, fission products (F.P.), corrosion products (C.P.)	H	Homogeneous Reactor Test (HRT) process piping
	F.P., C.P.	M	Molten Salt Reactor Experiment (MSRE) off-gas system
	F.P., C.P.	M	Oak Ridge Research Reactor (ORR) demineralizer piping (outside pool)
	Cs-137, Sr-90	M	Building 3517 process piping and tankage
Stainless steel pipe exterior	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60	L	Graphite Reactor process piping
	Uranyl sulfate, F.P., C.P.	H	HRT process piping
	F.P., C.P.	M	MSRE off-gas system
	F.P., C.P.	M	ORR demineralizer piping (outside pool)
Steel pipe interior	Cs-137, Sr-90	H	Building 3517 process piping and tankage
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60	VL	Graphite Reactor process piping
	F.P., C.P.	M	MSRE off-gas system
	U, Th, molten salt (M.S.)	VL	Drain lines from molten salt cells, Bldg. 9201-3
Copper tubing interior	U, Th, coolant salt (C.S.)	VL	Drain lines from coolant salt cell, Bldg. 9201-3
	U, Th, M.S.	VL	Drain lines from Bldg. 9419-1
Copper tubing exterior	U, Th, H-3, M.S.	L	Instrument and air lines in coolant cell, Bldg. 9201-3
Steel pipe exterior	U, Th, H-3, M.S.	VL	Instrument and air lines in coolant cell, Bldg. 9201-3
Steel pipe, painted, exterior	F.P., C.P.	M	MSRE off-gas system
INOR-8 piping exterior	U, Th, M.S.	L	Handrall, Bldg. 9201-3
INOR-8 piping interior	U-Be-Li-F, TlF ³ , F.P.	H	MSRE reactor piping
INOR-8	U-Be-Li-F, TlF ³ , F.P.	H	MSRE reactor piping
Aluminum piping exterior	U-Be-Li-F, TlF ³ , F.P., activation products (A.P.)	H	MSRE reactor
	U-Be-Li-F, TlF ³ , F.P.	H	MSRE fuel processing system
	Trace U-Be-Li-F, F.P.	H	MSRE storage tank
	F.P., C.P.	H, M, L	ORR primary coolant piping
	F.P., C.P., A.P.	VL	Low-Intensity Test Reactor (LITR) water piping exterior

Table 5.1 (continued)

Substrate	Contaminant	Radiation level ^a	Example
Aluminum piping interior	F.P., C.P. F.P., C.P., A.P.	H, M, L	ORR primary coolant piping LITR water piping exterior
Stainless steel	F.P., C.P.	H	Piping southeast of 7500
347 stainless steel	F.P., C.P.	H	Tank SE of 7500
Stainless steel	F.P., C.P.	M	ORR hot cell liners
	F.P., Cm-147, Pm-241, Am	M	Building 3028 hot cell liners
	Cs-137, Sr-90, Co-60, Ir-192	H	Building 3029 hot cell liners
	43 Beta, gamma emitters	M	Building 3030 hot cell liners
	Gd-153, Am-241	L	Building 3031 hot cell liners
	P-32, Am-241	L	Building 3032 hot cell liners
	Cs-137, Sr-90, Co-60	M	Building 3517 hot cell liners
	transuranic (TRU), F.P.	L	Building 3505 hot cell liners
	Cs, Sr, Co, Cm, Eu, Am, Pu	M	Building 3047 hot cell liners
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	M	Building 7852 hot cell liners
	U-233, Pu-239, F.P.	H, M	Building 3019 hot cell liners
	H-3, Kr-85	VL	Building 3033 process piping
	Pu-238, Am-241, Cm-244	VL	Glove boxes in Bldg. 3038
	Pu, Cf, Cm, Np, Pa, U, Sr, Cs, Co, I	L	Glove boxes and cell interiors in Bldg. 3038
	Cs-137, Sr-90	L	Stainless steel tank (SST) cask wall
	H-3	VL	Building 7025 process piping
	H-3, Actinides	VL	Building 7025 hoods, glove box
Zircalloy 2	Uranyl Sulfate, F.P., C.P., A.P.	H	HRT reactor
Stainless clad steel	Uranyl sulfate, F.P., C.P.	H	HRT pressure vessel
High-density concrete	F.P., C.P., A.P.	H	HRT structure
Carbon steel plate	F.P., C.P.	H	Membrane between HRT concrete
	Cs-137, Sr-90, Co-60, Ir-192	M	Building 3029, Cell 2 wall
Asphalt pavement	F.P., C.P.	VL	Pavement over 55-gal drum 7500 Cells
	Heavy water, F.P.	M	Pulsefeeder pumps

Table 5.1 (continued)

Substrate	Contaminant	Radiation level ^a	Example
Concrete	Uranyl sulfate, F.P.	M	Floor under and shield around evaporator in 7500
	F.P., C.P.	H, M, L	ORR biological shield
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, A.P.	M	Graphite Reactor biological shields
		M	Graphite Reactor canal
		L	Graphite Reactor duct work
		L	Graphite Reactor stack
	F.P., C.P., A.P.	L	Slab supporting LTR components
	F.P., Cm-244, Pm-147, Am-241	M	Building 3028 hot cell interiors
	Cs-137, Sr-90, Co-60, Ir-192	M	Building 3029 hot cell interiors
	43 Beta, gamma emitters	M	Building 3030 hot cell interiors
	Gd-153, Am-241	L	Building 3031 hot cell interiors
	P-32, Am-241	L	Building 3032 hot cell interiors
	Cs-137, Sr-90	VL	Building 3036 floor
	Cs-137, Sr-90, Co-60	M	Building 3517 hot cell interiors
	U, Th, M.S.	L	Roofs of molten salt cells, Bldg. 9201-3
	U, Th, M.S.	L	Floor of Bldg. 9419-1
	U, Th, M.S.	L	First floor of molten salt cells, Bldg. 9201-3
	Sr-90, Cs-137, Co-60, I-129	M	Cell interiors in Bldg. 3038
	TRU, F.P.	L	Building 3505 hot cell interiors
	F.P.	VL	Building 3506 hot cell interiors
	F.P.	M	Building 3515 hot cell interiors
	Cs, Sr, Co, Cm, Eu, Am, Pu	M	Building 3047 hot cell interiors
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	M	Building 7852 pump house pads
	U-233, Pu-239, F.P.	H, M	Building 3019 hot cell interiors
Brick/tile	U, Th, M.S.	L	One wall of molten salt cell, Bldg. 9201-3
Brick	Sr-90, Cs-137, Co-60, I-129	VL	Building 3038 exterior walls

Table 5.1 (continued)

Substrate	Contaminant	Radiation level ^a	Example
Painted concrete	F.P., TRU	L, VL	ORR hot cell interiors, floors, cell faces
	F.P., Cm-147, Pm-241, Am	L, VL	Building 3028 hot cell interiors, floors, cell faces
	Cs-137, Sr-90, Co-60, Ir-192	VL	Building 3029 cell faces
	43 Beta, gamma emitters	VL	Building 3030 floors, cell faces
	Gd-153, Am-241	VL	Building 3031 floors, cell faces
	P-32, Am-241	L, VL	Building 3032 floors, cell faces
	H-3, Kr-85	VL	Building 3033 cell faces
	Cs-137, Sr-90	VL	Building 3036 floors
	Cs-137, Sr-90, Co-60	VL	Building 3517 high bay floors, cell faces
	U, Th, C.S.	L	Floor of coolant salt cell, Bldg. 9201-3
	U, Th, M.S.	L	Floor of molten salt cells, Bldg. 9201-3
	Sr-90, Cs-137, Co-60, I-129	M, L, VL	Cell floors, surfaces in Bldg. 3038
	TRU, F.P.	VL	Building 3505 floors, cell faces
	F.P.	VL	Building 3506 hot cell interiors
	F.P.	VL	Building 3515 floors, cell faces
	Cs, Sr, Co, Cm, Eu, Am, Pu	VL	Building 3047 floors, cell faces
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	L	Building 7852 floors, cell faces
	U-233, Pu-239, F.P.	H, M	Building 3019 hot cell interiors, floors, cell faces
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60, A.P.	VL	Graphite Reactor biological shield exterior

Table 5.1 (continued)

Substrate	Contaminant	Radiation level ^a	Example
Sheet steel	Cs, Sr, TRU, Co-60	VL	7500 high bay area
	Cs, Sr, TRU, Co-60	VL	MSRE exterior siding
	F.P.	VL	ORR building siding
	F.P., TRU	VL	Building 3028E charging area
	Cs-137, Sr-90, Co-60, Ir-192	VL	Building 3029 exterior walls
	43 beta, gamma emitters	VL	Building 3030 siding/interior walls
	Gd-153, Am-241	VL	Building 3031 siding/interior walls
	P-32, Am-241	VL	Building 3032 siding/interior walls
	H-3, Kr-85	VL	Building 3033 siding/interior walls
	Cs-137, Sr-90	VL	Building 3036 siding/interior walls
	Cs-137, Sr-90, Co-60	VL	Building 3517 interior/exterior walls
	U, Th, M.S.	L	Three walls of molten salt cells, Bldg. 9201-3
	U, Th, C.S.	L	Walls of coolant salt cells, Bldg. 9201-3
	U, Th, C.S.	L	Roof of coolant salt cell, Bldg. 9201-3
	U, Th, M.S.	L	Upper floors of molten salt cells, Bldg. 9201-3
	Sr-90, Cs-137, Co-60, I-129	VL	Building 3038 interior walls
	TRU, F.P.	VL	Building 3505 siding
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu		Building 7852 building interior walls
	U-233, Pu-239, F.P.	VL	Building 3019 siding
	H-3, Actinides	VL	Building 7025 siding
Corrugated steel sheet	F.P., Pu, C-14, Fe-55, C-137, Sr-90, Co-60	VL	Graphite Reactor building siding
	U, Th, M.S.	L	Floor of molten salt cells, Bldg. 9201-3
Sheet metal (painted)	U, Th, C.S., H-3, Oil	L	Floor of coolant salt cell, Bldg. 9201-3
Aluminum	F.P., C.P, A.P.	H, M, L	ORR reactor vessel, pool liner
Metal	U, Th, M.S.	L	Scales, hoist, size metal parts in Bldg. 9419-1

Table 5.1 (continued)

Substrate	Contaminant	Radiation level ^a	Example
Structural steel	Cs, Sr, TRU, Co-60	VL	7500 high bay area
	Cs, Sr, TRU, Co-60	VL	MSRE building structure
	F.P.	VL	ORR steel building structure
	F.P., TRU	VL	Building 3028E steel structure
	Cs-137, Sr-90, Co-60, Ir-192	VL	Building 3029 structure
	43 Beta, gamma emitters	VL	Building 3030 steel building structure
	Gd-153, Am-241	VL	Building 3031 structure
	P-32, Am-241	VL	Building 3032 structure
	H-3, Kr-85	VL	Building 3033 structure
	Cs-137, Sr-90	VL	Building 3036 structure
	Cs-137, Sr-90, Co-60	VL	Building 3517 structure
	U, Th, M.S.	VL	Frame of Bldg. 9419-1
	U, Th, H-3, M.S.	L	Frame of coolant cell
	U, Th, M.S.	L	Frame of molten salt cells and equip., Bldg. 9201-3
	U, Th, M.S.	L	Frame & stairs of Bldg. 9419-1
	Sr-90, Cs-137, Co-60, I-129	VL	Building 3038 structure
	TRU, F.P.	VL	Building 3505 structure
	Cs, Sr, Co, Cm, Eu, Am, Pu	VL	Building 3047 structure
	Cs-137, Sr-90	VL	SST steel structure
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	L	Building 7852 structure
	U-233, Pu-239, F.P.	VL	Building 3019 structure
	H-3, Actinides	VL	Building 7025 structure
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60	VL	Graphite Reactor building structure
Steel grating	U, Th, M.S.	L	Upper floors of molten salt cells, Bldg. 9201-3
	U, Th, M.S.	L	Stairs in Bldg. 9419-1

Table 5.1 (continued)

Substrate	Contaminant	Radiation level ^a	Example
Concrete block	Cs, Sr, TRU, Co-60	VL	Building 7500 interior/exterior walls
	F.P., C.P.	VL	MSRE Building interior/exterior walls
	F.P.	VL	ORR Building interior/exterior walls
	F.P., TRU	VL	Building 3028 interior/exterior walls
	Cs-137, Sr-90, Co-60, Ir-192	VL	Building 3029 interior/exterior walls
	Gd-153, Am-241	VL	Building 3031 stacked shielding
	P-32, Am-241	VL	Building 3032 interior/exterior walls
	Cs-137, Sr-90	VL	Building 3036 interior walls
	Sr-90, Cs-137, Co-60, I-129	VL	Building 3038 interior walls
	Cs-137, Sr-90, Co-60	VL	Building 3517 interior/exterior walls
	TRU, F.P.	L	Building 3505 hot cell interiors
	TRU, F.P.	VL	Building 3505 interior/exterior walls
	F.P.	VL	Building 3505 exterior walls
	F.P.	VL	Building 3515 interior/exterior walls
	Cs, Sr, Co, Cm, Eu, Am, Pu	VL	Building 3047 interior/exterior walls
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	L	Building 7852 interior/exterior walls
	U-233, Pu-239, F.P.	VL	Building 3019 interior/exterior walls
	Cs, Sr, Co, Cm, Eu, Am, Pu	VL	Building 3047 interior walls
Plaster/concrete block			

Table 5.1 (continued)

Substrate	Contaminant	Radiation level ^a	Example
Tiled concrete	Cs, Sr, TRU, Co-60	VL	Building 7500 floors
	F.P., C.P.	VL	MSRE building floors
	F.P.	VL	ORR building floors
	F.P., TRU	VL	Building 3028 floors
	Cs-137, Sr-90, Co-60, Ir-192	VL	Building 3029 floors
	43 Beta, gamma emitters	VL	Building 3030 floors
	Gd-153, Am-241	VL	Building 3031 floors
	P-32, Am-241	VL	Building 3032 floors
	H-3, Kr-85	VL	Building 3033 floors
	Cs-137, Sr-90	VL	Building 3036 floors
	Cs-137, Sr-90, Co-60	VL	Building 3517 floors
	U, Th, C.S.	L	Floor of coolant salt cell, Bldg. 9201-3
	U, Th, M.S.	L	Floor of molten salt cells, Bldg. 9201-3
	Sr-90, Cs-137, Co-60, I-129	VL	Building 3038 floors
	TRU, F.P.	VL	Building 3505 floors
	F.P., alpha	VL	Building 3505 floors
	F.P.	VL	Building 3515 floors
	Cs, Sr, Co, Cm, Eu, Am, Pu	VL	Building 3047 floors
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	L	Building 7852 floors
	U-233, Pu-239, F.P.	VL	Building 3019 floors
	H-3, Actinides	VL	Building 7025 floors
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60	VL	Graphite Reactor building floors

Table 5.1 (continued)

Substrate	Contaminant	Radiation level ^a	Example
Wood/sheet rock	Cs, Sr, TRU, Co-60	VL	Building 7500 interior walls
	F.P., C.P.	VL	MSRE building interior walls
	F.P.	VL	ORR building interior walls
	F.P., TRU	VL	Building 3028 interior walls
	Cs-137, Sr-90, Co-60, Ir-192	VL	Building 3029 interior walls
	43 Beta, gamma emitters	VL	Building 3030 interior walls
	Gd-153, Am-241	VL	Building 3031 interior walls
	P-32, Am-241	VL	Building 3032 interior walls
	Cs-137, Sr-90	VL	Building 3036 interior walls
	Cs-137, Sr-90, Co-60	VL	Building 3517 Bldg. 3517 interior walls
	TRU, F.P.	VL	Building 3505 interior walls
	F.P.	VL	Building 3505 interior walls
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	L	Building 7852 interior walls
	U-233, Pu-239, F.P.	VL	Building 3019 interior/exterior walls
	U, Th, M.S.	VL	Rafters of Bldg. 9204-1
	U, Th, M.S.	L	Pallets in Bldg. 9419-1
	Be	VL	Frame of Be Bldg. in Bldg. 9201-3
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60	VL	Graphite Reactor building internal walls
Wood/asphalt	F.P.	VL	Building 3505 roof
Tar and felt roofing	Cs, Sr, TRU, Co-60	VL	Building 7500 roof
	F.P., C.P.	VL	MSRE building roof
	F.P.	VL	ORR building roof
	F.P., alpha	VL	Building 3028 roof
	Cs-137, Sr-90, Co-60, Ir-192	VL	Building 3029 roof
	Cs-137, Sr-90	VL	Building 3036 roof
	43 Beta, gamma emitters	VL	Building 3030 roof
	Gd-153, Am-241	VL	Building 3031 roof
	P-32, Am-241	VL	Building 3032 roof
	H-3, Kr-85	VL	Building 3033 roof
	Sr-90, Cs-137, Co-60, I-129	VL	Building 3038 roof
	Cs-137, Sr-90, Co-60	VL	Building 3517 roof
	F.P., alpha	VL	Building 3505 roof
	Cs, Sr, Co, Cm, Eu, Am, Pu	VL	Building 3047 roof
	U-233, Pu-239, F.P.	VL	Building 3019 roof

Table 5.1 (continued)

Substrate	Contaminant	Radiation level ^a	Example
Graphite	C-14, A.P.	H	MSRE moderator
	Alpha (U, Pu)	L	Piece in molten salt cells, Bldg. 9201-3
	C-14, Fe-55, Cs-137, Sr-90, Co-60, F.P., Pu, A.P.	M	Graphite Reactor Moderator
Charcoal	F.P., C.P.	M	MSRE off-gas system
Stainless Steel	F.P., C.P.	M	MSRE liquid waste system
Fiberglass insulation, Al foil, and wire	F.P., C.P.	H	MSRE coolant piping
	Cs-137, Sr-90, Co-60	VL	Insulation in Bldg. 3517
	TRU, F.P.	VL	Building 3505 insulation
	U-233, Pu-239, F.P.	VL	Building 3019 insulation
Asbestos insulation	U, Th	VL	Pipe insulation in Bldg. 9419-1
	U, Th, H-3, M.S.	L	Piping insulation in coolant salt cell, Bldg. 9201-3
	U, Th, M.S., PCB	L	Piping insulation in molten salt cells, Bldg. 9201-3
Transite	U, Th, M.S.	L	Walls of molten salt cells, Bldg. 9201-3
	U, Th, M.S.	L	Bldg. 9419-1 Walls
	Cs, Sr, F.P., C.P., TRU, Co, Cm, Eu, Am, Pu	L	Building 7852 waste pit roof
Glass-lined stainless steel	U, Th, M.S., Oil	VL	3000-gal tank in Bldg. 9201-3
Metal process piping and equip. (interior)	U, Th, M.S.	VL	Molten salt cells in Bldg. 9201-3
	U, Th, C.S., H-3	VL	Coolant salt cells in Bldg. 9201-3
Metal process piping and equip. (exterior)	U, Th, M.S.	L	Molten salt cells in Bldg. 9201-3
	U, Th, C.S., H-3	L	Coolant salt cells in Bldg. 9201-3
Metal piping and tank	U, Th, M.S.	L	Near 3000-gal tank in Bldg. 9201-3

Table 5.1 (continued)

Substrate	Contaminant	Radiation level ^a	Example
Metal equipment	U, Th, M.S.	VL	Building 9419-1
	F.P., Pu, C-14, Fe-55, Cs-137, Sr-90, Co-60	VL	Graphite Reactor equipment
Instruments	U, Th, C.S.	L	Coolant salt cell, Bldg. 9201-3
	U, Th, M.S.	L	Molten salt cells, Bldg. 9201-3
Electrical boxes	U, Th, C.S.	L	Coolant salt cell, Bldg. 9201-3
	U, Th, M.S.	L	Molten salt cells, Bldg. 9201-3
Electrical conduit	U, Th, C.S.	L	Coolant salt cell, Bldg. 9201-3
	U, Th, M.S.	L	Molten salt cells, Bldg. 9201-3
	U, Th, M.S.	L	Building 9419-1
Electrical heating elements	U, Th, M.S.	L	On five molten salt vats, Bldg. 9201-3
Light fixtures	U, Th, M.S.	L	Building 9419-1
Electrical cables and thermocouple wire	U, Th, M.S.	L	Molten salt cell, Bldg. 9201-3
Notebooks and paper	U, Th, H-3, M.S.	L	Items in coolant salt cell, Bldg. 9201-3
Rubber hose and plastic tubing	U, Th, M.S.	L	Molten salt cell, Bldg. 9201-3
Rubber hose	U, Th, M.S.	L	Items in Bldg. 9419-1
Ladder, scales, vacuum cleaner	U, Th, M.S.	L	Molten salt cell, Bldg. 9201-3
Steel	Cs, Sr, Co, Cm, Eu, Am, Pu	M	Building 3047 in-cell crane
	C.P., F.P., A.P.	H	LTR tank internal surfaces
Steel	Cs-137, Sr-90	VL	SST cask wall
Ion exchange resin	Cs-137, Sr-90	M	SST cask resin

^a H = >100 R/h; M = 1-100 R/h; L = 0.01-1 R/h; VL = background to 0.01 R/h. (Most values are estimates.)

Because of the large number of problems listed, some simplification was necessary to limit the size of the decontamination logic diagram. This was done by dividing the problems into different groups. The criterion for assigning a problem to a particular group was that all problems in that group could, in general, be treated by the same decontamination technologies. Finally, having identified the technologies applicable to each group of problems and with the detailed information for each technology as provided in the *Technology Evaluation Data Sheets*, the decontamination section of the TLD was developed.

5.2 TECHNOLOGY OPTIONS

5.2.1 Introduction

The scope of this activity is to decontaminate DOE surplus facilities (systems or components), particularly at ORNL. Reasons or requirements for decontamination include the following:

- to permit unrestricted reuse/recycle,
- to permit reuse of the item in the DOE complex,
- to reduce worker-radiation exposure,
- to avoid potential criticality accidents,
- to permit or enhance disposal, and
- to separate the hazardous from the radioactive constituents during decontamination.²

This section summarizes the decontamination technologies that have been demonstrated or that have the potential to fulfill these requirements.

Decontamination technologies have been grouped into six generic technologies as follows:

- bulk decontamination methods,
- chemical surface cleaning methods,
- metal refining methods,
- mechanical surface removal methods,
- surface cleaning methods, and
- thermal surface removal methods.

As suggested by the name, surface removal methods take off the surface layer of the substrate (e.g., metal, concrete, etc.) itself and, at the same time, any fixed or loose (i.e., transferable) contamination that is present on the surface. The surface cleaning methods remove the fixed or loose contamination without disturbing the surface of the substrate. The metal refining and the bulk decontamination methods remove contamination that is distributed throughout the substrate.

The decontamination technologies that have been identified are grouped according to generic technology in Table 5.2. The technologies listed are at various levels of development, including (1) in an available stage that is accepted by industry, (2) in the demonstration phase, (3) under study at the laboratory scale, and (4) at the conceptual stage. A brief description of the technologies is provided in the following sections.

5.2.2 Bulk Decontamination Methods

Solvent extraction removes organics from bulk materials simply by dissolution. The technology could be applied as a "factory style" process in either a batch or continuous fashion. For waste-volume reduction, separation of the contaminants from the solvent and recycling of the solvent would be needed. Also, the solvent would have to be removed from the decontaminated material by a method such as heating or vacuum. The chemical leaching technology would be applied in a manner similar to that of solvent extraction. The chemical leaching and biological technologies are essentially the same as described under chemical surface cleaning. Solvent extraction and chemical leaching are well-established technologies in current use.

Table 5.2. Decontamination technologies

Bulk decontamination methods	
1. Solvent extraction	5. Centrifugal cryogenic CO ₂ blasting
2. Incineration	6. Ice blasting
3. Dry heat	7. Supercritical CO ₂ blasting
4. Chemical leaching	8. Plastic pellet blasting
5. Catalytic extraction process	9. Hand grinding, honing, scraping
6. Vacuum (low pressure)	10. Automated grinding
7. Transmutation	11. Metal milling
	12. Concrete milling
	13. Explosive
<hr/>	
Chemical surface cleaning methods	Surface cleaning methods
1. Chemical foams	1. Compressed air cryogenic CO ₂ blasting
2. Chemical gels	2. High-pressure water
3. Organic acid treatment	3. Superheated water
4. Fluoboric acid treatment	4. Water flushing
5. Inorganic acid treatment	5. Steam cleaning
6. Detergent treatment	6. Hand brushing
7. REDOX treatment	7. Automated brushing
8. Chelation treatment	8. Sponge blasting
9. Electropolishing	9. Hot air
10. Gas phase	10. Dry heat (roasting)
11. UV/ozone (UV light activation)	11. Solvent washing to remove radiological contamination
12. Electromigration	12. Solvent washing to remove organics
	13. Strippable coatings
Metal refining methods	14. Vacuum cleaning
1. Smelt purification	15. Ultrasonic cleaning
2. Electrorefining	
3. Leach/electrowinning	Thermal surface removal methods
	1. Microwave scabbling
Mechanical surface removal methods	2. Plasma torch
1. Ultrahigh-pressure water	3. Laser heating
2. Shot blasting	4. Laser etching and ablating
3. Scabblers/scarifiers	5. Plasma surface cleaning
4. Grit blasting	6. Plasma etching/fluorination
	7. Flashlamp cleaning

Incineration of various materials is accepted by the EPA. The incineration of contaminated combustible building materials is common in the nuclear industry. The waste generated will depend upon the design of the incinerator and the ash content of the material being burned. The fly ash and smoke particles have to be contained with particular care.³

The technology of dry heat (e.g., calcination) would be used to remove volatiles such as oils and PCBs. Treatment of off-gases to remove the volatilized contaminants would be necessary.

The catalytic extraction process is similar to smelt purification in that a furnace is used to form a molten metal bath. In the catalytic extraction process, the bath is used not only to purify metal but also, at the high-operating temperatures, to effectively destroy hazardous-organic materials such as aromatic hydrocarbons and PCBs. Also, mixing is better in the catalytic extraction process because material is introduced from the bottom of the process; control of the oxidation potential is better with the catalytic extraction process because oxygen, rather than air, is injected into the furnace. The process has not been used commercially to treat scrap contaminated with radionuclides. Waste generated could include radioactive slag and wet scrubber solutions.

Very limited use of vacuum (i.e., low pressure to remove volatile compounds) has been made for bulk decontamination. Some information has been obtained on a proprietary vacuum-based process for removing water soluble Cr^{+6} from transite sheeting surfaces. Vacuum can also be used to remove contamination from porous materials by boiling solvents out of the material if the solvent foams out and the solvent is collected.³ Because of their low-vapor pressures, the technique would probably be rather ineffective for most oils and PCBs.

Transmutation appears to be the only technology capable of eliminating induced radiation, which results from exposure of material to high-neutron fluxes. The neutron fluxes, such as those near the core of a fission reactor, often result in the change of some of the atoms in the exposed material to radioactive species that are chemically identical isotopes of the other unchanged atoms in the material. Thus, the radioactive isotope cannot be removed from the base material by chemical means. (If the induced radiation comes from different elements from the bulk of the material, chemical methods such as metal refining techniques could be used to decontaminate the material.) Transmutation might be used to convert radioactive isotopes into nonradioactive ones by bombarding the radioactive species with neutrons or alpha particles. This technique could only be used if particles could be found that have energies such that the cross-sections of the radioactive isotopes were much larger than those of the nonradioactive isotopes. Otherwise this technique might generate as much, or more, radioactivity than it eliminated. Even then, the practicality of this technology is doubtful.

5.2.3 Chemical Surface Cleaning Methods

Technologies comprising chemical foams, chemical gels, acid treatments, caustic treatments, and redox treatments involve reaction with the contaminant to form a species that is dissolved in the cleaning solution and thereby removed from the substrate. Depending upon the strength of the chemical solution, physical degradation of the surface can also occur. Foams and gels are used to enhance the performance of the chemicals and to reduce subsequent waste volumes by holding the decontamination chemical in better contact with the contaminated surface. These methods of application can be used for in situ decontamination of exterior surfaces. The other solutions may be applied in dipping baths, in loop systems, or through spraying. Recovery would be a

problem in the use of the spraying technique for decontamination of exterior surfaces unless decontamination is done in a spray booth with suitable critically safe drains. Spray booths similar to car washes are used at gaseous diffusion plants to decontaminate the interior and exterior of disassembled equipment. For waste volume reduction, regeneration and recycling of the chemical is necessary. Depending upon the strength or reactivity of the chemical, decontamination factors range from as low as five to ten up to several hundred. British Nuclear Fuels, Ltd., uses several different chemical technologies to decontaminate equipment from the Capenhurst Diffusion Plant to below regulatory concern (BRC) of British limits.

Electropolishing selectively removes contaminant metal ions from a metal surface. This method, using an electrolyte and electricity, has usually been applied on small areas. For waste-volume reduction, separation of the contaminant from the electrolyte and recycling of the electrolyte would be needed.

Gas-phase decontamination uses a strong fluorinating gas to convert uranium fluoride and oxyfluoride deposits inside gas-tight equipment to uranium hexafluoride gas, which could then be recovered with chemical or cold traps. Lab studies have shown that over 99.9% uranium removal can be obtained by reaction at room temperature.⁴ However, thorium and protactinium fluorides and most of the fluorides of elements formed in the decay chains of ^{235}U and ^{238}U are not volatile. Treatment of the off-gases will generate wastes from liquid scrubbers and dry-chemical traps when using current technology.

Plasma etching and fluorination technologies may be used to enhance performance of gas-phase decontamination. The plasmas of fluorinating gas can be created to promote room-temperature chemical reactions, converting uranium fluoride and oxyfluoride deposits into uranium hexafluoride gas. A research project would be needed to perform a feasibility test in the gas-phase facility.

The UV/ozone and electromigration technologies are in the evolving technology stage. In the use of UV/ozone to remove oils, greases, and solvents, UV light produces ozone from oxygen and also excites and/or dissociates contaminant molecules. These reactive species then produce CO_2 and water vapor (and HCl in the case of chlorinated solvents). Electromigration uses an electric potential to cause migration of metal ions from a surface into an electrolyte. The technology may be applied in a localized area or as a "factory style" process in batch fashion to contaminated areas. For waste-volume reduction, separation of the contaminant from the electrolyte and recycle of the electrolyte would be needed.

5.2.4 Metal Refining Methods

Smelt purification involves adding oxidizing fluxes to scrap metal that will react with impurities when the metal is heated. The contaminants are removed in the slag that forms and floats to the top of the molten metal. Lab-scale and large-scale studies of smelt purification of radioactive metals have been made. Good results were obtained with the easily oxidized elements like uranium, but reportedly the more noble technetium is not removed by this technology. Estimates of capital and operating costs for smelting 90,000 tons of DOE scrap metal have been developed.

Electrorefining is a well-established, commercial technology but is much less established for decontaminating radioactive metal. Electrorefining uses an electrolysis cell that contains an anode made from contaminated metal and deposits a cathode of pure metal. A voltage applied between the cathode and anode causes metal to ionize from the anode and to plate out on the cathode. Lab-scale tests that electrorefined contaminated nickel resulted in plate out of technetium with the nickel on the cathode. The electrolytic

waste solutions from this process will be characterized as mixed wastes. Decontamination and recycle of the electrolytic solutions will be needed. Studies to determine the electropotentials, current densities, and concentrations to use might make this method successful. At the thermodynamic limit, this process can separate all elements adequately.³

In the leach/electrowinning process, impure metal is dissolved, the solution is passed through a purification step, and purified metal is then plated out on a cathode in an electrolytic cell. This process is a well-established, commercial method for producing nickel from ore but is not used commercially to refine contaminated nickel metal. As in the case of electrorefining, decontamination and recycle of the electrolytic solutions will be needed. Technetium can be removed by ion exchange with the impure metal solution.

5.2.5 Mechanical Surface Removal Methods

Most of the technologies in this generic group involve impacting or blasting a surface with a high-velocity stream of fluid or solid particles. These technologies include ultrahigh-pressure water, shot blasting, grit blasting, centrifugal cryogenic CO₂ blasting, ice blasting, supercritical CO₂ blasting, and plastic pellet blasting. The supercritical CO₂ blasting is under development by industry.⁵ The centrifugal CO₂ blasting technology is being developed using the DOE Fusion Energy Program's centrifuge pellet acceleration method. The others are accepted and used by industry for decontamination work. The grit and shot blasting technologies will remove the surface layer of most substrates. The other blasting methods will remove concrete surface layers. For purposes of cost reduction and waste minimization, separation of the removed contamination and recycle of the working fluid or solid particles would be desired. For technologies using CO₂, separation is facilitated as the solid or supercritical CO₂ converts to the gaseous phase during impact with the surface being decontaminated. But containment and collection of the contaminated dust could be a problem depending upon the configuration of the surface being blasted.

Mechanical scarifiers and scabblers are available for removing a surface layer of contaminated concrete. Scarifier heads usually have several carbide tips; multiple-head machines are used for large-surface floor or wall applications. Scabblers use moving chains, saws, and steel bars or rollers. The method is effective but is slow and can generate airborne contaminants.

Manual methods such as scraping tend to be labor intensive and slow and might result in excessive worker exposure to radiation or contamination. Grinding, honing, and milling machines are commercially available for decontaminating surfaces. These machines would be more suitable for regular surfaces. The explosive technique involves the selective detonation of small explosive charges in the surface of concrete to shatter the surface layer.

Since the technologies in this generic group remove the surface layer of the substrate, 100% decontamination should result if the depth of penetration of the contamination is less than the depth of surface removal and if back-contamination can be prevented. For blasting technologies, the waste generated will consist of the particular blasting medium and the contaminated layer of substrate that is removed. If the blasting medium can be separated, the waste generated by the technologies in this generic group will consist primarily of the detached substrate layer. These techniques will also produce a small volume of contaminated filters. Recycle systems for ultrahigh-pressure water will probably produce small volumes of contaminated ion exchange media and other components such as filter cakes or sludges.

5.2.6 Surface Cleaning Methods

Surface cleaning methods remove the fixed and/or loose contamination without disturbing the surface of the substrate. They should be particularly effective for loose contamination. Several technologies that are described in the mechanical surface removal methods group may also be listed in this group in their less-aggressive modes. These include scraping, ultrahigh-pressure water, shot blasting, grit blasting, centrifugal cryogenic CO₂ blasting, ice blasting, supercritical CO₂ blasting, and plastic pellet blasting. Depending upon the operating conditions or the particular substrate being treated, these technologies can achieve decontamination without affecting the substrate surface. Other blasting technologies in this generic group are compressed air cryogenic CO₂ blasting, sponge blasting, high-pressure water, superheated water, hot water, and steam.

In this CO₂ blasting method, the cryogenic pellets are accelerated by compressed air rather than by centrifugal force. The sponge blasting technology decontaminates by blasting surfaces with various grades of patented, water-based urethane foam particles using 110 psig air as the propellant. The foam is absorptive and can be used either dry or wet to treat a variety of surface contaminants such as oils, greases, lead compounds, chemicals, and radionuclides. A nonaggressive grade of foam is used for surface cleaning on sensitive or otherwise critical surfaces. Aggressive grades, which are impregnated with abrasives, are capable of removing tightly adherent materials such as paints, protective coatings, and rust and can roughen concrete and metallic surfaces if desired. High-pressure (500–1000 psi) water sprays are used extensively in the nuclear industry for smearable contamination. Decontamination factors of 1.5–10 are typically obtained, depending upon the amount of fixed contamination. Superheated-water (300–400°F and several hundred psi) machines are commercially available. Their use is usually limited to floors. Commercial equipment using steam and hot-water jets for decontamination is also available.

Manual decontamination methods of brushing and scrubbing will remove loose contamination but are ineffective for fixed contamination. Also, they have the same undesirable features of the manual methods in the mechanical surface removal group.

Solvent washing is typically used for organic contamination such as oils and PCBs. Loose or smearable contamination may also be removed by this method. To minimize waste, solvent recovery is needed. All low-boiling organic solvents are Resource Conservation and Recovery Act (RCRA) hazardous by the rules and increase the cost of operation.

The strippable coating technology involves "painting" a surface with, for example, a water-based organic polymer. When dry, the coating can be removed, along with the contaminants captured by the coating, mechanically, chemically, or, in the case of "auto-release" coatings, by vacuuming. Decontamination factors are reported to range from as low as three to five up to several hundred, depending upon how tightly the contaminants are bound to the surface.

The technology of dry heat (e.g., roasting) would be used to remove volatiles such as mercury, tritium oils, and PCBs.

The use of vacuum cleaners and their filters is accepted and widely used for removing and collecting loose contamination at gaseous diffusion plants. This method is often used to clean up during and after grinding, honing, scraping, and other surface removal methods. Vacuuming might be effective for removing loose contamination that has settled on girders, other nonvertical surfaces, cracks, etc.

Ultrasonic cleaning has been used for many years to remove surface contamination from relatively small metal parts. Use of this technology on a large scale would likely require separation of the contaminants from the cleaning fluid so that the fluid could be recycled.

5.2.7 Thermal Surface Removal Methods

For surface removal of concrete, the microwave scabbling and plasma torch methods flash the hydration water in the concrete to steam. The resulting volume expansion fractures the concrete surface. Removal of the debris captures most of the contamination.

The plasma torch, flashlamp, and laser heating methods remove the surface layer of other substrates by supplying enough heat to the surface to cause vaporization. The laser ablation method removes surface layers by photochemical and photothermal processes. The vaporized materials and contaminants may then be captured by vacuum removal with a cover-gas stream, thus effecting decontamination. The plasma torch method will produce a significantly higher gas-flow rate than the laser method. Because of the unidirectional nature of these technologies, application to complex geometries might be a problem. Burn-through could also occur when treating walls.

In plasma cleaning, glow discharges might be used either to clean the inside surfaces of vessels or, in reactive plasma cleaning, to produce chemically reactive species that clean contaminated surfaces by the processes of chemisorption, reaction, and desorption or gasification. For example, with an oxygen plasma, oxygen atoms, ozone, and UV photons convert hydrocarbons to CO_2 and water vapor, and a fluorine plasma may provide for separation and recovery of valuable uranium by converting it to UF_6 . For the latter, the low volatility of UF_6 would need to be taken into account in the system design. Because of the relatively low-melting point of metal fluorides, burn-through with aggressive fluorine plasmas would have to be prevented. This could be done by monitoring the production of UF_6 and other off-gases and by controlling the plasma discharge parameters. The UF_6 gas can be recovered and the excess fluorine reused. Plasma cleaning is routinely used to clean the inside of fusion devices before the main plasma is lighted. A pollution control methodology for the effluent gas from the plasma treatment step would be needed.

For the technologies in this generic group that remove the surface layer of the substrate, 100% decontamination should result if a sufficient depth of surface is removed. Thus, control of the depth of surface removal is a critical factor. The waste generated will consist primarily of the detached substrate layer.

The thermal surface removal technologies produce smokes that have smaller particle sizes than the dusts resulting from mechanical surface removal. The smokes from thermal surface removal will be harder to remove by filtration than the dusts from mechanical surface removal.³

5.3 SCIENCE AND TECHNOLOGY NEEDS

5.3.1 Introduction

This section summarizes the science and technology needs of the decontamination technologies that were described in Sect. 5.2.2, irrespective of how high they were ranked by the ranking process. The science (i.e., basic research) needs usually apply to technologies that are in the evolving or predemonstration phase. Technology development needs are related to those technologies in the predemonstration or demonstration phase; whereas, technology improvement needs pertain to technologies that have been demonstrated or accepted. The science and technology needs have also been grouped into the six generic technologies.

5.3.2 Bulk Decontamination

The effectiveness of the catalytic extraction process should be demonstrated for the materials and contaminants of interest at ORNL.

Literature searches of existing cross-section data are needed to determine whether transmutation is a feasible technology for decontaminating items like reactor cores that have induced radiation from exposure to high-neutron fluxes. Such a search would determine whether combinations of particles and energies exist such that the cross-section for radioactive isotopes are sufficiently larger than those for nonradioactive isotopes that the radioactive species could be "burned out" of the matrix of nonradioactive atoms. Additional cross-section determinations may also be needed.

5.3.3 Chemical Surface Cleaning

The fluoboric acid technology generates a metal waste as a result of surface removal. The optimum material for solidification of this waste needs to be determined.

To advance the gas-phase technology, laboratory studies should be continued to determine the feasibility of the process and, if results are favorable, a demonstration of a mobile system for in situ decontamination should be conducted.⁶ If recovery of an unreacted fluorinating agent is to be a part of the process, research to determine the best method will be needed. This method will then need to be demonstrated. Separation of reaction by-products could be a problem.

Research projects would be needed to investigate the feasibility of using the UV/ozone technologies for surface decontamination. A pilot-scale UV/ozone decontamination system, which is available from a private company, could be used for such a study.

Several aspects of electromigration require fundamental evaluation. Selection of the best characteristics for an electrolyte to cause migration of all contaminants to the surface is needed. Concrete imbibing studies are needed to evaluate the flow or migration mechanism. Parametric studies are needed to optimize operating conditions. Electrolyte gels must be developed for nonhorizontal surfaces. Systems that will recycle electrolytes must be designed and demonstrated.

5.3.4 Metal Refining

For the electrorefining technology, a recycle system for the electrolyte solution needs to be developed.

5.3.5 Mechanical Surface Removal

For waste minimization, a water treatment and recycle system needs to be developed for the ultrahigh-pressure water and ice blasting technologies. Also, improved vacuum systems are needed to recover the water to prevent the spread of contamination when cleaning equipment and structures with complex geometries. For the abrasive blasting technologies—shot, grit, and plastic pellet—more durable materials that resist deformation and abrasion and can be recycled through the process more times are needed for waste minimization. Higher-velocity and harder-cryogenic CO₂ pellets are needed to increase the aggressiveness of this technology and extend its usefulness to more difficult decontamination applications. Again, better containment methods are needed to avoid the spread of contamination.

The supercritical CO₂ technology, which appears promising because of its similarity to ultrahigh-pressure water, requires development work to establish it as an accepted technology. Better containment methods for the dust that is generated are also needed for the grinding and milling technologies.

Capabilities for remote operation of the mechanical surface removal technologies for use in areas of high levels of radiation or contamination need to be developed.

5.3.6 Surface Cleaning

The surface cleaning technologies that use either liquid water or steam have the same needs for development of water recycle systems and improved vacuum systems as listed for ultrahigh-pressure water and ice blasting under the mechanical surface removal technologies.

The solvent washing technology needs to identify and demonstrate solvents that are more environmentally acceptable. Water is the standard for these techniques.

5.3.7 Thermal Surface Removal

For microwave scabbling, development and testing of a mobile concrete-removal prototype should be completed. Mathematical modeling is recommended for optimization of concrete-removal rates and efficiencies. Remote operation requires the development of remote-controlled robotic arms for the microwave applicator and the vacuum collection system. Development of real-time monitoring sensors to monitor the progress of decontamination would help to minimize wastes.

Commercially available laser heating, laser ablation, and flashlamp systems should be evaluated on a bench scale for possible use on decontamination problems at ORNL. If these tests are successful, larger-scale demonstrations should be initiated.

5.4 IMPLEMENTATION NEEDS

5.4.1 Introduction

This section summarizes the implementation needs of the decontamination technologies that were described in Sect. 5.2.2. Implementation needs include (1) technology development/improvement and (2) prerequisites to successful technology deployment after demonstration or acceptance.

5.4.2 Summary of Implementation Needs

The specific implementation needs of each technology are detailed in the data sheets. In this section, only those needs that are considered significant, primarily in terms of resources, are cited. Table 5.3 shows three such implementation needs and the specific technologies that have these needs. In Table 5.3, the relation of a need to a particular technology is indicated either by an "X" or, whenever available, by the estimated cost of providing that need.

The three implementation needs listed in Table 5.3 are R&D/DEMO, WASTE, and ROBOTICS. The first need pertains to those technologies that have not advanced to the accepted status level and need R&D and/or demonstration programs to bring the basic decontamination technology to that level. The second need is usually associated with accepted technologies for which the development of systems for waste collection, waste treatment, waste minimization, or material recycle is recommended. The last need is related to those technologies that are adaptable to remote-controlled operation. Reasons for implementing remote-controlled operation include (1) necessity (e.g., due to high-radiation levels), (2) improvement of the operability of the equipment, and (3) increase of the decontamination efficiency.

One implementation need worthy of note is for the incineration technology. Installation of a new incinerator similar to the K-1435 incinerator might require as much as 8–10 years for writing an environmental impact statement, holding public hearings, and obtaining the necessary permits—TSCA, RCRA, National Emission Standards for Hazardous Air Pollutants (NESHAP), and Clean Air Act (CAA).⁷ Streamlining of this process would be needed if implementation of this technology is required within a shorter time period and for less money.

Table 5.3 Summary of implementation needs

Technology	Implementation need ^a		
	R&D/Demo ^b	Waste ^c	Robotics ^d
Bulk decontamination			
Solvent extraction	<2	X	
Incineration		X	
Dry heat		X	
Chemical leaching	<1	X	
Catalytic extraction process	3-5	X	
Vacuum (low pressure)	1-3	X	
Transmutation	0.1-10	X	X
Chemical surface cleaning			
Chemical foams	1-4	X	
Chemical gels	1-4	X	
Organic acid treatment	0.4-1	X	
Fluoboric acid treatment		X	
Inorganic acid treatment		X	
Detergent treatment		X	
REDOX treatment	~1	X	
Chelation treatment		X	
Electropolishing	0.4-1	X	
Gas phase	5	X	
Biological	0.3-0.6	X	
UV/ozone (UV light activation)	<1		
Electromigration	1.0	X	
Metal refining			
Smelt purification	3-5	X	
Electrorefining	3	X	
Leach/electrowinning	<1	X	
Mechanical surface removal			
Ultrahigh-pressure water	1.3	X	X
Shot blasting		X	X
Scabblers/scarifiers		X	X
Grit blasting		X	X
Centrifugal cryogenic CO ₂ blasting	<1	X	X
Ice blasting	0.25	X	X
Supercritical CO ₂ blasting	0.25-1	X	X

Table 5.3 (continued)

Technology	Implementation need ^a		
	R&D/Demo ^b	Waste ^c	Robotics ^d
Plastic pellet blasting		X	X
Hand grinding, honing, scraping		X	
Automated grinding	<1	X	X
Milling—metal			
Milling—concrete		X	X
Explosive	1-4	X	
Surface cleaning			
Compressed air cryogenic CO ₂ blasting	-0.5	X	
High-pressure water	-1.2	X	X
Superheated water	-1.2	X	X
Water flushing	-1.2	X	X
Steam cleaning	-1.2	X	X
Hand brushing			
Automated brushing	<1	X	X
Sponge blasting	-1.2	X	
Hot air	1-5	X	
Dry heat (roasting)	0.2-1	X	
Solvent washing (radioactive contamination)	<1	X	
Solvent washing (organic contamination)		X	
Strippable coatings		X	
Vacuum cleaning			
Ultrasonic cleaning		X	
Thermal surface removal			
Microwave scabbling	2.5	X	X
Plasma torch	<0.5	X	X
Laser heating	2+	X	X
Laser etching and ablating	2-3	X	
Plasma surface cleaning	4	X	
Plasma etching/fluorination	2+	X	
Flashlamp cleaning	2.5	X	

^aNumbers in table are costs in millions of dollars. An "X" indicates the relation of a need to a particular technology.

^bR&D/Demo = research and development and/or demonstration

^cWaste = waste collection systems

^dRobotics = technologies that are adaptable to remote-controlled operations

5.5 TECHNOLOGY RANKINGS

5.5.1 Ranking Method

Decontamination technologies applicable to ORNL D&D problems were ranked using the method described in Sect. 2.4. The rankings for the decontamination technologies are given in Table 5.4. Individuals that were assigned specific technologies first ranked the technologies. Because of the experience of these persons, their estimates of the time required to bring the technologies to maturity was believed to be more accurate than the guidelines given in Table 2.4. The rankings originally assigned to the various technologies were reviewed by other team members. If the team members disagreed with the original ranking, the ranking was discussed among the team, and the team arrived at a consensus ranking that was then used.

Because of the large number of variables that could affect the projected unit processing cost at ORNL, the Decontamination Team had great difficulty estimating reasonable values for this parameter. To achieve greater specificity for estimating the unit-processing cost, operating costs were based on decontamination of relatively large areas of concrete floor for all technologies applicable to this problem. For technologies that were only applicable to the decontamination of metals, the operating cost was based on decontamination of large sections of sheet metal. For technologies that were not applicable to either concrete or metals, unit processing costs were estimated for the applications that would give the lowest cost. Even so, the costs given in Table 5.4 should be regarded as approximate at best, treated only as relative values, and not used for estimating job costs.

5.5.2 High-Ranking Existing Technologies

Many existing technologies were ranked high. These technologies and the improvements recommended in them are briefly discussed in this section. No development or technology improvements are recommended for many of the high-ranking existing technologies.

5.5.2.1 Mechanical Surface Removal Methods

Mechanical surface removal methods are good for decontaminating concrete and exterior metal items. Mechanical scabblers are available and have been used extensively for decontaminating concrete surfaces. No secondary waste streams other than the removed concrete surface layer are produced. Mechanical scabblers have problems with uniform application on irregular and nonhorizontal surfaces. However, this problem is typical of other technologies for concrete decontamination and is one of the areas for development.

Shot blasters and grit blasters are also available and have been used extensively for decontaminating concrete and metal surfaces. The volume of waste shot created is a reasonably small fraction of the waste created from removing a concrete surface layer. The relative proportion of waste grit is larger. Grit blasting is more effective than shot blasting for decontaminating metal surfaces. The proportion of waste shot or grit created is greater for metal surfaces than for concrete surfaces. More durable blasting materials that resist abrasion and can be recycled through the process more times for waste minimization would improve the utility of these technologies. Shot and grit blasting are not recommended inside hot cells.

Table 5.4. Rankings of decontamination technologies for D&D

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-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	Detergent treatments	M-4-0 (\$0M;>\$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 decontamination	M-4-4 (\$5M;<\$0.50/lb)
DCON-17-OL	Biological surface cleaning	L-2-3 (\$1M;~\$1/ft ²)
DCON-19-OL	Ultraviolet light/ozone	M-4-2 (\$1M;~\$1/ft ²)
DCON-20-OL	Electromigration	M-3-3.5 (\$1.2M;N/ft ²)
DCON-21-OL	Chelation treatment	M-4-2 (\$1.5M;<\$1/ft ²)
Metal refining methods		
DCON-31-OL	Smelt purification	H-3-3 (\$100M;~\$1/lb)
DCON-32-OL	Electrorefining	M-2-5 (\$200M;\$6/lb)
DCON-34-OL	Leach/electrowinning	M-2-5 (\$200M;\$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)

Table 5.4 (continued)

Data sheet code number	Technology	Ranking ^a
DCON-38-OL	Grit blasting	H-4-0 (\$<0.1m;~\$5/ft ²)
DCON-39-OL	Centrifugal cryogenic CO ₂ blasting	H-5-2 (\$1.0M;<\$1/ft ²)
DCON-40-OL	Ice blasting	H-5-1 (\$<1.0M;\$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;\$1;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 used to remove surface contamination	H-2-0 (\$0M;\$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)
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)

Table 5.4 (continued)

Data sheet code number	Technology	Ranking ^a
Thermal surface removal methods		
DCON-71-OL	Microwave scabbling	H-3-2 (\$2.5M; >\$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 ablation	M-4-4 (\$3.5M; >\$1/ft ²)
DCON-75-OL	Plasma surface cleaning	H-4-2 (\$1.0M; >\$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:

- 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.

Ultrahigh-pressure water blasting is also available and accepted for concrete and metal decontamination. The depth of the concrete surface that is removed can be controlled by varying the water pressure and unit speed. A water recycle system may be available for some environments but generally will have to be developed and demonstrated for each specific application.

Supercritical CO₂ blasting, which is under development commercially, should act very much like ultrahigh-pressure water except that no water will remain that must be treated. Development of this technology should be completed. Commercial cryogenic CO₂ pellet blasting has been used to decontaminate tools at nuclear power plants. More abrasive high-speed pellets from a centrifugal cryogenic CO₂ pellet blasting system under development may be needed to remove many contaminants at ORNL. This technology should be effective in decontaminating metal and concrete surfaces.

Ice blasting offers the advantage that the pellet melts to form water rather than becoming a waste. The contaminated wastewater formed by the melting ice particles must then be treated for discharge in commercially available evaporators. Remote-controlled operation of the cleaning head is desirable for some applications and will be required for others (e.g., decontamination of hot cells). Consequently, the adaptation of the equipment to a robotics control system would be necessary.

5.5.2.2 Advanced Catalytic Extraction Process

The advanced catalytic extraction process is widely applicable to contaminated metals and nonmetals. The catalytic extraction process is similar to smelt purification when applied to contaminated metal refining but reportedly mixes better and maintains better control of the oxidation potential. For contaminated nonmetals, the catalytic extraction process acts similar to an incinerator but reaches higher temperatures and generally has longer processing times with more intimate contact of the contaminant with the molten metal bath. Impurities are removed by the off-gas treatment system as well as slags. This technology should be demonstrated on materials and contaminants of interest at ORNL.

5.5.2.3 Fluoboric Acid

Fluoboric acid effectively decontaminates concrete and metals by removing up to a few millimeters of the surface. Fluosilicic acid can also decontaminate concrete, brick, and similar masonry surfaces. The acid can be electrolytically regenerated and recycled. One treatment option is neutralization and precipitation with solidification in cement. Another treatment is ion exchange with solidification of the ion exchange resin or mineral in cement. The optimum materials for solidification of these wastes needs to be determined. Treatment systems that permit recycle of decontamination agents are needed for fluoboric acid and all liquid-based systems.

5.5.2.4 Organic Acids

Organic acids were used by British Nuclear Fuels, Ltd., as part of the treatment to decontaminate the Capenhurst Gaseous Diffusion Plant. Tests should be conducted to further verify that this process will remove the contaminants of interest at ORNL from the substrate metals on which they are found. Implementable waste treatment technologies in the United States are different than in Great Britain, but in most ways their controls are equally demanding.

5.5.2.5 Smelting

Smelting would be an attractive secondary decontamination method if a *de minimus* limit were in place for bulk-contaminated materials. The additional purification that would be obtained by using smelting as a secondary decontamination step would permit the use of primary decontamination technology that is only partially effective while still providing thorough overall decontamination. Primary decontamination technologies that leave some contamination behind (e.g., in cracks and crevices) could be used. Previously bulk contaminated metals cannot be recycled to the commercial sector for reuse no matter how well they have been decontaminated because the U.S. does not have a *de minimus* limit. Metals could be recycled within the DOE system to make shield blocks, waste containers, and other items without a *de minimus* limit. However, use of these items would still have to be accepted by the user or acceptance would have to be mandated by DOE headquarters. Techniques for improving the purification of aluminum and for removing technetium should be developed if possible.

5.5.2.6 Grinding, Brushing, and Vacuuming

Hand grinding, brushing, and vacuuming will continue to find applications in areas of negligible radiation because of their very low capital cost. These technologies are very effective for some applications. Remotized versions of these technologies are needed in higher-radiation or -contamination areas.

5.5.2.7 Solvent Washing

Solvent washing is an effective way to remove organic contamination. However, environmentally acceptable solvents must be used. Solvents that are less damaging to the environment need to be identified and demonstrated.

5.5.3 High-Ranking Technologies Requiring Development

Microwave scabbling is a potentially attractive decontamination method for concrete. Development of this technology should be continued. The secondary waste is the removed concrete surface layer. Microwave scabbling may result in the removal of a deeper concrete layer than is desired, with attendant generation of more secondary waste than is necessary. Because there is no reaction force, this technology appears particularly suitable for use on walls and ceilings and for remote use in hot cells and other high-radiation areas.

Use of a plasma torching is a potentially attractive decontamination method for concrete and metal that should be investigated. This technology could be effective, generate little secondary waste, and have low-capital and operating costs. Development and demonstration should not take long or be very expensive.

Plasma surface cleaning and flashlamp cleaning are potentially attractive decontamination methods for metals that should also be investigated. They could be effective and generate little secondary waste. Capital costs could be higher, especially for plasma surface cleaning. Flashlamp cleaning would be ideal for decontamination of hot cells, other higher-radiation areas, and difficult-to-reach areas since it acts remotely.

All of these technologies should be developed to the point that capital and operating costs can be estimated.

5.5.4 Implementation

Technologies that generate mists, dusts, and smokes will require effective vacuum and filtration systems. Smokes generated by most thermal surface removal methods have smaller particle diameters than dusts generated by mechanical surface removal methods or mists generated from liquid decontamination techniques and will require particularly effective filtration systems. Many will require glove boxes or special decontamination rooms.

Operating costs that are achievable in clean environments are less important than donning and doffing, setup and breakdown, and waste disposal costs. Because these costs appear to run just under \$1/ft² under the most favorable conditions, estimated costs for the fastest and least labor intensive decontamination methods tended to be estimated at about \$1/ft².

5.5.5 Remotization

Remotization is needed for decontamination in areas having moderate- or high-radiation fields. Mechanical control of decontamination operations will also be helpful during the decontamination of walls, ceilings, and similar surfaces. Since decontamination operations at ORNL—unlike those at the K-25 Site—will be characterized by few replications of a given task, automation will not be needed. Remotization should be accomplished by teleoperation with an operator in the loop rather than by use of an independent robot.

5.5.6 Components with Induced Radiation

Decontamination of metal components with induced radiation, such as reactor cores, is generally not feasible. Metal refining technologies will be ineffective in most cases because the induced radiation comes from atoms that are isotopes of and chemically identical to the bulk of the metal atoms. In principal, transmutation could be used but only if the radioactive isotope had a larger cross section than the base metals. In any event, this would be a prohibitively expensive operation. In general, these components will have to be removed and disposed of in their radioactive state. Concrete with induced radiation can be removed, leaving clean concrete (or concrete that can be decontaminated as indicated in the logic diagram). Similarly, equipment that is partially contaminated with induced radiation is decontaminated by cutting out only the parts with induced radiation.

5.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE

DOE is currently developing technologies that could contribute to solving environmental and waste recycling problems at the different DOE sites. Some of these projects may have relevant and beneficial elements with respect to the decontamination technologies listed in Table 5.2. Table 5.5 gives the results of a search of available information on programs funded in FY 1992 and FY 1993 and identifies possible matches with this list of decontamination technologies. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding decontamination technology code by TTP number. When no FY 1993 matches were found and the searcher (based solely on personal knowledge) knew of valid FY 1992 matches, these were entered in the 1993 TTP column. Decontamination technologies for which no matches were found are omitted from the table. When many matches were found, only one or two were cited. The relevance column indicates the degree of overlap between the listed decontamination technologies and active TTP projects. The TTPs comprising the search data base are listed in the appendix.

Table 5.5. Decontamination technologies under development by DOE

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Solvent extraction	DCON-1-OL	OR-373-AH	H	Organic extraction from sludge Mature technology
Catalytic extraction process	DCON-6-OL	ID421201	H	Molten metal/salt extraction
Chemical gels	DCON-9-OL	RL332003	M	Hanford Tank example. Widely used
Detergent treatments	DCON-13-OL	RL132002	L	Supporting technology
Biological surface cleaning	DCON-17-OL	AL121121	L	Biological cleaning of soil
Electromigration	DCON-20-OL	AL231009	L	Electrokinetic removal of Cr from soil
Chelation treatments	DCON-21-OL	ID111701 AL1320028	M H	Chelation and extraction of lanthanides and actinides Removal of metal ions from wastewater
Smelt purification	DCON-31-OL	ID132011 ID421201	L M	Arc melter vitrification Actinide concentration
Leach/electrowinning	DCON-34-OL	ID421201	L	Mentions LMFBR ^c fuel reprocessing— Accepted Ni Ore refining
Ultrahigh-pressure water	DCON-35-OL	SF221205	M	Use on WHC ^d UST ^e cleaning
Scabblers/scarifiers	DCON-37-OL	RL332003	M	Accepted
Hot air stripping	DCON-59-OL	RF121204	M	Rocky Flats Integrated Demo
Solvent washing to remove radiological contamination	DCON-61-OL	OR132012 RL321204	M L	Sludge washing at ORNL MVST ^f Innovative chemical separations
Solvent washing to remove organics	DCON-62-OL	RL321204	M	Innovative chemical separation
Microwave scabbling	DCON-71-OL	OR101204	H	Demonstrated small scale
Plasma torch	DCON-72-OL	OR113206 AL223201 SR113201	M H H	Combined with Robotics Used at SRTC Used at SRTC WFO ^g
Transmutation	DCON-78-OL	AL121207 (FY 92)	M	Accelerator based

^aTTP = Technical Task Plan Identifier.

^bThe relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagrams* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need;
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

^cLMFBR = Liquid Metal Fast Breeder Reactor

^dWHC = Westinghouse Hanford Company

^eUST = underground storage tanks

^fMVST = Melton Valley storage tanks

^gWFO = work for others

5.7 REFERENCES

1. *Decontamination of Nuclear Facilities to Permit Operation, Inspection, Maintenance, Modification, or Plant Decommissioning*, Technical Reports Series No. 249, International Atomic Energy Agency, Vienna, 2985.
2. *Decontamination and Decommissioning Integrated Demonstration Strategy*, DOE/OR-1051, Office of Technology Development, Environmental Restoration and Waste Management, U.S. Department of Energy; Oak Ridge, Tenn., March 1993.
3. J. M. Googin, personal communication to R. D. Bundy (Some Notes on the TLD Project), Y-12 Plant, Oak Ridge, Tenn., February 3, 1993.
4. E. B. Munday and D. W. Simmons, *Feasibility of Gas-Phase Decontamination of Gaseous Diffusion Equipment*, K-TCD-1048, Martin Marietta Energy Systems, Inc., Oak Ridge K-25 Site, February 1993.
5. C. E. Benson, personal communication to R.D. Bundy, Oak Ridge National Laboratory.
6. E. B. Munday, *Advanced Gas-Phase Decontamination Technology*, TTP OR-1-4-20-08, Office of Technology Development, Oak Ridge National Laboratory, February 13, 1993.
7. L. V. Gibson, Jr., telephone conversation with D. H. Bunch, June 16, 1992.

6. ROBOTICS/AUTOMATION

6.1 INTRODUCTION

Robotic devices and automation will be required for the decommissioning of facilities at ORNL to displace humans from what are, in some cases, very hazardous environments. Specific applications of robotics/automation for the various types of facilities are described in detail in Sect. 6.2.

It should be noted that robotics/automation supports the characterization, dismantlement, and decontamination activities that are required for D&D primarily through the deployment of sensors and tools required for these activities.

6.2 TECHNOLOGY OPTIONS

The robotics/automation technologies required for D&D of various facilities at ORNL are listed in Table 6.1. As shown in the table, the technologies are grouped into nine functional areas, each representing a different element of a robotic or automation system.

For convenience, the different types of facilities requiring D&D have been grouped into the following categories. These categories and the problems likely to be encountered at each type of facility (particularly for the application of robotics/automation technologies) are described in the remainder of Sect. 6.2.

6.2.1 Stabilized Hot Cells (Bldgs. 3026C, 3028, 3029, 3030, 3031, 3038, 3047, 3517, and 3019A)

In assessing the applicability of various robotic/automation technologies for the decommissioning of stabilized hot cells, it is assumed that standard shutdown procedures will have been completed prior to bringing the facility into the D&D program. These assumptions include (1) all loose, unanchored equipment will have been dismantled and removed from the cell, (2) all in-process, radioactive materials will have been taken out of the cells, (3) limited decontamination will have been performed to remove known gross contamination, (4) general cell characterization will have been performed, (5) LLLW system within the cell will be permanently plugged and will not be available for D&D activities, and (6) the cells will still be connected to the central off-gas system.

Tasks that must, in general, be performed robotically for these stabilized hot cells include the following:

- *Characterization*—Although a general characterization may have been performed at the time of shutdown, a more rigorous characterization will probably be required, particularly for the service penetrations, off-gas ducts, and transfer ports.
- *Decontamination*—To effectively decontaminate the cells, access must be created to all surfaces. This will require that decontamination and dismantlement proceed as integrated activities rather than sequentially. Robotics will have to be used for both types of activities. Further, since the LLLW system may no longer be functional, decontamination wastes will have to be removed from the cell by other means and probably handled remotely by robotic devices.
- *Dismantlement*—Depending on the ultimate disposition for the hot cell, dismantlement activities may include the cutting-up or dismantling of remaining process equipment (generally that equipment permanently installed in the cells), pipe removal, manipulator removal, hoist removal, dismantlement of transfer systems, cell windows, and filter houses. These activities will have to be performed remotely and probably with some form of secondary containment.
- *Terminal Activities*—These tasks (which may be part of the RA program and depend on the final disposition planned for the facility) could include activities such as filling/plugging/removing penetrations, backfilling of the hot cell with grout or clay caps, entombing of the cell, or total removal of the structure. Although many of these tasks may not have to be performed robotically, some, like disconnecting the facility from the cell ventilation system, may require remote operations.

Table 6.1. Relationship of robotics/automation technologies to D&D

Robotics/ automation technology	Facility categories					
	Hot cells		Reactors, fuel		Reactor support buildings	Storage buildings
	Stable	Abandon	Solid	Liquid		
Mechanical—mobility						
ROBA-1-OL			X ^a	X	X	X
ROBA-5-OL			X	X	X	
ROBA-6-OL	X	X	X	X	X	
ROBA-7-OL	X	X		X		
ROBA-8-OL			X	X	X	
ROBA-9-OL			X	X		
ROBA-10-OL	X	X	X	X	X	X
ROBA-11-OL	X	X	X	X		
ROBA-12-OL	X	X	X	X	X	
ROBA-13-OL	X	X	X	X	X	X
Mechanical—manipulation						
ROBA-14-OL	X	X				
ROBA-15-OL	X	X				
ROBA-16-OL		X	X	X	X	
ROBA-19-OL			X	X		
Mechanical—mechanisms						
ROBA-20-OL (for characterization)						
ROBA-21-OL	X	X	X	X	X	
ROBA-22-OL			X	X	X	

Table 6.1 (continued)

Robotics/ automation technology	Facility categories					
	Hot cells		Reactors, fuel		Reactor support buildings	Storage buildings
	Stable	Abandon	Solid	Liquid		
Mechanical—end-of-arm tooling						
ROBA-23-OL		X	X	X		
ROBA-24-OL	X	X	X	X	X	X
ROBA-25-OL	X	X	X	X	X	X
ROBA-26-OL			X	X		
Controls—algorithms						
ROBA-27-OL	X	X	X	X	X	X
ROBA-28-OL			X	X	X	X
ROBA-29-OL			X	X	X	
ROBA-30-OL	X	X	X	X	X	X
ROBA-31-OL	X	X	X	X	X	X
ROBA-32-OL		X	X	X		
ROBA-33-OL		X	X	X		
ROBA-34-OL			X	X	X	X
ROBA-35-OL			X	X		
ROBA-36-OL			X	X		
ROBA-37-OL	X	X	X	X	X	X
Controls—human/machine interface						
ROBA-38-OL	X	X	X	X	X	X
ROBA-39-OL			X	X		
ROBA-40-OL		X	X	X	X	
ROBA-41-OL		X	X	X	X	
ROBA-42-OL		X	X	X	X	

Table 6.1 (continued)

Robotics/ automation technology	Facility categories					
	Hot cells		Reactors, fuel		Reactor support buildings	Storage buildings
	Stable	Abandon	Solid	Liquid		
Sensors—perception						
ROBA-43-OL	X	X	X	X	X	X
ROBA-44-OL			X	X		
ROBA-45-OL			X	X		
ROBA-46-OL			X	X	X	
Sensors—control						
ROBA-48-OL	X	X	X	X	X	
ROBA-50-OL	X	X	X	X	X	
ROBA-51-OL		X	X	X		
ROBA-52-OL		X	X	X	X	
Other technologies						
ROBA-53-OL	X	X	X	X	X	X
ROBA-54-OL		X	X	X		
ROBA-55-OL (for characterization)						
ROBA-56-OL (for characterization)						
ROBA-57-OL	X	X	X	X	X	X
ROBA-58-OL (for characterization)						
ROBA-59-OL (for characterization)						

^aAn X signifies that a technology is applicable to a facility category.

Challenges that will be encountered in the D&D of stabilized hot-cell are listed below.

- *Very limited access into/within the cells*—In some cases, the only access is through the horizontal transfer ports. Further, many of the cells are rather small and odd shaped with limited maneuvering room in the cell.
- *Limited access to some buildings*—Accessibility to the cells in some buildings is somewhat limited and may require some amount of decontamination and dismantlement of the facility before the cells, themselves, can be accessed.
- *Lack of hot drains*—This may add to the difficulty of the robotic tasks since the waste disposal streams will probably require remote handling.

6.2.2 Abandoned Hot Cells (Bldgs. 3019B, 3033 and 3033-A, 3042, 3505, 3515, 3517, 4507 and 7025)

There are a number of hot-cell facilities at ORNL that were basically abandoned at the time of termination of programs' funding operations of the cells. These facilities currently receive minimum monitoring and only the most essential surveillance and maintenance. The hot cells are in various stages of disrepair. In some cases, manipulators do not function and viewing windows have deteriorated to the point of being useless. Large volumes of loose equipment and general waste are believed to exist in these hot cells. Decommissioning of these cells will require the same types of tasks as in the case of stabilized hot cells as described above. However, because of the condition of the cells, manipulators and windows will not be available to assist in the operations. In these cases, the use of robotics will be more extensive than the case of the stabilized hot cells. Robotics will be needed to make initial entry into the cells to characterize the condition of the cell and to perform the initial removal of any inventory and loose equipment. The characterization and decontamination tasks in these cells will be much more difficult than with the stabilized facilities. However, once these tasks are completed, the dismantlement and terminal activities will be very similar to those required at the stabilized facilities.

6.2.3 Reactors and Reactor Support Facilities (Bldgs. 3001, 3005, and 3042)

Various types of reactors are included in the D&D program. These include both liquid-fueled reactors (Molten Salt Reactor Experiment and Homogenous Reactor Experiment) and solid-fueled reactors (both water and air cooled).

The broad variety in types of reactors, as well as reactor support facilities, will present significant robotics/automation challenges, particularly since the facilities are in varying stages of stabilization. It is assumed, with the possible exception of the Molten Salt Reactor Experiment, that before D&D efforts are initiated, all reactors and facilities will be stabilized to a point that will permit reasonable robotic access. Specific facilities to be decommissioned include the following:

- *ORNL Graphite Reactor, Filter House, Fan House, and Exhaust Stack*—This was an air-cooled reactor and the only unusual problems are fuel capsules that ruptured during operation, causing the graphite pile to be very radioactively hot. Also the east face of the reactor must be maintained as a national historic monument. The system is reasonably well contained and accessible and is a good candidate for robotic

applications, particularly for the crushing and packaging of the graphite core—which, because of the high radiation levels, must be performed remotely.

- *Low-Intensity Test Reactor and Cooling Tower*—The contamination levels associated with this reactor are low compared to other facilities. The facility is reasonably accessible and is also a good candidate for the robotic deployment of characterization, dismantlement, and decontamination tools and sensors. The only unusual problem is the need to access multiple levels (a problem common to most reactor facilities), implying either a robotic platform capable of negotiating stairs or, if radiation levels are not too high, hands-on deployment by humans. The cooling tower associated with this reactor is also internally contaminated. However, the dismantlement of this tower should be relatively straightforward and, indeed, may be possible by using suited workers rather than robotic devices.
- *Oak Ridge Research Reactor, Pool Cooling Tower, Reactor Cooling Tower, Heat Exchanger Pit, Demineralizer, and Pump House*—This reactor and its associated facilities will require extensive use of robotics/automation for decommissioning. Almost every aspect of this decommissioning task presents unique problems, not only because many of the components are very hot, but also because of the existence of other chemically hazardous materials (e.g. asbestos, oils, chromates, lead, etc.). It should be noted that the original water-to-air radiator heat exchanger was replaced by a cooling tower system in 1960. The need for decommissioning of the cooling tower is not known at this time.
- *Molten Salt Reactor, Filter Pit, Exhaust Stack, Cooling Tower, Supply Air Filter House, and Diesel Generator House*—Many components of this system are very hot and will require robotic deployment of sensors and tooling. Accessibility is considered to be a major problem. Radiation hardening of some robotic components, including sensors, may be required. The need for a tool caddy is also an important consideration to minimize the number of trips into the highly contaminated areas. This facility, compared to other facilities, is not well defined and numerous unanticipated problems can be expected in the decommissioning effort.
- *Homogenous Reactor Experiment, Waste Evaporator, Charcoal Absorber Pit, Waste Evaporator Loading Pit, Charcoal Absorber Valve Pit, and Decontamination Pad*—Although some components in these facilities are relatively hot, the present plan for limited decontamination and dismantlement limits the application of robotics/automation. To the extent that robotics are used, accessibility, including maneuvering room for the robotic device, are considered to be the major problem.
- *Storage pads*—It is not anticipated that these facilities will present any unique problems for robotics/automation.

Each of the categories of facilities identified above require a somewhat different mix of robotics/automation technologies. Table 6.1 shows which technologies are applicable to each kind of facility.

6.3 SCIENCE AND TECHNOLOGY NEEDS

Specific needs, with a short explanation of the reason why additional R&D is required, are given below for robotics/automation. These needs are also related to the specific types of facilities requiring D&D.

6.3.1 Control Methods for Operator Assistance During Remote Operations (ROBA-41-OL)

In the past, remote operations have been typically inefficient. Research leading to the development of operator assists would improve the efficiency of these operations. There are a number of possible avenues that could be pursued, but the most productive are considered to be Dynamic Allocation of Function Research and Machine Learning Research. These increased capabilities would be particularly useful in highly constrained environments such as those likely to be encountered in abandoned hot cells and reactor facilities.

6.3.2 Combined Mobility/Manipulation Capabilities (ROBA-34-OL)

R&D is required to permit mobility and manipulation to occur as parallel rather than sequential activities with the objective being to increase the efficiency of remote operations. Control algorithms must be developed and tested to permit this type of operation. This capability would be beneficial in almost all application of robotics to D&D activities. For example, in conducting radiation surveys of contaminated areas, it would be considerably more efficient to move the deployment vehicle as the manipulator arm carrying the detectors is sweeping the area rather than first moving the vehicle and then moving the arm in a sequential manner.

6.3.3 Wheeled/Tracked Vehicles (ROBA-1-OL)

Although a multitude of robotic vehicles are commercially available, none appear to meet all the needs of D&D activities. The ability of this technology is to (1) efficiently work and navigate in constrained areas (for example, in abandoned hot cells or in the coolant piping of reactor systems), (2) be easily decontaminated or transported, and (3) manage cabling systems required for power or data transmission. These features are not totally available in any commercial system.

6.3.4 Tool Caddies and Rapid Changeout Mechanisms (ROBA-21- and 24-OL)

In the D&D of many of the ORNL facilities, entry into the contaminated area for a robotic device is difficult and time consuming. It is essential that the robotic device carry all the required tools anticipated for the D&D activity and that the system be designed to easily access and perform tool changeout. Although this R&D need may appear to be trivial, it is an area that has not been adequately addressed in previous programs, and there is probably no other feature that would increase the efficiency of remote operations as much as this capability.

6.3.5 Single-/Dual-Arm Manipulators with Force-Reflection/Tactile Capabilities (ROBA-16-OL)

Many D&D tasks can only be performed by single-arm manipulators because of access constraints. Other tasks require dual-arm capabilities. Similarly, some tasks require full-force reflection capabilities, while other tasks need no-force reflection. No commercial systems can function in either the single- or dual-arm mode, particularly when force-reflection capabilities are also required. R&D leading to the development of this type of system would reduce costs (multiple units would not have to be procured) and increase operational efficiency.

6.4 IMPLEMENTATION NEEDS

For D&D activities, high-priority implementation needs are explained below with a summary explanation of why the need is important.

6.4.1 Cold Test Facilities for Verifying the Effectiveness of the Robotic Device

A lesson too frequently learned in remote operations is that cold test facilities are essential for verifying the ability of the robotic device to perform the required tasks. These test facilities can usually be relatively simple and inexpensive partial mockups of the anticipated work area, but they are absolutely needed, particularly for complex operations in constrained areas.

6.4.2 Operator Training on Advanced Control Systems and/or Human-Machine Interfaces

Present operators of robotic devices are trained as teleoperators (i.e., they control all motions and make all decisions on how to proceed with the completion of the task). Enhanced control systems, equipped with operator assistance capabilities, are a new concept for the operators, and they must be adequately trained on these systems to realize the systems' full potentials. Arms with greater than 6 degrees of freedom, which may be required for some D&D tasks, also present a unique problem for the operators (i.e., they may be operating slave arms with more degree of freedom than their own arms, and it is easy to become disoriented). Adequate training is an implementation need that must be provided. Note that the cold test facilities identified above as an implementation need can also serve as training facilities for the operators.

6.5 TECHNOLOGY RANKINGS

The rankings of the robotics/automation technologies required for D&D activities is given in Table 6.2. It should be noted that the criteria used for rankings are biased toward those technologies that are mature and commercially available. Hence, a one-for-one comparison between the rankings and the science and technology needs identified in Sect. 6.3 is not possible because commercially available devices generally require little additional R&D. It should also be noted that several of the criteria suggested for rankings were not considered applicable to robotics/automation. These include (1) compliance with requirements or regulations, (2) ES&H requirements, and (3) unit-processing costs. Others of the criteria have limited applicability to robotics/ automation.

A number of the technologies were considered essential. However, many of these technologies also had a high ranking, which meant they were commercially available. The essential technologies were usually associated with highly ranked site problems also.

The development costs identified in Table 6.2 should be considered rough order-of-magnitude estimates. They have more validity in the comparison of relative costs between various robotics/automation technologies (i.e. they are internally consistent) than they do in their absolute magnitude.

Table 6.2. Rankings of robotics/automation technologies for D&D

Data sheet code number	Technology	Ranking ^a
Mechanical—mobility		
ROBA-1-OL	Wheeled/tracked vehicles	E-5-2 (\$3M;N)
ROBA-5-OL	Pipe/duct crawlers (internal)	M-3-2 (\$1M;N)
ROBA-6-OL	Pipe/duct crawlers (external)	M-3-4 (\$5M;N)
ROBA-7-OL	Specialized robotic deployment platforms	M-4-3 (\$5M;N)
ROBA-8-OL	Mounted robotic platforms	M-2-1 (\$5M;N)
ROBA-9-OL	Long-arm deployed robotic platforms	M-4-3 (\$5M;N)
ROBA-10-OL	Power sources for mobile platforms	E-5-1 (\$0.5M;N)
ROBA-11-OL	Failure recovery systems for mobile platforms	E-5-1 (\$0.5M;N)
ROBA-12-OL	Transportation systems for mobile platforms	M-3-1 (\$0.5M;N)
ROBA-13-OL	Data/signal transmission	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	E-5-1 (\$1M;N)
ROBA-19-OL	Compact, high-capacity manipulators	H-5-1 (\$1M;N)

Table 6.2 (continued)

Data sheet code number	Technology	Ranking ^a
Mechanical—mechanisms		
ROBA-20-OL	Precise programmable motions	H-5-1 (\$0.5M;N)
ROBA-21-OL	Tool caddies	H-4-1 (\$0.5M;N)
ROBA-22-OL	Stabilization/support mechanisms or booms	M-3-1 (\$0.5M;N)
Mechanical—end-of-arm tooling		
ROBA-23-OL	End effectors/alternatives	E-5-2 (\$1M;N)
ROBA-24-OL	End-effector changeout mechanisms	M-3-1 (\$0.5M;N)
ROBA-25-OL	General gripper/tool interface	H-4-1 (\$0.5M;N)
ROBA-26-OL	Force limiting/compliant mechanisms	M-3-1 (\$0.5M;N)
Controls—algorithms		
ROBA-27-OL	Control modes	E-5-N (\$N;N)
ROBA-28-OL	Vehicle/mobility driving	E-5-1 (\$0.5M;N)
ROBA-29-OL	Vehicle/mobility navigation	M-4-1 (\$0.5M;N)
ROBA-30-OL	Manipulation (joint control)	H-4-1 (\$0.5M;N)
ROBA-31-OL	Manipulation (cartesian control)	H-4-1 (\$1M;N)
ROBA-32-OL	Manipulation (special purpose control)	H-4-2 (\$1.5M;N)
ROBA-33-OL	Manipulation (redundancy control)	M-3-2 (\$2M;N)
ROBA-34-OL	Combined mobility/manipulation	M-2-2 (\$1M;N)
ROBA-35-OL	Safety (collision avoidance)	H-4-1 (\$1M;N)
ROBA-36-OL	Safety (load/rate limiting)	H-3-1 (\$0.5M;N)
ROBA-37-OL	Emergency shutdown	E-4-1 (\$0.5M;N)
Controls—human/machine interface		
ROBA-38-OL	Console (fixed/mobile/suitcase)	E-5-1 (\$0.5M;N)
ROBA-39-OL	Console (data handling methods)	M-3-1 (\$1M;N)
ROBA-40-OL	Operator interface (command-input)	H-3-1 (\$0.5M;N)
ROBA-41-OL	Operator interface (operator assistance)	H-3-2 (\$1.5M;N)
ROBA-42-OL	Operator interface (status/alert system)	E-5-1 (\$0.5M;N)
Sensors—perception		
ROBA-43-OL	Visual/aural systems	E-5-1 (\$1M;N)
ROBA-44-OL	Range finders	M-3-2 (\$1.5M;N)

Table 6.2 (continued)

Data sheet code number	Technology	Ranking ^a
Sensors—perception (continued)		
ROBA-45-OL	Proximity probes	M-2-2 (\$1M;N)
ROBA-46-OL	Force/torque sensors	M-2-1 (\$0.5M;N)
Sensors—control		
ROBA-48-OL	Position/velocity sensors	E-5-1 (\$0.5M;N)
ROBA-50-OL	Force/torque	H-3-1 (\$0.5M;N)
ROBA-51-OL	Proximity probes as control sensors	H-3-1 (\$1M;N)
ROBA-52-OL	Tooling sensors	H-3-1 (\$0.5M;N)
Other technologies		
ROBA-53-OL	Field hardening	M-3-1 (\$0.5M;N)
ROBA-54-OL	Radiation hardening	E-5-2 (\$2M;N)
ROBA-55-OL	Integrated automated analytical laboratory	E-5-2 (\$3M;N)
ROBA-56-OL	Information management for sample handling	E-5-1 (\$1M;N)
ROBA-57-OL	Sample collection	E-5-1 (\$1.5M;N)
ROBA-58-OL	Characterization sensor integration	M-3-2 (\$1M;N)
ROBA-59-OL	Sample preparation	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.

6.6 RELEVANT TECHNOLOGIES UNDER DEVELOPMENT BY DOE

DOE is currently developing technologies that could contribute to solving environmental and waste recycling problems at the different DOE sites. Some of these projects may have relevant and beneficial elements with respect to the robotics/automation technologies listed in Table 6.2. Table 6.3 gives the results of a search of available information on programs funded in FY 1992 and FY 1993 and identifies possible matches with the complete set of robotics/automation technologies listed in the *Oak Ridge National Laboratory Technology Logic Diagram*, Volume 1, Parts A, B, and C. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding robotics/automation technology code by TTP number. When no FY 1993 matches were found and the searcher (based solely on personal knowledge) knew of valid FY 1992 matches, these were entered in the 1993 TTP column. Robotics/automation technologies for which no match was found are omitted from the table. When many matches were found, only one or two were cited. The relevance column indicates the degree of overlap between the technologies listed in Volume 1, Parts A, B, and C and active TTP projects. The TTPs comprising the search data base are listed in the appendix.

Table 6.3. Robotics/automation technologies under development by DOE

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Wheeled/tracked vehicles	ROBA-1-OL	OR113202	M	Robotics for buried waste
		OR113203	H	Crosscutting and advanced technology
		OR113206	H	Demonstration of telerobotic dismantlement
		SR123201	H	Robotics for decontamination and decommissioning (D&D)
Pipe/duct crawler (internal)	ROBA-5-OL	AL213204	L	Miniature robotics
		SF213203	L	Remote microsensor technology
Pipe/duct crawler (external)	ROBA-6-OL	AL223201	H	Robotic external pipe decontamination
		OR113206	H	Robotic asbestos removal
		SR123201	H	Robotic asbestos bagging
Specialized robotic deployment platforms	ROBA-7-OL	AL213204	H	Crosscutting and advanced technology
		SF213203	H	Crosscutting and advanced technology
		SF223203	H	Robotics technology development
		OR113203	H	Crosscutting and advanced technology
Transportation methods for mobile platforms	ROBA-12-OL	AL213205	M	Remote drum handling equipment
Data/signal transmission	ROBA-13-OL	AL213204	H	High-bandwidth long cable, harsh env.
		AL322002	H	Data acquisition modules
		SF213205	H	Data & video telemetry
Long-reach manipulator (light duty)	ROBA-14-OL	RL313202	H	Long-arm, light-duty manipulator for underground tanks
Long-reach manipulator (heavy duty)	ROBA-15-OL	OR113206	H	Demonstration arm collision avoidance
		AL213204	H	Development high-payload long arm
Dexterous manipulators	ROBA-16-OL	OR113202	H	Robotics for buried waste
		AL213201	H	Robotics for buried waste
		AL213202	H	Robotics for buried waste
Precise programmable motions	ROBA-20-OL	AL213204	M	Programmed robotic motion
		SR113201	M	Programmed teleoperated control
		RL332004	M	Short-reach dexterous manipulator
End effectors/alternatives	ROBA-23-OL	AL213201	H	End-effector development
		AL213207	H	End-effector development
		RL332004	H	End-effector development
End-effector changeout mechanisms	ROBA-24-OL	SR123201	M	Robotics for D&D

Table 6.3 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Vehicle/mobility navigation	ROBA-29-OL	OR113203	L	Crosscutting and advanced technology
		OR113205	L	Crosscutting and advanced technology
		RL313203	L	Robotics for buried waste
Manipulation (joint control)	ROBA-30-OL	AL213201	M	Joint failure reconfiguration
Manipulation (special purpose control)	ROBA-32-OL	AL221205	L	In-tank hardware removal
Manipulation (redundancy control)	ROBA-33-OL	AL213104	M	Kinematic redundancy of controls in crosscutting
Safety (collision avoidance)	ROBA-35-OL	AL213201 (Many)	M	Robotics for storage tanks (no new methods developed)
Console (data handling methods)	ROBA-39-OL	AL232002	L	Computer interface/end effector
Operator interface (command input)	ROBA-40-OL	RL313203	L	Robotics for buried waste
		OR113202	L	Robotics for buried waste
Operator interface (operator assistance)	ROBA-41-OL	OR113203	L	Crosscutting and advanced technology
		AL213204	L	Crosscutting and advanced technology
Operator interface (status/alert system)	ROBA-42-OL	OR113203	L	Crosscutting and advanced technology
		AL213204	L	Crosscutting and advanced technology
Range finders	ROBA-44-OL	OR113201 (Many)	L	Robotics storage tanks
Proximity probes	ROBA-45-OL	OR113203	L	Crosscutting and advanced technology
		AL213204	L	Crosscutting and advanced technology
Force/torque sensors	ROBA-46-OL	OR113203	H	Crosscutting and advanced technology
		RL313205	H	Crosscutting and advanced technology
Force/torque	ROBA-50-OL	OR113203	H	Crosscutting and advanced technology
		AL213204	H	Crosscutting and advanced technology
Tooling sensors	ROBA-52-OL	SR123201	M	Robotics for D&D
Field hardening	ROBA-53-OL	AL213204 (Many)	L	Crosscutting and advanced technology
Radiation hardening	ROBA-54-OL	AL213204 (Many)	M	Crosscutting and advanced technology

Table 6.3 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Integrated automated analytical laboratory	ROBA-55-OL	AL213203	H	Robotic contaminant analysis automation
Information management for sample handling	ROBA-56-OL	AL213203	H	Robotic contaminant analysis automation
Sample collection	ROBA-57-OL	AL213203	H	Robotic contaminant analysis automation
Characterization sensor integration	ROBA-58-OL	AL213204	H	Crosscutting and advanced technology
Sample preparation	ROBA-59-OL	AL213203	H	Robotic contaminant analysis automation

^aTTP = Technical Task Plan Identifier.

^b The relevance column indicates how closely a TTP is focused on satisfying the technology development needs indicated in the *Technology Logic Diagrams* (Vol. 2) and the *Technology Evaluation Data Sheets* (Vol. 3), where

- H means the TTP is focused on the perceived technology development need;
- M means the TTP is partially focused on the technology development need;
- L means the TTP is not directly focused on the technology development need;
- Blank space designates no determination of how closely a TTP is focused on the technology's development need.

7. Regulatory Compliance

7. REGULATORY COMPLIANCE

7.1 INTRODUCTION

Many government-owned facilities that supported the early nuclear energy research and defense programs have no current use and have been retired. Some of these DOE facilities have residual radioactive or chemical contamination levels that require cleanup. The D&D Program is responsible for managing these surplus facilities to protect the public health and environment from radioactive contamination or hazardous materials that may be present. D&D is concerned with the safe caretaking of surplus nuclear facilities until their decontamination, entombment, dismantling and removal, or conversion to another nonnuclear reuse.

Presently there is no law or regulation mandating decommissioning at DOE facilities or setting *de minimis* or BRC radioactivity levels to guide decommissioning activities at DOE facilities. DOE Order 5820.2A, Chap. V (*Decommissioning of Radioactively Contaminated Facilities*), outlines D&D project activities that include: (1) surveillance and maintenance, (2) assessment and characterization, (3) environmental review, (4) engineering design, (5) D&D operations, (6) waste disposal, and (7) closeout. The D&D Program cost-effectively maintains surplus facilities awaiting decommissioning in a safe and secure state and ultimately completes decommissioning activities of the facilities. DOE Order 5820.2A requires that each field organization prepare and maintain a complete list of contaminated facilities, both operational and excess, under its jurisdiction; these facilities may be assigned to other jurisdictional program responsibilities.

The U.S. DOE ORR was placed by the EPA on the National Priorities List under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) on Nov. 21, 1989, effective Dec. 21, 1989 (54 FR 48184). As a result of this listing, DOE, EPA, and the Tennessee Department of Environment and Conservation (TDEC) have signed an FFA for ER of the ORR (effective Jan. 1, 1992). An effort is under way to incorporate into the FFA all inactive facilities at the ORR that are known or suspected to contain significant quantities of residual hazardous materials. It is proposed that inactive facilities that contain or could possibly contain hazardous substances that need to undergo a detailed CERCLA assessment will be added to project lists under the FFA. Management of wastes, soil, or debris generated during D&D activities that are within the jurisdictional boundary of a CERCLA operable unit would proceed under the ER umbrella in an attempt to reduce duplication of responses and costs. To meet the needs of the ER schedule for a particular operable unit, the schedule for D&D activities may need to be modified.

As D&D commences or continues, the decommissioning and dismantling activities associated with it and the wastes produced will become subject to a number of federal and state environmental laws as well as DOE Orders. Additional regulatory drivers for these activities may be established through negotiated agreements, with associated compliance requirements and milestones defined therein. DOE Order 5820.2A requires that the regulatory status of each project be identified and that technical engineering planning must assure D&D compliance with all environmental regulations during cleanup activities. To assist in the performance of this requirement, this chapter will define regulatory drivers for those D&D activities that only involve decontamination and dismantling of buildings or structural components. The D&D of a facility generally

includes analysis and/or excavation of the soils 5 ft on each side of the building and 5 ft below the bottom of the building. RA activities performed under CERCLA generally address contaminated soil, ground water, burial grounds and other point and line sources of contamination, as well as pond-waste sludges (see Vol. 1, Pt. B). Volume 1, Pt. B, Chap. 6, will address regulations and negotiated agreements for RA activities proceeding under CERCLA (i.e. FFA ER sites).

In addition to regulatory issues pertaining to D&D and RA, wastes generated under any regulatory umbrella must be managed according to prescribed WM procedures. Volume 1, Pt. C, Chap. 6, will address federal, state, and local codes, DOE Orders, Interagency Agreements and Federal Facility Compliance Agreements as they apply to WM practices at ORNL.

Requirements promulgated under the RCRA, the Clean Water Act (CWA), the CAA, and the Occupational Safety and Health Administration (OSHA) may direct D&D activities at ORNL. Additionally, compliance with a variety of regulations may be required under the National Environmental Policy Act (NEPA). The regulatory summary presented in this chapter has been modified from the ER report *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws*.¹ This summary is meant to represent an overview of potential regulatory compliance issues related to D&D activities and only presents excerpts in the text and tables from the complete set of regulatory requirements. In addition, compliance with other federal, state, and local regulations not addressed here may be required.

7.2 RESOURCE CONSERVATION AND RECOVERY ACT

The purpose of RCRA is to ensure the safe and environmentally acceptable management of hazardous and nonhazardous solid wastes. This law outlines the framework for national programs to achieve environmentally sound management of both hazardous and nonhazardous wastes from "cradle to grave." The Hazardous and Solid Waste Amendments (HSWA) of 1984 both expanded the scope of RCRA and increased the level of detail in many of its provisions.

Minimum national standards for acceptable management of hazardous waste appear in RCRA, although Tennessee has been authorized by EPA to administer and enforce its own standards in lieu of the federal RCRA regulations. Federally authorized state RCRA programs relate only to RCRA standards in place before enactment of HSWA. New regulations imposed in 1984 by HSWA are enforceable under federal law in all states until each authorized state promulgates its own HSWA-related standards. Tennessee received authorization for its base RCRA program effective February 5, 1985 and has received authorization for subsequent revisions to its program. Table 7.1 lists RCRA requirements discussed below, and the corresponding sections of the RCRA-authorized TDEC hazardous-waste management regulations found in TDEC Rules, Chap. 1200-1-11 *et seq.*

RCRA has nine distinct sections (subtitles) that regulate various aspects of hazardous waste. RCRA Subtitle C "Hazardous-Waste Management," regulates the generation, transportation, treatment, storage, and disposal of hazardous waste. Standards for the management of hazardous waste at RCRA-permitted treatment, storage, and disposal facilities were promulgated July 26, 1982, and appear in 40 Code of Federal Regulations (CFR) 264. Standards for interim status treatment, storage, and disposal facilities are found in 40 CFR 265. This text will generally address the Part 264 rather than the Part 265 standards that are virtually identical although at times less stringent.

In general, given that D&D activities only involve buildings, structural components, and possibly abandoned tanks or containers, many of the subparts of Subtitle C will not apply to D&D. The general closure and postclosure standards of Subpart G and specific closure standards for tanks and containers (Subparts J and I, respectively), as well as the standards for treatment of contaminated debris in "containment buildings" (Subpart DD) or miscellaneous treatment units (Subpart X) may apply to D&D activities. These are listed on Table 7.1 and summarized below. In addition, the new final rule implementing Subpart S ("Corrective Action for Solid Waste Management Units"), which may facilitate the integration of D&D and WM activities, is discussed below. In any situation where D&D activities generate waste, compliance with federal and state regulations becomes the responsibility of WM (see Vol. 1, Pt. C, Chap. 6 for a discussion of regulatory drivers for WM).

7.2.1 Closure of Tank Systems

The general requirements for closure are set forth in 40 CFR 264.111 and require that closure minimizes the need for further maintenance, and prevents postclosure escape of hazardous constituents to ground water, surface water, or the atmosphere.

During partial or final closure, all contaminated equipment and structures must be properly disposed of or decontaminated (see Sect. 7.2.2). This process may result in the generation of hazardous waste, and such waste must be handled in accordance with WM requirements (40 CFR 264.114).

Table 7.1. Federal and state regulations applicable to D&D activities at ORNL

Actions	Requirements	Federal citation	TDEC ^a Rules, Chapter
Closure	General performance standard requires elimination of need for further maintenance and control; elimination of postclosure escape of hazardous waste, hazardous constituents, leachate, contaminated runoff, or hazardous waste decomposition products to ground water, surface water, or the atmosphere.	40 CFR ^b 264.110-120 40 CFR 264.111	1200-1-11-.06-7
	All contaminated equipment and structures must be properly disposed of or decontaminated; any waste generated by this process must be handled in accordance with 40 CFR 262.	40 CFR 264.114	1200-1-11-.06-7
Closure, containers	At closure, remove all hazardous waste and residues from the containment system, and decontaminate or remove all containers, liners, bases, or soils.	40 CFR 264.178	1200-1-11-.06(9)(i)
Closure, tanks	At closure, remove all hazardous waste and hazardous waste residues from tanks, discharge control equipment, and discharge confinement structures.	40 CFR 264.197	1200-1-11-.06(10)(h)
Demolition of asbestos-containing structures	Remove all regulated asbestos-containing material (RACM) from a facility being demolished before any activity begins that would break up, dislodge, or disturb the material and preclude access to the material for subsequent removal; certain Category I and II materials are exempt from this requirement.	40 CFR 61.145(c)	

Table 7.1 (continued)

Actions	Requirements	Federal citation	TDEC ^a Rules, Chapter
Demolition of asbestos-containing structures (continued)	When a facility component is coated or covered with RACM and being removed from the facility as a unit or in pieces, <ul style="list-style-type: none"> adequately wet all RACM exposed during cutting or disjoining operations; and carefully lower each unit to the floor being careful not to dislodge RACM. 	40 CFR 61.145(c)(2)	
	If a facility component is stripped of RACM in place, wet the RACM during the stripping operation.	40 CFR 61.145(c)(3)	
	After a facility component has been removed as a unit or in sections, adequately wet the RACM during stripping or use a local exhaust ventilation and collection system designed and operated to collect particulate asbestos emission produced by stripping.	40 CFR 61.145(c)(4)	
	No visible emissions to the outside air from the ventilation and collection system are permissible. System must be designed and operated in accordance with 40 CFR 61.152.	40 CFR 61.145(c)(4)	
	Large facility components may not need to be stripped of RACM if certain requirements are met.	40 CFR 61.145(c)(5)	

Table 7.1 (continued)

Actions	Requirements	Federal citation	TDEC ^a Rules, Chapter
Direct discharge of treatment system effluent	<i>National Pollutant Discharge Elimination System (NPDES) Permitting Program</i>	40 CFR 122	1200-4-5
	Use of best available technology economically achievable is required to control toxic and nonconventional pollutants. Use of best conventional pollutant control technology is required to control conventional pollutants. Technology-based limitations may be determined on a case-by-case basis.	40 CFR 122.44(a)	
	The discharge must comply with applicable federal water quality requirements and more stringent state requirements under the Clean Water Act (CWA).	40 CFR 122.44(d) and state regulations approved under 40 CFR 131	1200-4-3-.03
	The discharge must be consistent with the requirements of a Water Quality Management plan approved by EPA under CWA §208(b).	40 CFR 122.44(d)	
	Discharge limitations must be established for all toxic pollutants that are or may be discharged at levels greater than that which can be achieved by technology-based standards.	40 CFR 122.44(e)	
	Develop and implement a best management practice (BMP) program and incorporate in the NPDES permit to prevent the release of toxic constituents to surface waters.	40 CFR 125.100	

Table 7.1 (continued)

Actions	Requirements	Federal citation	TDEC ^a Rules, Chapter
Direct discharge of treatment system effluent (continued)	<p><i>Criteria and standards for NPDES</i></p> <p>The BMP program must</p> <ul style="list-style-type: none"> • establish specific objectives and BMP for the control of toxic and hazardous pollutants; • include a prediction of direction, rate of flow, and total quantity of toxic pollutants, where experience indicates a reasonable potential for equipment failure; and • ensure proper management of solid and hazardous waste in accordance with regulations promulgated under RCRA.^c <p>To ensure compliance, discharge must be monitored for</p> <ul style="list-style-type: none"> • the mass of each pollutant; • the volume of effluent; and • frequency of discharge and other measurements as appropriate. <p>Approved test methods must be followed for monitored waste constituents. Detailed requirements for analytical procedures and quality control are provided.</p> <p>Comply with additional permit conditions, such as</p> <ul style="list-style-type: none"> • duty to mitigate any adverse effects of any discharge; and • proper operation and maintenance of treatment systems. 	<p>40 CFR 125</p> <p>40 CFR 125.104</p> <p>40 CFR 122.44(i)</p> <p>40 CFR 136.1-136.3(e)</p> <p>40 CFR 122.41(d,e)</p>	1200-4-5

Table 7.1 (continued)

Actions	Requirements	Federal citation	TDEC ^a Rules, Chapter
Fugitive dust emissions	Take reasonable precautions to prevent particulate matter from becoming airborne; no visible emissions are permitted beyond property boundary lines for more than 5 min/h or 20 min/day.		1200-3-8-.010
Land disposal restrictions (LDR)	Treatment and disposal of contaminated soil—Soils containing RCRA hazardous waste are subject to the LDR if moved to another unit.	40 CFR 268 (Subpart C)	
	Treatment and disposal of contaminated debris—Effective November 16, 1992, disposal of contaminated debris resulting from CERCLA response actions is subject to the LDR and/or treatment standards.	40 CFR 268.45	
Operation and maintenance	General postclosure standards require 30-year postclosure care to ensure a closed RCRA unit is maintained and monitored.	40 CFR 264.117	1200-1-11-.06(7)(h)
Sampling/analysis	Must follow designated test methods and detailed sampling and analysis protocols as specified in RCRA; see appropriate subparts for specifications.	40 CFR 124 40 CFR 148 40 CFR 260-262	
Surface-water control	NPDES permit required for storm-water discharges associated with construction activities that result in a disturbance of greater than 5 acres of total land area.	40 CFR 122	1200-4-10-.05
	Sediment and erosion controls and BMPs must be utilized to control runoff from construction activities.	40 CFR 122	1200-4-10-.05
	NPDES permit required for storm-water discharges at industrial sites. Monitoring required to ensure compliance with state water-quality standards.	40 CFR 122	1200-4-10-.04

Table 7.1 (continued)

Actions	Requirements	Federal citation	TDEC ^a Rules, Chapter
Treatment in a miscellaneous unit	Design and operating standards for units in which hazardous waste is treated must ensure protection of human health and the environment.	40 CFR 264.601	1200-1-11-.06(19)(b)
	Prevention of any releases that may have adverse effects on human health or the environment due to migration of waste constituents.		
	Specific considerations must be made to prevent adverse effects in:		1200-1-11-.06(19)(b)
	<ul style="list-style-type: none"> · ground water or subsurface environment; · surface water, wetlands, or soil surface; and · air. 	40 CFR 264.601(a) 40 CFR 264.601(b) 40 CFR 264.601(c)	
Treatment (chemical, physical, or biological)	Hazardous wastes or treatment reagents must not be placed in the treatment process or equipment if they could cause the treatment process or equipment to rupture, leak, corrode, or otherwise fail before the end of its intended life.	40 CFR 265.401	1200-1-11-.05(17)
	Where hazardous waste is continuously fed into a treatment process or equipment, the process or equipment must be equipped with a means to stop the inflow.	40 CFR 265.401	1200-1-11-.05(17)
	General requirements for ignitable, reactive, or incompatible wastes.	40 CFR 265.17	1200-1-11-.05(2)

Table 7.1 (continued)

Actions	Requirements	Federal citation	TDEC ^a Rules, Chapter
Treatment in a containment building	Owners or operators of containment buildings designed and operated under the requirements of §268.1101 are not subject to the definition of land disposal in RCRA 3004(k) given certain provisions outlined in §268.1100.	40 CFR 264.1100	
	Design and operating standards are intended to assure containment of managed wastes and to prevent exposure to the elements via precipitation, wind, run-on, etc.	40 CFR 264.1101(a)	
	Maintain primary barrier to be free of significant cracks, gaps, corrosion, or other deterioration that could cause release of hazardous substances;	40 CFR 264.1101(c)(1)	
	Take measures to prevent the tracking of hazardous waste outside of the unit by personnel or equipment; and		
	Take measures to control fugitive dust emissions.		
	Obtain certification by a qualified, registered professional engineer that the building design meets the requirements of §268.1101.	40 CFR 264.1101(c)(2)	
	Any condition that could lead to the release of a hazardous substance must be repaired promptly in accordance with prescribed procedures.	40 CFR 264.1101(c)(3)	
	Inspect at least weekly, and keep a log book of the facility's operating record.	40 CFR 264.1101(c)(4)	

Table 7.1 (continued)

Actions	Requirements	Federal citation	TDEC ^a Rules, Chapter
Treatment in a containment building (continued)	Secondary containment requirements are listed for management of hazardous wastes containing free liquids or treated with free liquids.	40 CFR 264.1101(b); 40 CFR 264.1101(d)	
	At closure, remove or decontaminate all waste residues, contaminated containment system components, contaminated subsoils, and structures or equipment contaminated with waste and leachate, and manage them as hazardous waste. The closure plan, etc., must meet all the requirements of 40 CFR 264 Subparts G and H.	40 CFR 264.1102(a)	
	If not all contaminated subsoils can be removed from the structure, it must be closed in accordance with the landfill closure and post-closure requirements of 40 CFR 264.310.	40 CFR 264.1102(b)	

^a TDEC = Tennessee Department of Environment and Conservation

^b CFR = Code of Federal Regulations

^c RCRA = Resource Conservation and Recovery Act

Source: E. L. Etnier, E. P. McDonald, and L. M. Houlberg, *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws*, ES/ER/TM-1/R2, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, July 1993.

In addition to the general closure standards, closure standards for tanks and containers may apply if either are present at D&D sites. The specific closure requirements for tank systems are codified at 40 CFR 264.197. For clean closure, these standards require that the operator decontaminate the tank system and secondary containment, remove contaminated soils, and render the tank unfit for further use if it remains on site. If all contaminated soils or wastes cannot be removed from the tank system, the tank system is considered a landfill, and must be closed in accordance with the landfill requirements of 40 CFR 264.310 [40 CFR 264.197(b)].

Similarly, during container closure, all hazardous wastes and residues must be removed from containment systems at closure, and managed as hazardous waste. Remaining containers, liners, bases, and soil containing hazardous waste must be decontaminated or removed (40 CFR 264.178).

7.2.2 Land Disposal Restrictions

EPA determined that the RCRA treatment standards for land disposal of hazardous wastes are generally inappropriate or infeasible when applied to contaminated soil or debris (55 FR 8760). Therefore, EPA proposed separate rulemakings to establish treatment standards for disposal of such contaminated soil and debris. The Notice of Proposed Rulemaking for debris appeared January 9, 1992 (57 FR 958); final rule, August 18, 1992 (57 FR 37194). Debris is defined as "solid material exceeding a 60 mm particle size that is intended for disposal, and is a manufactured object; plant or animal matter; or natural geologic material" (40 CFR 268.2).

This rule promulgates treatment standards for hazardous debris prohibited from land disposal; hazardous debris must be treated by specified technologies based on the type of debris and type of contaminants, or, as an alternative, must meet the land disposal restrictions for the specified prohibited listed or characteristic waste with which it is contaminated. Such treated debris will no longer be subject to the land disposal restriction (LDR) standards or other Subtitle C regulation, and could be reused, returned to the natural environment, or disposed of at a Subtitle D facility. Treatment residuals from the treatment of contaminated debris are subject to the waste-specific treatment standards for the waste contaminating the debris. However, debris removed by spalling techniques will be large pieces of debris, which are not considered by EPA to be classified as a treatment residual; therefore, such treatment debris is still subject to the debris treatment standards.

The rule requires that contaminated debris be treated prior to land disposal using physical or chemical extraction, destruction, or immobilization technologies (40 CFR 268.45). However, since immobilization does not remove contaminants, immobilized debris must still be land disposed as hazardous waste (i.e., at a Subtitle C facility). EPA identifies six categories of debris as well as other miscellaneous types of debris contaminated with PCBs, asbestos, or radionuclides. Hazardous debris that is also contaminated with waste PCBs must comply with both the applicable PCB requirements, and the contaminated debris requirements. Disposal of debris and materials resulting from the cleanup of PCB spills must also comply with the PCB spill cleanup policy of 40 CFR 761.125.

The rule includes treatment standards for debris that contains asbestos, which is also regulated under OSHA and the CAA (see other sections in this report). These debris standards for asbestos are a subset of those required for other types of contaminated debris and include water washing and spraying, vapor-phase solvent extraction,

biodegradation, chemical oxidation or reduction, and macroencapsulation (see preamble to the rule, 57 FR 37238).

As with other mixed wastes (see Vol. 1, Pt. B, Sect. 6.4, for a discussion of mixed waste issues at ORNL), debris contaminated with both hazardous and radioactive waste must comply with the RCRA treatability standards for contaminated debris as well as those under the Atomic Energy Act. However, the rule specifically excludes the radioactive mixed wastes, including the D008 radioactive lead solids that have established treatment standards in 40 CFR 268.42 and which may be generated in particle sizes greater than 60 mm (40 CFR 268.2).

The advanced notice of proposed rulemaking for soil appeared October 24, 1991 (56 FR 55160); the notice of proposed rulemaking is expected August 1993, final rule August, 1994.² Under 40 CFR 268.5, EPA has granted an interim case-by-case extension of the LDR effective date, to May 8, 1993, applicable to all persons disposing of soils contaminated with radioactive mixed waste or RCRA hazardous soils whose best demonstrated available technology is incineration, retorting, or vitrification (57 FR 47772, October 10, 1992). In the interim, EPA has developed guidance for obtaining and complying with a treatability variance for soil and debris that are contaminated with RCRA hazardous wastes for which treatment standards have already been set (Office of Solid Waste and Emergency Response Directive 9347.3-06FS, July 1989). Alternate treatment levels are presented for structural functional groups of organics and for ten inorganics based on actual treatment of soil and best management practices for debris. These will be considered as TBC guidance when remedial alternatives are selected and more information becomes available on waste types.

7.2.3 Treatment Units

Treatment of contaminated structural components may be required before D&D is complete. This may occur while the building is in place, or the components may be disassembled and treated in an adjacent area. The new final rule for contaminated debris (Subpart DD) addresses this process.

7.2.3.1 Contaminated Debris

In the debris rule, EPA established a new treatment unit for treating contaminated debris; "containment building" has been added to the definitions of 40 CFR 260.10 to provide for storage and treatment of contaminated debris that does not contain free liquids and is not amenable to treatment in tanks or containers (57 FR 979, January 9, 1992). Performance standards for the design and operation of such containment buildings are promulgated in a new Subpart DD (40 CFR 264.1100 and 265.1100 for permitted facilities and interim status facilities, respectively). All containment buildings, permitted or unpermitted, must comply with the same level of performance. These standards would apply to any D&D activities involving dismantlement of structures and subsequent decontamination in an adjacent building. Closure and postclosure care standards appear in 40 CFR 264.1102 (see Table 7.1).

If decontamination of a structure occurs in place (i.e., before dismantlement), physical extraction technologies (such as abrasive blasting or spalling used to treat debris in place that is intended for discard) are subject to the permit standards of 40 CFR 264, Subpart X for miscellaneous units or the interim status standards for chemical, physical, or biological treatment in 40 CFR 265, Subpart Q (preamble to the final rule, 57 FR 37241). Requirements for these units are discussed below.

7.2.3.2 Miscellaneous Treatment Units

Treatment in a unit may involve biological, chemical, thermal, or physical processes (see Table 7.1); however, the 40 CFR 264 regulations do not differentiate between these processes, considering them all to be via "miscellaneous treatment units." Standards for the operation and maintenance of miscellaneous units are codified in 40 CFR 264.601 (see "Treatment in a miscellaneous unit," Table 7.1). These standards require location, design, operation, and closure of the unit in a manner that is protective of human health and the environment. Unlike other RCRA units, where the general performance objectives are achieved by specified design standards, only generalized environmental performance standards are applied to miscellaneous units. The general environmental performance standards require that the owner demonstrate prevention of releases to ground water or subsurface media [40 CFR 601(a)], surface waters or wetlands [40 CFR 601(b)], or air [40 CFR 601(c)] that could have adverse effects on human health and the environment. In demonstrating compliance with these standards, the operator must consider both waste and media characteristics.

7.2.3.3 Chemical, Physical, Biological, or Thermal Treatment

The interim status standards of 40 CFR 265 contain specific operating requirements for chemical, physical, or biological treatment (40 CFR 265.401). These standards are applicable to treatment in units other than tanks, surface impoundments, or land treatment facilities. Table 7.1 lists the standards for operation of these units. Per Subpart DD, these standards are legally applicable to operators of facilities whom have complied with the interim status requirements of RCRA 3005(e) until a permit is issued and whom are treating structural components in place. At closure, all hazardous waste and hazardous waste residues must be removed from the treatment unit.

7.2.4 Corrective Action Management Units

A portion of the proposed RCRA Subpart S ("Corrective Action for Solid Waste Management Units") was promulgated as a final rule for corrective action at Corrective Action Management Units (CAMUs) and temporary units (58 FR 8658, February 16, 1993). This Rule establishes two new sections in Subpart S: 40 CFR 264.552 (CAMUs) and 40 CFR 264.553 (temporary units). Both of these units function solely to manage wastes that are generated at a RCRA facility for the purpose of implementing RAs (i.e., remediation wastes). As a result of this rule, regulatory requirements for remediation wastes will differ from those for "as-generated" wastes regulated under Subtitle C, particularly LDRs and minimum technology requirements. The CAMU or temporary units designations must be made by the EPA Regional Administrator or a HSWA-authorized state, and such designations would be subject to the public review and comment process as part of a remedy selection. These designations would be incorporated to permit modifications for a facility and would include specifications of applicable design, operating, and closure requirements that may be less stringent than the appropriate 40 CFR 264 standards. As yet, TDEC has not adopted the provisions of this rule.

Under the CAMU provisions, movement and consolidation of remediation wastes within a designated CAMU will not be subject to LDRs or other hazardous-waste land disposal requirements. Also, CAMUs would not be subject to the minimum technology requirements, since they are not classified as landfills, surface impoundments, or waste piles. Placement of remediation wastes into a CAMU from an area at a facility but outside the CAMU or from one CAMU into another CAMU will not trigger land disposal

restrictions or minimum technology requirements, nor will excavation, treatment outside the CAMU, and replacement back in the CAMU. However, movement of wastes from a CAMU to another area in a facility not designated a CAMU would trigger the appropriate land disposal restrictions or minimum technology requirements.

The Regional Administrator may designate tanks and container storage units used for treatment or storage of remediation wastes at a facility as temporary units (40 CFR 264.553). Permit specifications for temporary units must include design, operating, and closure requirements; these may be less stringent than the 40 CFR 264 container and tank system requirements of Subpart I and J, respectively, so long as they are protective of human health and the environment and comply with statutory requirements. There is a one-year time limit for operation of temporary units, subject to a one-year extension by the Regional Administrator.

7.3 CLEAN WATER ACT

If D&D activities at a site involve discharges to surface water, compliance with the National Pollutant Discharge Elimination System (NPDES) permitting process may be necessary.

7.3.1 Direct Discharge to Surface-Water Bodies

The regulatory aspects of the CWA include site-specific pollutant limitations and performance standards designed to restore and maintain the chemical, physical, and biological integrity of the nation's surface waters. The NPDES permit program includes applicable effluent standards, monitoring requirements, and conditions for discharge. Tennessee has an EPA-authorized state program that is equivalent to the federal program. NPDES permit TN0002941 regulates discharges from ORNL to the Clinch River and its tributaries. The effluent limitations and monitoring requirements found in the NPDES permit should be analyzed on a site-specific basis for any cleanup at D&D sites that would include discharge of pollutants to surface waters. The current permit has expired (March 31, 1991); however, a submittal for permit renewal was made to TDEC, and ORNL is currently operating under the expired permit. Table 7.1 lists federal requirements for compliance with the NPDES permitting program.

DOE Order 5400.5 contains concentration limits for release of radionuclides in effluents discharged to surface water. These derived concentration guides are based on an annual exposure of 100 mrem/year (see Sect. 7.7.1 for a further discussion).

7.3.2 Storm-Water Discharges

Storm-water discharges from activities at industrial sites involving construction operations that result in the disturbance of five acres total land or more have been included in the final rule for NPDES permits for storm-water discharges. Construction activities include clearing, grading, and excavation (40 CFR 122). For D&D activities involving construction as defined, coverage under a construction activity general permit may be requested by submitting a Notice of Intent 15 days before construction will begin. The general permit requires that a construction site-erosion control plan be submitted before activity begins. Implementation of good site planning and best management practices to control storm-water discharges is required (Rules of the TDEC, Chap. 1200-4-10-.05). A construction activity storm water permitting checklist and a pamphlet describing erosion and sediment control practices are available from the TDEC Office of Water.

TDEC also has an NPDES permit process for regulating storm-water discharges during industrial activity (Rules of the TDEC, Chap. 1200-4-10-.04). Certain storm drains have been included in the existing NPDES permit, and it is possible that the revised permit will include the 40 CFR 122 requirements for storm-water runoff. The monitoring parameters and reporting levels are listed in Chap. 1200-4-10-.04(e) for biological oxygen demand, chemical oxygen demand, total suspended solids, ammonia as nitrogen, oil and grease, pH, floating material, color, sheen, and priority pollutants.

7.4 CLEAN AIR ACT

Treatment technologies or demolition techniques utilized at D&D sites might result in the release of air emissions that are regulated under federal and state law. Demolition and renovation of facilities that contain asbestos are also regulated by the CAA.

7.4.1 Process Emissions

Chapter 25, "Air Pollution Control," of the Tennessee Code Annotated (TCA) provides for the purity of the air resources of the state "consistent with the protection of normal health, general welfare and physical property of the people, maximum employment, and the full industrial development of the state." Implementing these objectives are the Tennessee ambient air quality standards established by the TDEC Division of Air Pollution Control, which appear in Chap. 1200-3-3 of the Rules of the TDEC. The ambient standards of Chap. 1200-3-3 are translated into source-specific emission limitations (Rules of the TDEC, Chaps. 1200-3-4 to 1200-3-21) that must be considered if they apply to any of the D&D sites or technologies. Table 7.2 lists sections of the Tennessee air emission standards that should be analyzed on a site-specific basis for each D&D activity or each technology.

**Table 7.2. Rules of the TDEC^a Bureau of Environment
Division of Air Pollution Control**

Chapter	Subject
1200-3-1	General provisions
1200-3-2	Definitions
1200-3-4	Open burning
1200-3-5	Visible emissions
1200-3-6	Nonprocess emission standards
1200-3-7	Process emission standards
1200-3-8	Fugitive dust
1200-3-11	Hazardous-air contaminants
1200-3-14	Control of sulfur dioxide emissions
1200-3-16	New source performance standards
1200-3-18	Volatile organic compounds
1200-3-21	General alternate emission standards
1200-3-22	Lead emission standards
1200-3-23	Visibility protection
1200-3-24	Stack height regulations

^aTDEC = Tennessee Department of Environment and Conservation.

Source: E. L. Etnier, E. P. McDonald, and L. M. Houlberg, *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws*, ES/ER/TM-1/R2, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, July 1993.

7.4.2 Fugitive Dust Emissions

Elevation of particulate concentrations may result from earth-moving, site-grading, or demolition activities occurring during D&D. The TDEC, Division of Air Pollution Control has promulgated regulations governing fugitive dust emissions (Rules of the TDEC, Chap.

1200-3-8-.010). An operator must take reasonable precautions to prevent particulate matter from becoming airborne. In addition, fugitive dust may not be emitted as visible emissions beyond property boundary lines for more than 5 min/hr or 20 min/day.

Design standards for containment buildings used to treat contaminated debris include controls sufficient to ensure that there are no visible fugitive dust emissions from any openings (doors, windows, vents, cracks). Additionally, all associated particulate collection devices must be operated and maintained with sound air pollution control devices per 40 CFR 60, Subpart 292 [40 CFR 264.1101(c)(1)(iv)].

7.4.3 Asbestos Emissions

National Emission Standards for Hazardous Air Pollutants are promulgated for particular air emissions from specific sources. Subpart M of 40 CFR 61 establishes standards for inactive waste disposal sites, for asbestos mills and manufacturing operations, for active waste disposal sites, and for disposal of asbestos from demolition or renovation activities. In addition, the NESHAPs for asbestos include standards for demolition and renovation of buildings that contain regulated asbestos-containing material (RACM) in several forms; these standards may be applicable for D&D activities that involve asbestos materials. However, these standards do not stipulate a safe threshold level for airborne asbestos fibers.

Asbestos is defined as "the asbestiform varieties of serpentine (chrysotile), riebeckite (crocidolite), cummingtonite-grunerite, anthophyllite, and actinolite-tremolite." RACM includes: friable asbestos material (any material containing more than 1% asbestos that, when dry, can be crumbled, pulverized, or reduced to powder by hand pressure); Category I nonfriable asbestos-containing material (ACM) that has become friable; Category I nonfriable ACM that will be subject to sanding, grinding, cutting, or abrading; or Category II nonfriable ACM that has a high probability of becoming, or has become crumbled, pulverized, or reduced to powder by the forces expected to act on the material in the course of demolition or renovation. Category I ACM is defined as asbestos-containing packings, gaskets, resilient floor covering, and certain asphalt roofing products. Category II ACM means any material, excluding Category I products, that contain more than 1% asbestos that, when dry, cannot be crumbled, pulverized, or reduced to powder by hand pressure (40 CFR 61.141).

The notification requirements and procedures for asbestos emission control of 40 CFR 61.145(b) and (c) apply to a facility being demolished if the combined amount of RACM is at least 80 linear meters on pipes or at least 15 square meters on other facility components, or at least 1 cubic meter of facility components where the length and area could not be measured previously. Notification to the Regional Administrator is required for any demolition or renovation activities. The specific requirements are listed in 40 CFR 61.145(b) and include an estimate of the total amount of RACM to be removed and a description of work practices and engineering controls, as well as waste-handling emission controls.

Procedures for asbestos emission controls are listed for both demolition and renovation activities [40 CFR 61.145(c)]. Only those for demolition are summarized in Table 7.1. A person trained in the provisions of the NESHAPs rule must be on-site during any stripping, removing, or other handling of RACM materials [40 CFR 61.145(c)(8)].

Standards for waste disposal for demolition activities are described in 40 CFR 61.150. In general, the standards include wetting of all asbestos-containing waste materials, sealing in leak-tight containers, and controlling all visible emissions during all stages of handling, packaging, and loading for transport to a disposal facility. These requirements fall under the jurisdiction of WM and are not discussed further here.

7.5 NATIONAL ENVIRONMENTAL POLICY ACT

The National Environmental Policy Act of 1969 [42 United States Code (USC) 4321 *et seq.*] establishes policies and goals for the protection of the environment; the Council on Environmental Quality is charged with promulgating regulations to implement the requirements of NEPA. It is understood that DOE will comply with the requirements of NEPA as specified in DOE Order 5440.1D (*National Environmental Policy Act Compliance Program*). This issue has been reaffirmed in the FFA §I(A)(3) and §III(A)(2) and Secretary of Energy Notice of February 5, 1990 (SEN-15-90), which was issued to ensure that DOE's NEPA activities are carried out in a centralized and uniform manner.

DOE has established procedures at 10 CFR 1021 for complying with NEPA as well as the Council on Environmental Quality requirements found at 40 CFR 1500-1508 (57 FR 15122, April 24, 1992). NEPA requires documentation in the form of Environmental Impact Statements or Environmental Assessments for any action that may significantly affect the quality of the environment. However, DOE has determined that certain classes of activities under DOE jurisdiction do not individually or cumulatively have a significant effect on the human environment, and therefore, may be eligible for a categorical exclusion for which neither an Environmental Impact Statement nor an Environmental Assessment is required (57 FR 15122). Various environmental regulations address specific environmental concerns, and those addressing wetlands, floodplains, other aquatic resources, archaeological and historical resources, and threatened and endangered species are summarized below. A synopsis of the provisions of these laws is given in Table 7.3.

7.5.1 Wetlands and Floodplains

ORNL is located within the Clinch River drainage basin and portions are located within 100- and 500-year floodplains. There are a number of wetlands located at ORNL. Therefore, before any D&D action is taken, pursuant to NEPA, a survey should be conducted of the particular site to determine whether there are wetlands present that could be impacted by D&D activities.

If any D&D activities are selected that would impact floodplains, compliance with the requirements found in Executive Order 11988, 40 CFR 264.18(b), 40 CFR 6.302(b), 40 CFR 6 (Appendix A), and 10 CFR 1022 may be necessary. If wetlands are affected, consideration should be given to Executive Order 11990, 40 CFR 6.302(a), 40 CFR 6 (Appendix A), 10 CFR 1022, CWA §404, and 40 CFR 230 for applicable requirements.

7.5.2 Aquatic Resources

If any D&D actions result in the control or structural modification of a natural stream or water body, the provisions found in the Fish and Wildlife Conservation Act (FWCA) (16 USC 661 *et seq.*) and 40 CFR 6.302(g) may be applicable. The Clinch River, with its various tributaries, and White Oak Creek have all been classified by TDEC for a variety of uses, including protection of fish and aquatic life and wildlife. Therefore, it is possible that compliance with the provisions of the Tennessee Water Quality Control Act (TCA 69-3-101 *et seq.*) would be required if any D&D actions at ORNL would cause, or be likely to cause, harm to wildlife or aquatic life in these waters.

In the event that streambed modifications occur during D&D activities, the requirements of the TDEC Aquatic Resources Alteration Permitting process (Rules of the

Table 7.3. Location-specific regulations applicable to D&D activities at ORNL

Location characteristic(s)	Requirement(s)	Citation(s)
Wetlands		
Presence of wetlands as defined in Executive Order (EO) 11990 §7(c) and 40 CFR ^a 6, Appendix A §4(j)	Whenever possible, actions must avoid or minimize adverse impacts on wetlands and act to preserve and enhance their natural and beneficial values. Wetlands protection considerations shall be incorporated into planning, regulating, and decision-making processes.	EO 11990 40 CFR 6.302(a) 40 CFR 6, Appendix A 10 CFR 1022
Presence of wetlands as defined in 40 CFR 230.3(t) and 33 CFR 328.3(b)	Action to avoid degradation or destruction of wetlands must be taken to the extent possible. Discharges for which there is a practicable alternative with less adverse impacts or those that would cause or contribute to significant degradation are prohibited. If adverse impacts are unavoidable, action must be taken to enhance, restore, or create alternative wetlands.	Clean Water Act §404 40 CFR 230 33 CFR 320-330
Floodplains		
Within "lowland and relatively flat areas adjoining inland and coastal waters and other floodprone areas such as offshore islands, including at a minimum, that area subject to a one percent or greater chance of flooding in any given year." [EO 11988 §6(c) and 40 CFR 6, Appendix A §4(d)]	Action shall be taken to reduce the risk of flood loss, minimize the impact of floods on human safety, health and welfare, and restore and preserve the natural and beneficial values of floodplains. The potential effects of actions in floodplains shall be evaluated and consideration of flood hazards and floodplain management ensured. If action is taken in floodplains, alternatives that avoid adverse effects and incompatible development and minimize potential harms shall be considered.	EO 11988 40 CFR 6.302(b) 40 CFR 6, Appendix A 10 CFR 1022

Table 7.3 (continued)

Location characteristic(s)	Requirement(s)	Citation(s)
Wilderness areas, Wildlife resources, Wildlife refuges, Scenic rivers		
Within area encompassing or affecting waters of the state of Tennessee as defined in TCA ^b 69-3-103(32) and the presence of wildlife or aquatic life	Discharge of "substances" that "will result or will likely result in harm, potential harm or detriment to the health of animals, birds, fish, or aquatic life" is prohibited.	Tennessee Water Quality Control Act of 1977 (TCA 69-3-101 <i>et seq.</i>) Stream Use Classifications (TDEC ^c Rule Chap. 1200-4-4)
Within area affecting stream or river and presence of fish or wildlife resources	Action must be taken to prevent, mitigate, or compensate for project-related damages or losses to fish and wildlife resources. Actions that alter a resource require consultation with the FWS ^d and/or appropriate state agency.	Fish and Wildlife Coordination Act (16 USC 661 <i>et seq.</i>) 40 CFR 6.302(g)
Location encompassing aquatic ecosystem with dependent fish, wildlife, other aquatic life, or habitat	Degradation or destruction of aquatic ecosystems must be avoided to the extent possible. Discharges that cause or contribute to significant degradation of the water of such ecosystem are prohibited.	Clean Water Act §404 40 CFR 230 33 CFR 320-330
Endangered, Threatened, or Rare Species		
Presence of endangered or threatened species or critical habitat of such species as designated in 50 CFR 17, 50 CFR 226, or 50 CFR 227	Actions that jeopardize species/habitat must be avoided or appropriate mitigation measures taken. Actions that affect species/habitat require consultation with DOI, ^e FWS, and/or state agencies, as appropriate, to ensure that proposed actions do not jeopardize the continued existence of the species or adversely modify or destroy critical habitat.	Endangered Species Act of 1973 (16 USC 1531 <i>et seq.</i>) 50 CFR 402 40 CFR 6.302(h) Fish and Wildlife Coordination Act (16 USC 661 <i>et seq.</i>)

Table 7.3 (continued)

Location characteristic(s)	Requirement(s)	Citation(s)
Archaeologic and Historic Resources		
Presence of archaeological resources on public land	Steps must be taken to protect archaeological resources and sites.	Archaeological Resources Recovery Act of 1979 (16 USC 470aa-ll) 43 CFR 7
Presence of archaeological or historic resources	The Secretary of Interior must be advised of the presence of the data. A survey of affected areas for resources and data must be conducted and steps taken to recover, protect, and preserve data therefrom or request that DOI do so.	Archaeological and Historic Preservation Act (16 USC 469a-c) 40 CFR 6.301
Presence of federally owned, administered, or controlled prehistoric or historic resources; the likelihood of undiscovered resources	Cultural resources included on or eligible for inclusion on the National Register of Historic Places (36 CFR 60) or National Historic Landmark Program (36 CFR 65) must be identified. Action(s) that will affect such resources must be identified and alternatives to the action(s) examined and considered. When alteration or destruction of the resource is unavoidable, steps must be taken to minimize or mitigate the impacts and to preserve records and data of the resource. When all or part of a remedial action is off site, the consultation requirements of 16 USC 470f must be completed.	National Historic Preservation Act (16 USC 470a-w) EO 11593 40 CFR 6.301 36 CFR 800

^aCFR = Code of Federal Regulations.

^bTCA = Tennessee Code Annotated.

^cTDEC = Tennessee Department of Environment and Conservation.

^dFWS = Fish and Wildlife Service.

^eDOI = Department of Interior.

Source: E. L. Etnier, E. P. McDonald, and L. M. Houlberg, *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws*, ES/ER/TM-1/R2, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, July 1993.

TDEC, Chap. 1200-4-7 *et seq.*) may be applicable. General permits are available for such activities as alteration of wet weather conveyances, bank stabilization activities, sand and gravel dredging, and debris removal, with corresponding requirements for protection of aquatic resources. Individual permits may be required by the TDEC Division of Water Pollution Control for certain activities.

7.5.3 Rare, Threatened, or Endangered Species

In addition to several Tennessee state-listed endangered or threatened plants found at ORNL, there are a number of federal- and state-listed endangered or threatened or "in need of management" animal and avian species known to occur in east Tennessee. An in-depth discussion of these species appears in Vol. 24 of *The Resource Management Plan of the Oak Ridge Reservation*.³ The list of rare and endangered species for the ORR, provided by the state of Tennessee, also includes two state-listed and federally listed endangered clams.⁴

Should any D&D actions at ORNL impact any federally listed endangered or threatened species, the provisions found in the Endangered Species Act of 1973 (16 USC 1531 *et seq.*), 50 CFR 492, 40 CFR 6.302(h), and the FWCA (16 USC 661 *et seq.*) may be legally applicable. If any proposed actions impact state-listed endangered or threatened animal species, the Tennessee Non-Game and Endangered or Threatened Wildlife Species Conservation Act of 1974 (TCA 70-8-101 *et seq.*) may be applicable.

7.5.4 Historic Sites and Archaeological Findings

The ORR, as well as the surrounding region, is rich in both archaeological and historic resources.⁵ Although there have not been complete and exhaustive archaeological or historical surveys of the reservation, there have been a number of studies over the years, all indicating the presence of abundant resources on and around the reservation. These surveys are summarized in Vol. 3 of the *Resource Management Plan for the U. S. Department of Energy Oak Ridge Reservation*,⁵ which also includes a list and descriptions of most of the documented sites. However, none of the surveys are recent, nor have they covered all of the specific sites where D&D actions may be planned or contemplated. Several laws require that such information be obtained and documented if there is ample reason to suspect the presence of these resources [Archaeological and Historic Preservation Act (16 USC 469a-c); Archaeological Resources Recovery Act of 1979 (16 USC 470aa-ll)].

The National Register of Historic Places lists the Graphite Reactor located at ORNL as an historic site, and the National Historic Preservation Act (16 USC 470a-w) mandates identification of cultural resources eligible for the National Register of Historic Places (36 CFR 60) or the National Historic Landmark Program (36 CFR 65).

If any D&D activity is undertaken that would cause irreparable harm, loss, or destruction to any historic or archaeological site, the provisions of the Archaeological Resources Recovery Act (16 USC 470aa-ll), 43 CFR 7, the Archaeological and Historic Preservation Act (16 USC 469a-c), and 40 CFR 6.301 may be legally applicable. The provisions of this latter statute would also apply to the Graphite Reactor along with Executive Order 11593, 40 CFR 6.301, and 36 CFR 800 *et seq.*

7.6 OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION

Title I, §126(b) of CERCLA mandated that OSHA promulgate standards for regulation of employee health and safety during hazardous-waste operations at RCRA or CERCLA sites and during emergency response to hazardous substance releases. The final regulations for *Hazardous Waste Operations and Emergency Response* (29 CFR 1910) have appeared in 54 FR 9294 (Final Rule, March 6, 1989). These regulations are designed to protect workers involved in cleanup operations at uncontrolled hazardous-waste sites and to provide for worker protection during initial site characterization and analysis, monitoring activities, materials handling activities, training, and emergency response. These regulations do not apply to those workers who would not be exposed.

Federal construction activities involving no potential for hazardous substance exposure are covered by the OSHA standards in 29 CFR 1926 (*Federal Service Contracts*) and 29 CFR 1910 (*General Industry*). Air contaminant permissible exposure limits for general industry for 212 substances were revised and updated on Jan. 19, 1989 (54 FR 2332), and are listed in Tables Z-1, Z-2, and Z-3 of the final rule. On July 7, 1992, a U.S. Circuit Court of Appeals vacated and remanded this final rule. The Clinton administration has decided not to appeal this ruling; this means the standards revert back to those in effect before 1989.

Standards for the protection of workers involved in construction, demolition, removal, alteration, or repair activities involving ACMs are listed in 29 CFR 1926.58 and would be applicable to D&D activities. These standards address asbestos as well as tremolite, anthophyllite, and actinolite (refers to the non-asbestos forms of these minerals, and any of these minerals that have been chemically treated or altered). The regulations include requirements for exposure monitoring, engineering controls and work practices, respiratory protection, and hazard communication. A permissible exposure limit is established which requires that no employee be exposed to an airborne concentration of asbestos, tremolite, anthophyllite, or actinolite, or a combination of these, in excess of 0.2 fibers per cubic centimeter of air as an eight-hour time-weighted average [29 CFR 1926.58(c)]. Fibers are additionally described as a particulate form of the above materials, 5 μm or longer, with a length-to-diameter ratio of at least 3 to 1 [29 CFR 1926.58(b)].

DOE also addresses occupational safety in DOE Orders 5480.11 (*Radiation Protection for Occupational Workers*), 5480.4 (*Environmental Protection, Safety, and Health Protection Standards*), 5483.1A (*Occupational Safety and Health Program for Contractors at GOCO Facilities*), and 5480.9 (*Construction Safety and Health Program*), and compliance is required during D&D activities.

7.7 RADIATION PROTECTION STANDARDS

Very few standards are available that are applicable to the cleanup of radioactively contaminated D&D sites at DOE facilities. The Atomic Energy Act and its amendments delegated authority for control of nuclear energy to the Nuclear Regulatory Commission (NRC), EPA, and DOE. The NRC has the authority to issue licenses and promulgate rules regulating NRC-licensed nuclear facilities and their decommissioning; however, DOE is authorized to control all types of nuclear materials at sites under its jurisdiction and is exempt, under the Atomic Energy Act, from the NRC's authority and is not subject to their decommissioning regulations. Although EPA intends to develop public health and environmental radiation protection criteria for cleanup of residual radioactive materials at decommissioned DOE, DOE, and NRC-licensed sites, as well as others (40 CFR 194) EPA has failed to date to promulgate *de minimis* or BRC radioactivity levels that would guide decontamination of the radioactive components at D&D sites. The absence of a regulatory driver for radioactive decontamination is viewed as a deterrent to the orderly planning and implementation of D&D activities.

DOE regulations for handling and cleaning up of radioactive materials and decommissioning activities are outlined in a series of internal DOE Orders, and include policies and guidelines for the management and D&D of radioactively contaminated facilities under DOE ownership or control. These are discussed in Sect. 7.7.1. In the absence of specific decontamination guidelines from EPA or DOE, the efforts of the NRC to establish such criteria are summarized in Sect. 7.7.2.

7.7.1 DOE Orders

DOE Order 5400.5 (*Radiation Protection of the Public and the Environment*, February 8, 1990) establishes standards and requirements for DOE operations "with respect to protection of members of the public and the environment against undue risk from radiation." The basic dose limit defined in DOE Order 5400.5 for routine DOE activities—including monitoring, cleaning up, and controlling of residual radioactive material—is 100 mrem/year. In all instances, the overriding principle of the DOE Order is that all releases of radioactive material shall be ALARA.

DOE Order 5400.5 lists derived concentration guides for radionuclide isotopes that are based on a committed effective dose equivalent of 100 mrem/year for ingestion of air or water. For liquid wastes containing radionuclides that are discharged to surface waters, the best available technology must be used if the receiving water, at the point of discharge, would receive radioactive material at a concentration greater than the derived concentration guides. Guidelines for selecting the best available technology are given. Implementation of the best available technology process is not required if annual releases to surface water are below the derived concentration guide. In the case of releases of multiple radionuclides, the sum of the fractional derived concentration guides must not exceed unity. In addition, effluent releases to surface water must not result in exposures to aquatic organisms that exceed an absorbed dose of 1 rad/d.

Chapter IV of the Order lists guidelines for cleanup of radioactive real and personal property, management of the resulting wastes and residues, and release of property. The guidelines are given for levels of residual surface contamination that will not be exceeded if decontamination is to be considered completed and property released to the public without restrictions on use [5400.5(II.5a)]. These levels are listed for specific isotopes and beta-gamma emitters in general (see Table 7.4). Information on application of the

Table 7.4. Surface contamination guidelines (dpm/100cm²)^a

Nuclides ^b	Averages ^{c,d}	Maximum ^{d,e}	Removable ^{d,f}
U-nat., ²³⁵ U, ²³⁸ U, and associated decay products	5000	15,000	1000
Transuranics, ²²⁶ Ra, ²²⁸ Ra, ²²⁸ Th, ²³⁰ Th, ²³¹ PA, ²²⁷ Ac, ¹²⁵ I, ¹²⁹ I	reserved	reserved	reserved
Th-nat., ²³² Th, ⁹⁰ Sr, ²²³ Ra, ²²⁴ Ra, ²³² U, ¹²⁶ I, ¹³¹ I, ¹³³ I	1000	3000	200
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except ⁹⁰ Sr and others noted above ^g	5000	15,000	1000

^aAs used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute measured by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

^bWhere surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

^cMeasurements of average contamination should not be averaged over more than 1 m². For objects of smaller surface area, the average should be derived for each such object.

^dThe average and maximum dose rates associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/h at 1 cm and 1.0 mrad/h at 1 cm, respectively.

^eThe maximum contamination level applies to an area of not more than 100 cm².

^fThe amount of removable material per 100 cm² of surface area should be determined by wiping an area of that size with dry filter or soft absorbent paper, applying moderate pressure, and measuring the amount of radioactive material on the wiping with an appropriate instrument of known efficiency. When removable contamination on objects of surface area less than 100 cm² is determined, the activity per unit area should be based on the actual area and the entire surface should be wiped. It is not necessary to use wiping techniques to measure removable contamination levels if direct scan surveys indicate that the total residual surface contamination levels are within the limits for removable contamination.

^gThis category of radionuclides includes mixed fission products, including the ⁹⁰Sr which is present in them. It does not apply to ⁹⁰Sr which has been separated from the other fission products or mixtures where the ⁹⁰Sr has been enriched.

Source: DOE Order 5400.5.

guidelines and requirements presented in the order, including procedures for deriving specific property guidelines for allowable levels of residual radioactive material from basic dose limits, is contained in DOE/CH-8901, "A Manual for Implementing Residual Radioactive Material Guidelines, A Supplement to the U.S. Department of Energy Guidelines for Residual Radioactive Material at FUSRAP and SFMP Sites," June 1989 [5400.5(IV.2)]. DOE proposed for codification as 10 CFR 834 the contents of DOE Order 5400.5 as radiation protection requirements for the public and the environment for DOE and DOE Contractor operations (58 CFR 16268, March 25, 1993).

DOE Order 5820.2A (*Radioactive Waste Management*, Sept. 9, 1988), states that the management of low-level radioactive waste must assure that external exposure to the waste and concentrations of radioactive material that may be released into surface water and soil do not exceed 25 mrem/year to any member of the public. Releases to the atmosphere shall not exceed 10 mrem/year. Reasonable effort should be made to maintain releases to the environment to ALARA levels.

Chapter V of this Order ("Decommissioning of Radioactively Contaminated Facilities") establishes policies and guidelines for the D&D of DOE-owned or controlled radioactively contaminated facilities. In summary, program offices are responsible for placing facilities

in a safe storage condition, providing surveillance and maintenance, and decommissioning excess facilities. The potential for reuse and recovery of materials and equipment must be addressed. Decommissioning project activities are outlined in the Order, and include: (1) surveillance and maintenance, (2) assessment and characterization, (3) environmental review, (4) engineering design, (5) D&D operations, (6) waste disposal, and (7) closeout. The environmental review and engineering design processes must assure that alternative actions and associated environmental issues are identified and assessed and that all regulatory requirements identified during the environmental review process are met.

The order requires that a Decommissioning Project Plan be prepared for approval by the appropriate program office in compliance with DOE Order 4700.1. The Plan must include: characterization data, an evaluation of decommissioning alternatives, plans for meeting the requirements identified in the environmental review process, and detailed administrative, cost, schedule, and management information. Radiological criteria to be used must be approved by the Headquarters program organization and EH-1. In addition, projections must be made of occupational exposures and estimations made of radioactive waste quantities to be generated.

DOE plans to revise DOE Order 5820.2A in order to consolidate all WM requirements for the Office of Environmental Restoration and Waste Management. Revisions are expected to be complete by 1994, and will cover all categories of wastes, including radioactive, hazardous, and sanitary waste.⁶

DOE Order 5480.11 (*Radiation Protection for Occupational Workers*) contains guidelines for worker protection: 5 rem/year and 50 rem/year annual effective dose equivalent for stochastic (cancer) and nonstochastic (systemic) effects, respectively, from both internal and external sources for continuous exposures. Also included in the order are standards for the general public when entering a controlled area. Exposures to the public are limited to an effective dose equivalent of 100 mrem/year. As with the other DOE orders, the ALARA principle prevails. Remediation of radionuclide-contaminated soils must ensure that exposures to on-site workers or public intruders will not exceed these standards. DOE has proposed for codification in 10 CFR 835 the primary standards for radiation protection of occupational workers from normal operation of DOE facilities (56 FR 64334, Dec. 9, 1991). A final rule is expected in July 1993. When promulgated, these standards will be legally applicable for cleanup activities at D&D sites.

7.7.2 Generic BRC Levels for Radioactive Wastes

The NRC has developed the concept of a risk threshold to distinguish those radioactive materials that do not warrant regulation to the same degree as other radioactive materials to ensure adequate protection of the public and the environment. The low levels of risk posed by these radioactive materials have been termed BRC. The NRC published a policy statement (55 FR 27522, July 3, 1990) to guide its decisions on exemptions of BRC materials from the full scope of the NRC's regulatory program.

The BRC policy was established, in part, to ensure adequate and consistent decisions on acceptable risks posed by decontaminated and decommissioned nuclear facilities. However, the adoption of the BRC policy generated widespread public concern over its implications and a general dissatisfaction with the process the NRC used to develop the BRC policy. Because of these concerns, the NRC declared a moratorium on implementation of the BRC policy and initiated a consensus process to provide advice to the NRC on the full range of issues related to the BRC policy (56 FR 36068, July 30, 1991).

The NRC policy stated that the average dose to individuals in a critical group should be less than 10 mrem/year (a hypothetical incremental annual risk of 5×10^{-6}) for each exempted practice. In addition, for such practices that result in widespread distribution of radioactive materials (e.g., consumer products or recycled materials), the NRC recommended an interim dose criterion for individuals in the critical group of 1 mrem/year (a risk of 5×10^{-7}). These individual annual doses translate to a lifetime risk from continuing annual exposures in the order of 10^{-4} and 10^{-5} , respectively.

EPA uses a similar policy in setting *de minimis* risk-based levels for exemption of hazardous chemicals from RCRA Subtitle C regulation (57 FR 21450, May 20, 1992). Health-based exemption levels are proposed for systemic toxicants and carcinogens based on reference doses and risk-specific doses, respectively. EPA has proposed a risk level of 10^{-6} to establish exemption criteria for Groups A, B, and C carcinogens (see 51 FR 33992, September 24, 1986, for a discussion of EPA's carcinogen classification scheme).

The NRC has made available a "Rulemaking Issues Paper" to enhance the assistance of interested parties in establishing radiological criteria for the decommissioning of NRC-licensed facilities and subsequent release of land and structures for unrestricted use (58 FR 4363, January 14, 1993). To assist in the participatory process, the NRC is conducting a series of workshops to address the issues outlined in the paper. NRC staff have identified four possible alternatives to developing radiological criteria. These include risk limits, risk goals, best effort, and return to preexisting background. In addition, the NRC has announced the availability of a report *Residual Radioactive Contamination from Decommissioning: Volume 1, Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent* (NUREG/CR-5512) (57 FR 49727, November 3, 1992).

7.8 REFERENCES

1. E. L. Etnier, E. P. McDonald, and L. M. Houlberg, *Applicable or Relevant and Appropriate Requirements (ARARs) for Remedial Action at the Oak Ridge Reservation, A Compendium of Major Environmental Laws*, ES/ER/TM-1/R2, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, July 1993.
2. L. M. Houlberg, G. T. Hawkins, and M. S. Salk, 1993. *Environmental Regulatory Update Table, March/April 1993*. ORNL/M-2648/R1. Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, May.
3. R. L. Kroodsmas, *Resource Management Plan for the Oak Ridge Reservation, Volume 24: Threatened and Endangered Animal Species*, ORNL/ESH 1/24, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, January 1987.
4. Division of Ecological Services, *List of Rare and Endangered Species for Oak Ridge National Laboratory*, Tennessee Department of Environment and Conservation, Nashville, Tenn., July 30, 1991.
5. M. Sanders, *Resource Management Plan for the U. S. Department of Energy Oak Ridge Reservation, Volume 3, Appendix B: Archeological Considerations*, ORNL-6026/V4, Oak Ridge National Laboratory, July 1984.
6. Report on Defense Plan Wastes 1992, *DOE Issues Radioactive Waste Management Revisions*, pp. 205, December 18, 1992.

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AL004201	AL213206	AL231009	CH026001	ID101101	ID425001
AL014204	AL213207	AL232001	CH028001	ID101301	ID431001
AL014209	AL213401	AL232002	CH036001	ID104201	
AL014212	AL214103	AL232004	CH038601	ID105001	NEWDALEY
AL024204	AL221103	AL232005	CH039001	ID111701	NEWPENCE
AL024207	AL221104	AL232006	CH039002	ID114103	NV001102
AL027001	AL221106	AL2332P1	CH101101	ID121102	NV004201
AL034201	AL221107	AL234103	CH101103	ID121103	NV011101
AL101202	AL221108	AL234104	CH101104	ID121110	NV021701
AL113101	AL221110	AL234301	CH111203	ID121114	NV025001
AL121101	AL221111	AL238023	CH114101	ID121203	NV026011
AL121120	AL221112	AL238024	CH123401	ID121204	NV031001
AL121121	AL221114	AL239001	CH124201	ID121208	
AL121122	AL221116	AL239002	CH125001	ID121210	OR013101
AL121125	AL221120	AL239003	CH131001	ID121217	OR014103
AL121202	AL221121	AL239004	CH213101	ID121301	OR014104
AL121215	AL221123	AL239005	CH221101	ID121701	OR021201
AL121218	AL221205	AL239007	CH221102	ID125001	OR021301
AL121219	AL221206	AL239008	CH224201	ID131001	OR023101
AL123101	AL221302	AL239009	CH225001	ID132001	OR023301
AL123102	AL223201	AL435001	CH225002	ID132002	OR024103
AL123103	AL223301	AL911201	CH228006	ID132003	OR024201
AL124103	AL223302	AL921101	CH239001	ID132005	OR101100
AL131001	AL223305	AL921102	CH239002	ID132006	OR101101
AL131002	AL224103	AL923101	CH239003	ID132007	OR101102
AL131003	AL224104	AL924201	CH321101	ID132008	OR101103
AL131004	AL224202	AL924202	CH321201	ID132009	OR101104
AL131005	AL225001	AL924203	CH321205	ID132010	OR101106
AL131006	AL228021	AL925001	CH323401	ID132011	OR101108
AL131007	AL228024	AL931001	CH324201	ID132012	OR101201
AL132005	AL231001	AL931102	CH331001	ID134101	OR101202
AL132006	AL231002	AL932002	CH331002	ID332001	OR101204
AL201101	AL231003	ALTTPMSA	CH332001	ID332002	OR111101
AL213201	AL231004		CH525001	ID332004	OR111102
AL213202	AL231005	CH013101		ID413200	OR111103
AL213203	AL231006	CH013102	ID018101	ID421102	OR111105
AL213204	AL231007	CH023101	ID025001	ID421201	OR111107
AL213205	AL231008	CH023102	ID034301	ID423101	OR111202

Partial 1992 and 1993 Technical Task Plan search data-base listing (continued)

OR111203	OR124103	RL034101	RL327001	RL424102	SF231001
OR113101	OR124201	RL132002	RL331001	RL424201	SF234201
OR113201	OR128019	RL311101	RL331002	RL431001	SF234202
OR113202	OR130003	RL311103	RL331003	RL432001	SF234203
OR113203	OR130004	RL311104	RL332001	RL432002	
OR113204	OR138001	RL313101	RL332002	RL432003	SR023101
OR113205	OR138002	RL313201	RL332003	RL432004	SR104201
OR113206	OR138005	RL313202	RL332004	RL438005	SR104202
OR120001	OR141102	RL313203	RL332006	RL438601	SR113201
OR121101	OR221101	RL313205	RL332008	RL439001	SR113202
OR121102	OR221102	RL314202	RL332009	RL439005	SR121101
OR121103	OR221103	RL315001	RL332010	RL439006	SR121102
OR121104	OR221104	RL321101	RL332011	RL439007	SR121103
OR121105	OR914201	RL321102	RL332012		SR121105
OR121106	OR925001	RL321104	RL332013	SF121101	SR121106
OR121108		RL321105	RL332014	SF211104	SR121107
OR121110	PE021103	RL321112	RL334101	SF211203	SR121202
OR121111	PE021104	RL321113	RL401203	SF213201	SR123201
OR121114	PE025001	RL321114	RL401206	SF213203	SR123202
OR121115	PE031001	RL321201	RL411101	SF213204	SR125001
OR121116	PE033502	RL321204	RL413101	SF213205	SR128101
OR121201		RL321205	RL413201	SF221101	SR131000
OR121203	RF025001	RL321211	RL413203	SF221102	SR131001
OR121204	RF026001	RL321221	RL415003	SF221205	SR131002
OR121206	RF101201	RL321701	RL421103	SF221207	SR132001
OR121210	RF101205	RL322001	RL421104	SF221208	SR132002
OR121211	RF111202	RL322101	RL421201	SF221210	SR132003
OR123101	RF111203	RL323101	RL421207	SF221211	SR132004
OR123201	RF121204	RL323301	RL421211	SF223203	SR134101
OR123301	RF132001	RL324103	RL421215	SF223401	SR135002
OR123302	RF138101	RL324105	RL421216	SF224102	SRNEW010
OR124101					