**Oak Ridge National Laboratory
Technology Logic Diagram**

**Volume 1
Technology Evaluation**

**Part B
Remedial Action**

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ACRONYMS AND INITIALISMS

AEA	Atomic Energy Act
AES	auger electron spectroscopy
ALARA	as low as reasonably achievable
ANPRM	advance notice of proposed rule making
ARAR	applicable or relevant and appropriate requirement
BDAT	best demonstrated available technology
BMP	best management practice
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
CSF	carcinogen slope factor
CT	computer tomography
D&D	decontamination and decommissioning
DOE	U.S. Department of Energy
EM	environmental management
EPA	U.S. Environmental Protection Agency
ER	Environmental Restoration
ES&H	Environmental, Safety, and Health
FFA	Federal Facilities Agreement
FFCA	Federal Facility Compliance Act
FR	Federal Register
FTIR	Fourier transform infrared
HDPE	high-density polyethylene
HMTA	Hazardous Materials Transportation Act
HSWA	Hazardous and Solid Waste Amendments
ICP	inductively coupled plasma
ICP-MS	inductively coupled plasma—mass spectrometry
IR	infrared
ISV	in situ vitrification
LDR	land disposal restriction
LDR-FFCA/ORR	Compliance Agreement Between the U.S. DOE - Oak Ridge Reservation and the EPA, Region IV
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MTR	minimum technology requirement
NARM	naturally occurring and accelerator-produced radioactive material
NEPA	National Environmental Policy Act
NERP	National Environmental Research Park
NPRM	notice of proposed rule making
NRC	Nuclear Regulatory Commission
NRDA	natural resource damage assessment
ORNL	Oak Ridge National Laboratory
ORR	Oak Ridge Reservation
OSHA	Occupational Safety and Health Act

OSHA	Occupational Safety and Health Administration
OU	Operable unit
PCB	polychlorinated biphenyl
R&D	research and development
RA	Remedial Action
RCRA	Resource Conservation and Recovery Act
RF	radio frequency
RfCs	reference concentrations
RfDs	reference doses
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
SMCL	secondary maximum contaminant level
SWDA	Solid Waste Disposal Act
SWSA	solid waste storage area
TCA	Tennessee Code Annotated
TDEC	Tennessee Department of Environment and Conservation
TLD	Technology Logic Diagram
TOA	Tennessee/DOE Monitoring and Oversight Agreement
TRU	transuranic
TSCA	Toxic Substances Control Act
TTP	Technical Task Plan
TU	Temporary Unit
UV	ultraviolet
VOC	volatile organic compound
WAG	waste area grouping
WQC	water quality criteria
XRF	X-ray fluorescence

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 uses information from the *Strategic Roadmap for the Oak Ridge Reservation, Oak Ridge K-25 Site Technology Logic Diagram* and a previous Hanford TLD.

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.

The focus of Vol. 1, Pt. B, is RA, and it has been divided into six chapters. The first chapter is an introduction, which defines problems specific to the ER Program for ORNL. Chapter 2 provides a general overview of the TLD. Chapters 3 through 5 are organized into necessary subelement categories: RA, characterization, and robotics and automation. The final chapter contains regulatory compliance information concerning RA.

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 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.

Several factors combine to distinguish ORNL from other R&D institutions. The laboratory melds a unique blend of excellent researchers with a large array of world-class facilities to conduct broad interdisciplinary research in areas of national importance. The laboratory's ability to integrate basic research, applied research, technology development, information dissemination, and technology transfer is unsurpassed among research institutions. The style of teaming with industry and academia to bring a multidisciplinary approach to problem solving provides exceptional value to ORNL's customers. Finally, the laboratory's ability to conceive, construct, and manage large, complex projects provides DOE and the nation with a rare resource.

1.2.1 Environmental Restoration Program

The purpose and scope of DOE's national Environmental Restoration (ER) program is contained in the "Environmental Restoration and Waste Management Five-Year Plan"² (updated annually). Goals and objectives for the Oak Ridge Reservation (ORR), including ORNL, are identified in the "Environmental Restoration and Waste Management Site-Specific Plan for the Oak Ridge Reservation."³

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

ER projects assess and clean up DOE sites and facilities that are no longer active. Waste of various types has accumulated at ORR sites from defense and research operations spanning nearly five decades. ER activities are divided into four areas.

1. Assessment of nature and extent of environmental contamination;
2. Remedial action (RA) to clean up inactive waste sites that have the potential for releasing contaminants;
3. Decontamination and decommissioning (D&D) to clean up surplus facilities (see Vol. 1, Pt. A); and
4. Research, development, and demonstration to apply to new technologies to enhance restoration activities.

It is ORR policy to comply with both the letter and spirit of all applicable federal, state, and local regulations and with DOE policies governing environmental protection. Historical practices at many DOE sites, although consistent with the standards of their time, did not fully recognize the potential hazards of certain materials. Many of these past practices are considered inadequate by modern standards. ER activities are conducted to ensure that all inactive ORR facilities meet current requirements for environmental cleanup and waste management (WM).

The fundamental goal of ER is to ensure that contaminants at inactive or surplus facilities and sites are either eliminated or reduced to prescribed, safe levels. Risks from these restored sites should be low and not endanger human health and safety or the environment. This goal is achieved by meeting separate strategic objectives established for RA and D&D (see Vol. 1, Pt. A). The six objectives identified for RA follow:

1. Identify inactive, contaminated facilities and sites at ORR installations;
2. Assess these facilities and sites to determine the nature and extent of contamination;
3. Confine and contain existing contamination to the extent necessary to minimize further spread;
4. Coordinate with regulatory authorities for negotiated agreements that specify the requirements and schedule for cleaning up the identified facilities and sites;
5. Ensure that cleanup strictly complies with these agreements; and
6. Provide long-term monitoring to ensure continuing compliance.

DOE has established four priority levels for ER, reflecting discrete goals:

1. To limit immediate or short-term health risk and contamination;
2. To comply with in-place or pending agreements;
3. To reduce out-year risk, promote out-year compliance, address public concern, and protect DOE missions; and
4. To accelerate overall compliance.

1.3 ORNL LEGACY OF CONTAMINATION

1.3.1 Introduction

The 50 years of operations have produced a diverse legacy of contaminated inactive facilities, research areas, and waste disposal areas that are potential candidates for RA. Remedial activities for the contaminated inactive sites at ORNL were initiated in 1985 under the auspices of the Remedial Action Program.⁴ One hundred sixty-four potential RA sites were identified and grouped into 13 categories that included diverse activities such as solid waste storage areas (SWSAs), pipeline leak sites, seepage pits and trenches, hydrofracture injection sites, and the White Oak Creek watershed.

The RA Program has been superseded by the ER Program, which currently includes over 275 sites. ER activities are carried out under the auspices of a Federal Facilities Agreement (FFA) between DOE, U.S. Environmental Protection Agency (EPA) and the Tennessee Department of Environment and Conservation (TDEC). This document formalized a procedural framework for developing, implementing, and monitoring appropriate response actions in accordance with Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), the National Contingency Plan, the Resource Conservation and Recovery Act (RCRA), the National Environmental Policy Act (NEPA), Tennessee State law, and appropriate guidance and policy.⁵

Because of the large number of contaminated sites and the hydrologic complexity at ORNL, the strategy developed in response to regulatory requirements has been oriented toward waste area groupings (WAGs) rather than individual sites. The WAGs are generally defined by watersheds that contain contiguous and similar RA sites. In some cases there has been hydrologic interaction among the sites within a WAG, making individual sites hydrologically inseparable. The use of groupings provides perimeter monitoring around a WAG of both ground water and surface water and the development of a remedial response that is protective of human health and environment. Twenty WAGs were initially identified at ORNL, of which 13 are definite candidates for further RA.

1.3.2 Waste Area Groupings

The concept of WAGs was developed initially to facilitate the investigation of potential sources of releases to the environment. Each WAG represents distinct, small, natural drainage areas that may encompass multiple sources of contaminants. The locations of the 13 individual WAGs are shown in Fig. 1.2. The WAG descriptions that follow are summarized from the WAG 2 Remedial Investigation Plan and the remedial investigation plans for the specific 6 WAGs.

WAG 1. This includes all the operating R&D facilities located within the main security fence at ORNL. Historically, ORNL has been involved in the development, testing, and operation of various reactor concepts; the development and operation of fuel reprocessing technologies; the large-scale production of radioactive and stable isotopes; and the management of wastes from these activities. These activities have been primarily focused in WAG 1, although several other WAGs have also been involved. Over 100 sites in WAG 1 are currently considered candidates for remediation, including radioactive waste collection pipelines and tanks, SWSAs, waste treatment facilities and impoundments, leak and spill sites, and miscellaneous waste handling and storage units. WAG 1 drains directly into White Oak Creek through storm drains and two small tributaries—First Creek and Fifth Creek. Conceptual modeling studies have demonstrated the potential for

rapid transport of contaminants along the massive array of subsurface pipeline trenches directly to White Oak Creek and its WAG 1 tributaries.

Virtually every radionuclide, element, and organic compound ever used at ORNL has been used at one time in WAG 1. Historical release data suggest that WAG 1 was a major source for radionuclide and heavy-metal contamination to White Oak Creek.

WAG 2. This grouping includes the major drainage system for ORNL of White Oak Creek and its tributaries and associated floodplain areas. WAG 2 consists of two sites: the area encompassed by the stream channels of White Oak Creek and Melton Branch and White Oak Lake, White Oak Dam, and the embayment leading into the Clinch River and Watts Bar Lake.

In addition to natural drainage, White Oak Creek has received treated and untreated effluents and reactor-cooling water from ORNL activities since 1943. Controlled releases include those from the Nonradioactive Waste Treatment Facility, the Sewage Treatment Plant, and a variety of process-waste holdup ponds throughout the ORNL main plant area (WAG 1). It also receives ground water discharge and surface drainage from WAGs 3, 4, 5, 6, 7, 8, 9, and 17.

Main contaminants in White Oak Creek are ^{90}Sr , ^{60}Co , ^{137}Cs , ^3H , and metals (mercury, zinc, and chromium). Hazardous chemicals, including polychlorinated biphenyls (PCBs), may also be present in the stream sediments.

White Oak Lake is a surface impoundment for radioactive and other hazardous wastes that drain from ORNL via the White Oak Creek watershed. It serves as a final settling basin for waste released from ORNL operations and waste storage areas. Contaminants of concern identified to date are ^{90}Sr , ^{137}Cs , thorium, uranium, transuranics (TRUs), and metals (mercury, zinc, and chromium). Hazardous chemicals, including PCBs, may also be present in the stream sediments.

WAG 3. This area includes SWSA 3, the closed scrap-metal area, and the current operating contractors' landfill and is located in Bethel Valley about 1 km (0.6 mi.) west of the west entrance to the main plant area. SWSA 3 and the closed scrap-metal area are inactive landfills known to contain radioactive solid wastes and surplus materials generated at ORNL from 1946 to 1979. The Contractors' Landfill was opened in 1975 and is used to dispose of various uncontaminated construction materials and fly ash from the ORNL steam plant. WAG 3 is drained by Northwest Tributary of White Oak Creek.

Contaminants of concern identified to date in SWSA 3 include small amounts of TRU, ^{90}Sr , and ^3H . Most of the metal in the scrap metal area has now been buried in other SWSAs; however, some contaminated tanks and equipment are still stored aboveground. The primary contaminant of concern identified to date is ^{137}Cs . No contaminants of concern are believed to be present at the Contractor's Landfill, but there is no confirming documentation.

WAG 4. Located southwest of the main plant area, WAG 4 consists of three sites: the low-level waste line north of Lagoon Road, pilot pits 1 and 2, and SWSA 4. From 1954 to 1975, liquid-radioactive wastes were transferred to the waste pits and trenches (WAG 7) through the low-level waste line north of Lagoon Road. Two known leak sites were covered with bentonite and asphalt caps in 1983. The pilot pit area (Bldg. 7811) was constructed in late 1955 for use in pilot-scale radioactive waste disposal studies. Currently, three large concrete cylinders embedded in the ground, a control building that is now used to store field and laboratory equipment, and four large concrete cylinders that were used in a municipal waste leaching experiment are all that remain at the site. SWSA 4, covering 9.3 ha (23 acres), was opened for routine solid waste burials from 1951

through 1959 but remained open as a disposal area for uncontaminated fill until 1973. For a period of time, SWSA 4 was designated as the Southern Regional Burial Ground by the Atomic Energy Commission and received wastes from nuclear installations in the eastern United States. Waste from sources outside ORNL accounts for about half of the waste buried in SWSA 4.

Contaminants of concern identified to date include ^3H , ^{90}Sr , ^{60}Co , ^{125}Sb , and ^{137}Cs . Radionuclides are the only contaminants stored at the two pilot sites, and no releases have been reported.

WAG 5. Located about 2 km (1.2 mi) south of the main plant area in Melton Valley, this WAG consists of SWSA 5 and SWSA 5 North, two line-leak sites, an old landfill, the process-waste sludge basin, and the surface facilities constructed in support of both Old and New Hydrofracture Facilities (including several low-level waste storage tanks and two impoundments). Melton Branch separates the New Hydrofracture Facility from the remainder of WAG 5. SWSA 5, covering 32.3 ha (80 acres), received radioactive wastes from 1959 through 1973. The area known as SWSA 5 North covers 4 ha (10 acres) and has been used for retrievable storage of TRU wastes since 1970. WAG 5 drains directly into White Oak Creek, Melton Branch, and two unnamed tributaries of White Oak Creek.

About 200,000 Ci of low-level waste and TRU wastes are buried at SWSA 5. In addition, more than 62,000 Ci of TRU waste is in retrievable storage in SWSA 5 North, much of it buried in concrete casks. Eight 190,00-L stainless-steel tanks at the New Hydrofracture Facility Site hold concentrate from the low-level waste evaporator. The Old Hydrofracture Facility pond contains contaminated water and sediments with almost 500 Ci of activity. The predominant isotopes in all the low-level waste facilities are ^{60}Co , ^{90}Sr , and ^{137}Cs . TRU wastes are primarily ^{244}Cm , with lesser amounts of several other isotopes. Some lead and mercury were also buried with the TRU wastes. Ground water in wells and seeps have shown elevated levels of ^3H , ^{90}Sr , and ^{137}Cs .

WAG 6. This area consists of three sites: SWSA 6, the emergency waste basin, and the explosives detonation trench. All three facilities are located in Melton Valley, 2 km (1.2 mi) southwest of the main plant area along Lagoon Road. SWSA 6, covering 28 ha (68 acres), is currently the only operating low-level waste disposal site at ORNL. Portions of this site have been closed under RCRA regulations applicable to the disposal of RCRA-regulated waste after 1980. The emergency waste basin was constructed in 1962 as a holding basin if water could not be released from ORNL to White Oak Creek. To date, the basin has not been used. The explosives detonation trench was used for destruction of explosive and shock-sensitive chemicals. WAG 6 drains to White Oak Lake through four unnamed small streams.

Through the end of 1984, more than 250,000 Ci of low-level waste had been disposed of at SWSA 6. RCRA-regulated wastes (e.g., scintillation fluids, oils, cleaning solutions, alcohols, paint thinners, kerosene, jet fuel, acids, and sodium) were disposed of in several trenches and auger holes. These disposal areas have subsequently been covered by high-density polyethylene (HDPE) caps. As the only operating low-level waste disposal site at ORNL, SWSA 6 continues to receive solid low-level waste that is buried using greater confinement disposal technologies such as concrete silos, steel-lined auger holes, and concrete vaults on a concrete pad.

Site characterization data has been collected as part of the RCRA Facility Investigation for WAG 6.⁷ Tritium, ^{60}Co , ^{90}Sr , and ^{137}Cs were the principle radioactive contaminants found in samples of 35 ground-water wells. These same contaminants were found in surface water and in both surface and subsurface soil samples. Trace levels of TRU isotopes were also found in two wells and two surface samples. Trace levels (generally

below health criteria) of several metals and solvents were found in a few wells. Only trace levels of metals from organics were found in surface water of soil samples. Sampling of wells in burial trenches by ORNL staff has measured numerous radioisotopes, heavy metals, volatile organic compounds (VOCs), and nitrates in the leachate.

WAG 7. This grouping is located in Melton Valley about 1.6 km (1 mi) southwest of the main plant area. The primary Solid Waste Management Units in this WAG are seven pits and trenches used for disposal of liquid low-level waste from 1951 through 1966. WAG 7 also includes a decontamination facility, three leak sites, a storage area containing shielded transfer tanks and other equipment, and seven fuel wells containing the acid solutions of enriched uranium from Homogeneous Reactor Experiment fuel. WAG 7 drains through three unnamed drainage channels into White Oak Creek.

More than 1,100,000 Ci of liquid low-level waste, primarily ^{90}Sr , ^{106}Ru , and ^{137}Cs , was transferred to the waste pits and trenches; another 2000 Ci of ^{137}Cs was placed in the shielded transfer tanks, and nearly 4 kg of ^{235}U in liquid form was placed in the Homogeneous Reactor Experiment fuel disposal auger holes. Characterization studies suggest that WAG 7 has been a source of ^3H , ^{60}Co , ^{90}Sr , ^{99}Tc , chromium, and zinc.

WAG 8. Located in Melton Valley, south of the main plant area, WAG 8 consists of reactor facilities and associated tank and piping systems, six leak sites and an old transfer line, five surface impoundments, a contractor spoils area, and RCRA-permitted hazardous waste storage facilities. Liquid low-level waste and process wastes from the reactors and associated facilities are collected on site in tanks and then pumped to the main plant area for storage and treatment. Wastes from the Homogeneous Reactor Experiment (WAG 9) were pumped using the same transfer system. WAG 8 drains into Melton Branch.

There is no existing inventory on the contents of the low-level waste collection and storage tanks, which are still in active use. Historical data are insufficient to determine whether or not any contamination remains at the leak sites in WAG 8. Samples of the sludge in the impoundments were not hazardous based on the EP-toxicity test. There is probably less than 10 Ci of radioisotopes in these ponds. There is no indication that radioactive or hazardous wastes were ever introduced into the waste treatment facilities. Historical studies have identified WAG 8 as a major source of ^{60}Co to Melton Branch. The WAG has also been a source of ^{137}Cs , copper, chromium, and zinc. No data are available on organic contaminants. The WAG contributes negligible amounts of other radionuclides to the White Oak Creek system.

WAG 9. Located in Melton Valley about 1 km (0.6 mi) southeast of the main plant area, this WAG includes the Homogeneous Reactor Experiment, the Homogeneous Reactor Experiment pond, the low-level waste collection and storage tanks, a septic tank, waste evaporator and associated pit, and several miscellaneous sites. The Homogeneous Reactor Experiment pond was constructed in 1955 as a waste storage impoundment for condensate from the Homogeneous Reactor Experiment waste evaporator. In 1970 the pond was filled with soil and capped with asphalt. WAG 9 drains to upper Melton Branch.

About 750 Ci of gross beta activity is present in the sediments of the Homogeneous Reactor Experiment impoundment. Strontium-90 and ^{137}Cs were the primary isotopes contributing to this activity. The sediments passed the EP-toxicity test. Tritium and ^{90}Sr were found in ground water down-gradient from the Homogeneous Reactor Experiment impoundment, but only trace levels of metal and organics were found.³

WAG 10. This area consists of the injection wells and grout sheets from four injection sites, two of which were experimental sites used in the development of the hydrofracturing process at ORNL. The other two sites were operating facilities (now inactive) used to dispose of ORNL's liquid low-level waste. All four sites are located in Melton Valley; however, they are not adjacent to one another. WAG 10 is significantly different from the other WAGs in that the grout sheets are located at depths of 90 to 300 m (300 to 1,000 ft) below the ground surface.

About 12 million L of liquid-radioactive wastes were injected into the fractured shale at the two major hydrofracture sites. Except for ^{90}Sr , ^{137}Cs , ^{244}Cm , and TRU, little is known about the contaminants that may have been included in the grout mixtures. At the two experimental sites, radioactive tracers were used instead of actual waste.

WAG 11. This area is the White Wing Scrap Yard located at the west end of East Fork Ridge between State Highway 95 (White Wing Road) and the Oak Ridge Turnpike. The site is outside the White Oak Creek watershed. The site, which covers about 20 acres, was used to store contaminated materials from the three Oak Ridge facilities (ORNL, K-25 Site, and Y-12 Plant). Wastes (equipment, tanks, and trucks) were thought to have been stored aboveground, but additional investigations may prove otherwise. Much of the stored materials and contaminated soil was removed in 1966–1971; however, some scrap metal, concrete, and other waste remains. Contaminants of concern identified to date are gamma radiation, ^{137}Cs , ^{234}Th , ^{235}U , and PCBs.

WAG 13. This grouping consists of the ^{137}C Contaminated Field and the ^{137}C Erosion/Runoff Study Area. The contaminated field is located about 330 ft north of the Clinch River at Clinch River Mile 20.5. The 50-acre area was set aside to study simulated fallout of ^{137}Cs fused at high temperature to silica particles. After ~20 years (since contamination), about 5.2 Ci of activity should remain.

The Erosion/Runoff Study Area is located due north of the confluence of the White Oak Creek and the Clinch River. The purpose of this study area was to use the field contamination to study runoff, erosion, and infiltration of ^{137}Cs on a silt-loam soil. The unit was contaminated on October 20, 1964, and is still under study.

WAG 17. Located about 1.6 km (1.0 mi) east of the main plant area, this area is the major craft and machine shop area for ORNL and includes the shipping, receiving, shops, and garage operations. The sites in WAG 17 are all tanks, of which three are underground. These tanks have the capacity of 39,000 gal of domestic sewage, ~13,000 gal of waste oil, and 5,000 gal of photographic wastes. In addition to the Solid Waste Management Units, there are four underground tanks (capacity ~31,000 gal) used for diesel fuel and gasoline, and one 4,000-gal aboveground waste oil tank.

1.4 ORNL PROBLEM DEFINITION

Environmental contamination in the ORNL WAGs has been grouped according to source and media:

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

These groupings reflect the results of program planning (e.g., Life Cycle Baselines and WAG 5 Remedial Investigation) that have addressed RA activities through currently anticipated site remediation. The anticipated types of remediation are technology based and incorporate present understanding of the general types of contaminant releases from the ORNL WAGs. Considerable data exists from past research and monitoring of various WAGs, and the known contaminants are listed in Table 1.1. Limited data is available concerning the sources of contamination, especially in the burial grounds. Ongoing investigations are currently under way to define the nature and extent of the contamination at WAGs 1, 2, and 5. Table 1.2 correlates the WAGs previously identified with the problem areas.

Table 1.1. Contaminants known or suspected to have been released from each ORNL WAG^a

WAG	Contaminants ^b
1	⁶⁰ Cr, ⁹⁰ Sr, ¹³⁷ Cs, ^{15x} Eu, ²³² Th, ^{23x} U, ^{23x} Pu, ²⁴¹ Am, ²⁴⁴ Cm, other radionuclides, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Zn, trichloroethylene (TCE), polychlorinated biphenyls (PCBs), chlordane
3	³ H, ⁹⁰ Sr, ¹³⁷ Cs, TCE
4	³ H, ⁶⁰ Co, ⁹⁰ Sr, ¹⁰⁶ Ru, ¹³⁷ Cs, ^{23x} Pu, other radionuclides, TCE
5	³ H, ⁶⁰ Co, ⁹⁰ Sr, ¹³⁷ Cs, ²³³ U, ^{23x} Pu, ²⁴¹ Am, ²⁴⁴ Cm, other radionuclides, Cr, Hg, Ni, Pb, Zn, PCBs
6	³ H, ¹⁴ C, ⁶⁰ Co, ⁹⁰ Sr, ¹³⁷ Cs, ^{15x} Eu, ^{23x} U, Cr, Cu, Hg, Mo, Ni, Pb, Zn, volatile organic compounds, nitrates
7	³ H, ⁶⁰ Co, ⁹⁰ Sr, ⁹⁹ Tc, ¹⁰⁶ Ru, ¹³⁷ Cs, ²³³ U, Cr, Ni, Zn, nitrates
8	⁶⁰ Co, ⁹⁰ Sr, ¹³⁷ Cs, Cr, Cu, Zn
9	⁶⁰ Co, ⁹⁰ Sr, ¹³⁷ Cs, Cr, Zn
10	⁹⁰ Sr, ¹³⁷ Cs, ²⁴⁴ Cm, TRU isotopes
13	¹³⁷ Cs
17	¹³⁷ Cs, Cd, Cr, Cu, Zn, fuel-derived hydrocarbons, and solvents

^aWAG = waste area grouping

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

Table 1.2. Problem areas and their related waste area grouping

WAG ^a	Problem areas
1	Buried wastes, tanks, impoundments, pipelines, and soils/sediments,
2	Soils/sediments and ground water/surface water
3	Buried wastes, soils/sediments, and ground water/surface water
4	Buried wastes, pipelines, soils/sediments, and ground water/surface water
5	Buried wastes, tanks, impoundments, pipelines, soils/sediments, and ground water/surface water
6	Buried wastes, soils/sediments, and ground water/surface water
7	Pits and trenches, pipelines, and soils/sediments
8	Tanks, impoundments, pipelines, and ground water/surface water
9	Tanks, impoundments, and ground water/surface water
10	Hydrofracture and ground water/surface water
11	Soils/sediments and ground water/surface water
13	Soils/sediments
17	Tanks

^aWAG = waste area grouping

1.4.1 Buried Waste

Between 1944 and the present, waste was buried in six SWSAs (see Table 1.3). Waste sources at ORNL included physical, chemical, and biological laboratories, reactors, radioisotope operations, particle accelerators, hot-cell operations, and analytical labs. The buried waste was disposed on site in sanitary landfill-type areas, unlined trenches, alpha trenches and auger holes. Waste was disposed in a variety of containers, including drums, bags, boxes, bales, casks, concrete containers, and steel containers.

Table 1.3. Summary of SWSAs^a at ORNL

WAG ^b	SWSA	Operation	Acreage	Records
1	1	1944	1.5	None
1	2	1944-1946	3.5	None
3	3	1946-1951	7	None
4	4	1951-1959	23	None
5	5	1959-1973	33	Incomplete
6	6	1969-	68	Limited

^aSWSA = solid waste storage area

^bWAG = waste area grouping

From 1955 to 1963, SWSAs 4 and 5 were designated as the Southern Regional Burial Grounds by the Atomic Energy Commission and received waste from more than 50 off-site facilities, including Argonne National Laboratory, Mound Laboratory, Knolls Atomic Power Laboratory, and General Electric. The limited records available for all disposal activities indicate that low-level radioactive wastes, TRU waste, organic chemicals, mixed wastes, and asbestos were buried at ORNL.

1.4.2 Pits and Trenches

Low-level liquid-radioactive waste seepage pits and trenches were used between 1951 and 1966 for the disposal of 42 million gal of liquid-radioactive waste.⁸ The liquids and sludges were placed into seven shallow seepage pits that allowed excess water and some radionuclides (e.g., ^{106}Ru and ^3H) to disperse into ground water and surface water. Within the suspended sludge and proximate soils, large inventories of fission products (^{90}Sr and ^{137}Cs) were retained along with a variety of TRU isotopes ($^{239,240}\text{Pu}$, ^{244}Cm , and ^{233}U) and activation products (i.e. ^{60}Co). Over a million curies of radioactivity were disposed, and about half remain in the area (WAG 7).

Waste Pit 1 was constructed in 1951 to test the feasibility of the permanent disposal of liquid wastes into surface pits. To test the safety of the method, 100,000 gal of waste containing 100 Ci of activity were to be placed onto Waste Pit 1.

Waste Pit 1 began receiving waste in August 1951. Waste from the ORNL Main Plant South Tank Farm was hauled to the pit in two 500-gal capacity tanks attached to a Dempster Dumpster Truck. Tanks W-8 (containing radioactive metal waste supernate) and W-10 (containing chemical waste concentrate, located in the South Tank Farm) were the main sources of waste. Waste Pit 1 received a total of 122,200 gal of waste prior to termination of the transfer in early October 1951.

Waste Pits 2, 3, and 4 were operated collectively during their history but are physically separate from each other.

Waste Pit 2 was constructed in 1952 to implement the routine disposal of liquid-radioactive wastes. Waste Pits 3 and 4 were built as more disposal volume was required to meet the disposal needs of ORNL. Each of the pits is similar in design and at the ground surface measures about 200 x 100 ft. The pits are each 15 ft deep, have walls that slope at angles of 20 to 30 degrees, and have a volume of about 1 million gal at a fluid level of 12 ft.

Trenches were designed to increase the efficiency of the seepage method. This was accomplished by using elongated trenches perpendicular to the bedding planes of the underlying shale and the addition of an earthen cover that reduced rainfall infiltration. Trench 5 was 300 ft long and 10 ft across at the ground surface and 4 ft across at the trench bottom. The trench contained about 10 ft of limestone fill covered by a polyethylene film. An additional 6 ft of earth filled the rest of the trench and was mounded above the ground surface. The capacity of Waste Trench 5 was 64,000 gal at a level of 9 ft.

The design of Waste Trench 6 differed from Waste Trench 5 in that the trench was longer (425 ft) and had a pronounced curved shape that followed local topography.

Waste Trench 7 was designed to consist of three separate pit segments. At ground level the trench segments are each 100 ft long by about 10.5 ft wide and 16 ft deep. The total capacity of Waste Trench 7 was 50,000 gal.

Use of waste seepage pits and trenches was discontinued in 1966, after the hydrofracture method of disposal of low-level waste went into operation.

1.4.3 Tanks

Throughout the 50 years of ORNL operations, low-level radioactive wastes have been accumulated and stored in underground tanks. These wastes were neutralized to minimize corrosion and concentrated to conserve tank volume. Many of these tanks have leaked in the past, usually to an unknown extent. Liquids have been removed from many inactive older tanks and either treated for disposal by other means or concentrated into other and newer tanks. Radioactivity, however, usually remains in the tanks due to the pressure of residual sediments and sludges that could not be removed completely by the methods used to get the liquids from the tanks.

While tanks are located in WAGs 5, 8, 9, and 17, most of the tanks at ORNL are within WAG 1. There are 73 waste storage, processing, and chemical storage tanks within WAG 1, 69 of which have been used for the collection, treatment, and/or storage of liquid low-level waste. Of the remaining four, two are aboveground tanks used for temporary waste-oil accumulation and storage, and two are aboveground tanks formerly used for storage of acid and caustic liquids. Twenty-five of the tanks continue to receive waste; 48 were removed from service because they (1) were leaking, (2) were no longer needed, or (3) did not meet FFA criteria for leak detection and secondary containment and were not scheduled for replacement.

About 95% of the documented inventory of radionuclides within inactive liquid low-level waste tanks in WAG 1 are contained within the six large underground storage tanks in the South Tank Farm. About half of the South Tank Farm inventory is in Tank W-10. Each 170,000-gal-capacity tank is made of Gunitite—which is a construction process in which a mixture of sand, portland cement, and water is sprayed in layers onto steel reinforcement bars and/or welded wire mesh. The major contaminants in these Gunitite tanks, among the first constructed at ORNL in the 1940s, are isotopes of Sr, Cs, Th, U, Pu, and Cm. The total gross beta activity is estimated to be about 23,000 Ci, from ^{90}Sr and ^{137}Cs , and the total gross alpha activity is about 160 Ci, mostly from plutonium and curium.

The North Tank Farm contains inactive underground liquid low-level waste Gunitite and steel tanks; the Gunitite tanks are much smaller than those in the South Tank Farm. The inventory of alpha-emitting radionuclides among all the tanks is estimated to be 7 Ci, and the inventory of beta emitters is estimated to be about 1000 Ci.

Due to the failure potential of the dome of the Gunitite tanks, the fact that an estimated 95% of the waste curies at ORNL are stored within the Gunitite tanks, and the ongoing RA activities at the North/South Tank Farm, the focus in the TLD problem area will be on the Gunitite tanks.

1.4.4 Impoundments

Unlined impoundments have been used at ORNL to collect, treat, and, in some cases, dispose of process wastewater and storm water. These impoundments, also called waste basins or ponds, represent the earliest form of WM at the laboratory. The majority of the impoundments are located in WAG 1, although several ponds are located in WAG 5 and a closed pond in WAG 9. The mode of operation and contaminants at individual impoundments varied; however, the primary contaminants of concern are radionuclides, primarily ^{90}Sr , ^{137}Cs , ^{60}Co , ^{154}Eu , and other gamma emitters. Many of the impoundments are located at low elevations and are therefore in direct contact with the ground water.

Most of the impoundments were operated as process wastewater-settling or -storage basins, resulting in the deposition of sediments or sludge in the impoundments. The majority of impoundments are inactive; however, several, including 3524, 3539, and 3540, are still active and receive process wastewaters. The Homogeneous Reactor Experiment pond, used for storage of condensate from the Homogeneous Reactor Experiment evaporator, was filled with soil and capped with asphalt in 1970.

The 7835 impoundment, located in WAG 5, was used to contain and settle process sludge produced at the ORNL process-waste treatment plant. The 7852A impoundment is inactive but was used to receive accidental wastes generated during operation of the Old Hydrofracture Facility. White Oak Lake is a surface impoundment for radioactive and other hazardous wastes that drain ORNL via the White Oak Creek watershed. It serves as a final settling basin for waste released from ORNL operations and storage areas.

1.4.5 Pipelines

The ORNL main plant and outlying facilities have an extensive system of waste-carrying pipelines and tanks. There are 96 tanks used for radioactive, hazardous, and mixed waste known to exist at ORNL. Forty-two of these are active, and 54 are out of service (this total does not include petroleum tanks). The waste-carrying pipelines are divided into two types: low-level waste and process ("suspect") waste.

Low-level waste lines (mostly 1-in. to 4-in. stainless steel) carry liquid-radioactive waste from "hot drains" within buildings to an evaporator facility within the main plant area, where volume reduction is performed. The concentrate remains in the low-level waste system and is piped through double-contained lines to the Melton Valley Storage Tanks. The liquid is piped from the evaporator to the Waste Water Treatment Plant for removal of radionuclides. The effluent from this process is collected in aboveground storage tanks. The waste is then treated at the Nonradioactive Wastewater Treatment Plant, and the treated effluent is released at a National Pollutant Discharges Elimination System, which is a permitted discharge point to White Oak Creek.

Many of the process-waste lines (mostly 4-in. to 6-in. vitreous clay pipe) have been relined in recent years. Some sections are no longer used (the waste is transported to the Waste Water Treatment Plant from holding tanks via tanker truck). However, many of the sections of process pipe located between the building drains and holding tanks have held the most concentrated (and therefore most corrosive) waste, and it is conceivable that waste may have leaked into the soil beneath these buildings. The process and low-level waste lines are buried between 3 ft and 20 ft deep and cross over many other pipelines. Leaks from waste-carrying pipes may have spread to the pipe backfills of other types of piping, which may be serving as conduits for the transport of contaminants. Remediation of contaminated soil, without destruction of the buildings and other pipelines, calls for the use of innovative methods. The methods used at other remediation sites (information resulting from a reference search) have consisted exclusively of either capping the pipes and/or filling them with grout and leaving the pipe and contaminated soil in place or excavating the soil and pipe and disposing of the soil and pipe material.

1.4.6 Hydrofracture

As part of waste disposal operations conducted at ORNL, wastes were injected into low-permeability shale about 300 m below ground. The process, known as hydrofracture injection, was conducted during the 1960s through the 1980s. Radioactive wastes were mixed with grout and other additives to form a slurry then pumped down injection wells

and into the Pumpkin Valley Shale formation. The waste mixture extended horizontally from the injection well to form a solid grout sheet 2–25 mm thick with a radius of 150–200 m. Additional injections were made into the shale formation at slightly shallower depths in order to dispose of the waste volumes. About 3.2 million gal of low-level radioactive wastes containing 1.4 million Ci of radioactivity were disposed of between 1959 and 1984 at depths between 225 and 340 m (Table 1.4).

The Hydrofracture Experiment Site 1 is located within the boundary of WAG 7 and was the site of the first experimental injection of grout (October 1959) as part of a testing program for observing the fracture pattern created in the shale and identifying potential operating problems. Waste injected was water-tagged with ^{137}Cs and ^{141}Ce . Grout consisted of diatomaceous earth and cement.

The Hydrofracture Experiment Site 2 is located about 0.5 mile south of the Homogeneous Reactor Experiment area in WAG 8. The second hydrofracture experiment was designed to duplicate, in scale, an actual disposal operation. However, radioactive tracers were used instead of actual waste. Water tagged with ^{137}Cs , cement, and bentonite was used in formulating the grout.

The Old Hydrofracture Facility is located in the southwest corner of WAG 5. The facility, commissioned in 1963, served as a pilot plant to demonstrate the feasibility of permanent disposal of liquid-radioactive waste in impermeable-shale formations by hydrofracture methods. Wastes used in the experiments included concentrated liquid low-level waste, ^{90}Sr , ^{137}Cs , ^{244}Cm , TRU, and other unidentified radionuclides.

The New Hydrofracture Facility is located 900 ft southwest of the Old Hydrofracture Facility on the south side of Melton Branch. The facility was constructed to replace the Old Hydrofracture Facility and serve as the operational liquid low-level waste disposal system for ORNL. Wastes used in the injections were concentrated liquid low-level waste and sludge removed from the Gunit tanks and included ^{90}Sr , ^{137}Cs , ^{244}Cm , TRU, and other nuclides.

The hydrofracture problem area includes only the underground component at the four sites. It consists of the wells, grout sheets and contaminated subsurface media, and about 150 observational wells. The latter were used to measure changes to the geology around the injection site, and most of these wells do not penetrate the grout sheets.

For the purposes of the TLD, the problem area was divided into two subproblems: the well bores and the grout sheets. The well bores, though not a waste site, present a potential pathway for vertical migration of any mobile waste from the grout sheets to aquifers above or below the grout sheets. The grout represents a potential waste site because the potential exists that some of the waste may not have been immobilized with the grout or that a phase separation of the grout mixture may have left a liquid slurry capable of leaching or migrating to an aquifer.

1.4.7 Soils and Sediment at ORNL

Soils and sediments act as receptors of contaminants released to the terrestrial environment. Predominate modes of contamination result from spills, leaks from waste storage tanks and associated transfer lines, and uncontrolled WM practices, such as disposal in unlined lagoons and burial trenches. The concentration and character of contamination vary widely (i.e., radionuclides, heavy metals, as well as hazardous- and toxic-organic compounds) and are largely dependent on the historical operations conducted at ORNL. For example, there is a potential for contamination by a spectrum of fission and neutron activation products because of the wide diversity in fission research conducted over the nearly 40 years at ORNL. This is unlike the other DOE Oak

Table 1.4. Summary of hydrofracture grout injections^a

Injection type	Number of injections	Water plus			Primary waste constituents ^b (curies)					
		Waste volume (gal × 10 ³)	Water volume (gal × 10 ³)	Grout volume (gal × 10 ³)	⁹⁰ Sr	¹³⁷ Cs	²⁴⁴ Cm	TRU ^c	Other	Total
HF1										
Experimental (1959)	1	N/A ^d	N/A	27	--	35	--	--	8.7 (¹⁴¹ Ce)	44
HF2										
Experimental (1960)	2	N/A	N/A	224	--	50	--	--	--	50
HF3 (OHF)										
Experimental (1963–1965)	11	N/A	457	678	1,436	5,237	N/A	N/A	N/A	6,673
Operational (1966–1979)	18	969	1,200	1,650	38,640	603,881	233 ^d	5.8 ^e	N/A	642,760
HF4 (NHF)										
Experimental (1982)	1	N/A	66	98	--	--	--	--	20 (¹⁹⁸ Au)	184
Operational (1982–1984)	13	2,240	2,540	2,873	644,505	83,765	7,464	2,125	13,314	751,173
Total	46			5,550						1.4 × 10 ⁶

^aValues are estimates of injected volumes only. Accurate determination of phase separation and bleed-back volumes cannot be made for many of the injections.

^bOther radionuclides were present in waste in much smaller quantities, were in equilibrium with listed radionuclides, or were not analyzed prior to injection.

^cTRU represents transuranic elements.

^dNot analyzed.

^eTotals here should be used with caution. Data on radionuclide content are not available for injections in this series.

Source: Modified from Myrick and Stow, *Remedial Action Plan for ORNL Hydrofracture Operation*, ORNL/RAP-9, Martin Marietta Energy Systems, Inc., Oak Ridge National Laboratory, 1987.

Ridge Operations sites, where radioactive contamination is generally limited to U and ^{99}Tc in the uranium-enrichment and processing industry.

Due to the changing mission and needs of the laboratory, the management of liquid and solid wastes was generally one that involved considerable flexibility. In the early to late 1940s, high-level liquid wastes were treated with caustic and held in large Gunit tanks to allow for sludge settling and decay of short-lived radioisotopes. Supernatant from these tanks were diverted to settling basins and discharged to the White Oak Creek impoundment. In 1949, an evaporator was added to reduce the volume of liquid waste stored in the Gunit tanks. Storage space in Gunit tanks became limited, and in 1951 direct disposal of high-level liquid waste into disposal pits began. From 1951 to 1966 about 42 million gal of radioactive-liquid waste containing about 1.2 million curies were disposed in seven seepage pits and trenches. Much of the short-lived activity has decayed leaving an estimated 200,000 Ci of ^{90}Sr , 600,000 Ci of ^{137}Cs , and much smaller amounts of U and TRUs.⁸ A limited and unknown portion of activity has leached from these pits and trenches contaminating soils and sediment of the White Oak Creek impoundment. Low-level solid and liquid wastes have also been disposed of in unlined waste pits, trenches, and lagoons, resulting in the contamination of underlying soils as well as the floodplain soils and sediments of the White Oak Creek impoundment. To roughly estimate the quantity and characteristics of contaminated soils and sediments present at ORNL, each area containing potentially contaminated soil and/or sediment is discussed below.

1.4.7.1 Contaminated Soils in Low-Level Solid Waste Burial Grounds

Soils contaminated as a result of low-level solid waste disposal operations are predominately those in contact and adjacent to the unlined burial trenches. Treatment of these soils may be required if wastes from these trenches are removed off site. This scenario is being considered but is unlikely to take place in the next 10–20 years. Seven sites at ORNL have been used for disposal of low-level solid wastes. All but one (SWSA 6) are closed to active burial operations. The total surface area for all seven is about 130 acres.⁹ If one assumes about one-half of that area contains trenches (14 ft by 40 ft and 15 ft deep with 6 ft by 12 ft between trenches), then an estimate for the total number of burial trenches is about 1800. The contaminated soil surrounding these trenches would be on the order of $2.2 \times 10^5 \text{ yd}^3$, assuming contamination is confined to within 3 ft of the trench. Obviously, such an estimate is subject to a large error (by factors of 10–100), depending on cleanup levels and accessibility of contaminated soil after removing the waste forms. The main point to keep in mind is that large volumes of soil will likely require treatment if wastes are removed from these burial grounds.

1.4.7.2 Contaminated Soils Surrounding ORNL Seepage Pits and Trenches

Large quantities of radioactive-liquid wastes have been disposed of in the ORNL waste pits and trenches ($\sim 42 \times 10^6$ gal containing $\sim 1.2 \times 10^6$ Ci of activity).⁸ However, a direct association between levels of ^{90}Sr , ^{60}Co , and ^{137}Cs observed in stream-bed sediment and discharge from the waste pits and trenches was difficult to ascertain. Pit 1 and Trench 6 are the only identifiable sources of ^{90}Sr contamination in stream-bed sediment.¹⁰ Concentrations of ^{90}Sr on stream-bed gravels routinely measured $>220 \text{ pCi/g}$ in the streams draining these two sources. Very large concentrations of ^{60}Co ($>4.5 \times 10^3 \text{ pCi/g}$) were measured in stream-bed gravels immediately to the east of Trench 7. These concentrations of ^{60}Co likely reflect transport of ^{60}Co observed by Duguid in ground-

water seeps east of Trench 7 (concentrations >100 pCi/mL).¹¹ Concentrations of ^{60}Co or ^{90}Sr in surface soils or relict-contaminated subsurface soils adjacent to Trench 7 have not been reported. Thus, it is difficult to determine the extent of contamination so that estimates relating to the quantities of contaminated soils in these areas can be determined. Because of the high affinity of ^{137}Cs to become irreversibly sorbed to the illitic soil clays native to this area, ^{137}Cs contaminated surface soils are rarely observed.¹² The one exception appears to be soils and stream gravels immediately downstream from Trench 6. This trench was constructed in 1961 in the absence of geologic advice or preconstruction coring and water-table monitoring. It was U-shaped, and only small portions of it were perpendicular to the geologic strike as prescribed in the Trench 5 design. Its use was discontinued about one month after it received its first waste. Significant seepage containing ^{90}Sr and ^{137}Cs (~ 20 m³/h) was detected south of the trench indicating serious leakage through open fissures. Concentrations of radioactivity in soil or estimated quantities of soil contaminated by the seepage was not reported in Spalding's 1987 report.⁸

The need for remediation of soils and sediments within the ORNL seepage pit and trench waste grouping area will depend on two major factors: (1) the approach used to remediate the pits and trenches and (2) levels of cleanup established for soils and sediments. Obviously the most important remediation effort will be directed at the waste pits and trenches per se; however, ground water, as well as surface water contamination, will likely continue until relict-contaminated subsurface soils immediately adjacent to these waste disposal sites are remediated. The quantity of contaminated soil, as well as the level or forms of contamination, are not clearly understood.

1.4.7.3 Contaminated Soils Under Waste Impoundments

Unlined impoundments have been used at ORNL to collect, treat, and in some instances, dispose of liquid wastes. These impoundments, also called waste basins or ponds, represent the earliest form of WM at the laboratory. ORNL has used at least 11 waste impoundments to collect liquid low-level radioactive wastes.¹³ These include the 3513, 3524, 3539, and 3540 impoundments located in WAG 1; the 7905, 7906, 7907, and 7908 impoundments located in Melton Valley for the collection of liquid waste from the High Flux Isotope Reactor and Transuranium Process Plant; the 7835 impoundment located in WAG 5; the 7852A or the Old Hydrofracture Facility impoundment (the Old Hydrofracture holding pond); and the Homogeneous Reactor Experiment impoundment (Homogeneous Reactor Experiment No. 2) located just south of Melton Valley Drive. The two largest impoundments are 3513 and 3524 (design capacity of 2×10^9 gal and 1×10^9 gal, respectively). The bottoms of these impoundments are very near the limestone bedrock (usually within 2 ft, and in the case of the 3524 impoundment on bedrock at the west end). Thus, soil contamination is predominately that soil making up the berms of the impoundments and the surface soil between the impoundments and the White Oak Creek. The surface area within this complex (less the area of the impoundments) is $\sim 1.3 \times 10^5$ ft² (3 acres). If one assumes a soil depth of 15 ft to bedrock, the total volume of contaminated soil in this area would be about 7.2×10^4 yd³. The dominant contaminant, judging from concentrations in ground-water monitoring wells, would be ^{90}Sr . There may be unacceptable levels of mercury in some of the soil—sediment in the 3513 pond contained EP toxic levels of extractable mercury.¹⁴ Thus, sediment in the 3513 impoundment will likely be classified as a mixed waste. Characterization of sediment contained in all of the ponds was completed before promulgation of the Toxicity Characteristic Leaching Procedure to identify toxicity of

organic compounds in wastes; thus, it is likely that all the sediment from these impoundments (and possibly the soils below and adjacent to the impoundments) will require classification by the Toxicity Characteristic Leaching Procedure test.

The impoundments at the High Flux Isotope Reactor and TRU sites (7905, 7906, 7907, 7908) are relatively small (total capacity $< 8.5 \times 10^5$ gal) and have < 2 Ci of activity in the sludge of sediment contained in the bottom of the impoundments. Total volume of contaminated soil after remediation of the sludge in the impoundments is expected to be $< 10^3$ yd³ and, judging from the concentrations of radionuclides in the sludge, concentrations of radionuclides would also be low.

The 7834 impoundment was used to contain and settle process-waste sludge generated at the ORNL Process Waste Treatment Plant. The impoundment (85 × 80 × 8 ft deep) was constructed in 1976 and taken out of service in 1981. Characterization by Francis and Sealand¹³ showed the impoundment contained ~20 Ci of activity (predominately ⁹⁰Sr, ¹³⁷Cs with ~1 Ci of ⁶⁰Co) in a very low-density sediment (dominated by an organic resin).⁹ If one assumes soil contamination is limited to a distance of 4 ft around and below the impoundment, the volume of potentially contaminated soil would be on the order of 2.5×10^3 yd³. The Homogeneous Reactor Experiment impoundment was drained and backfilled with soil and partially weathered shale in 1970. The ground water has been monitored, and the sludge/sediment has been characterized as to concentration of radionuclides and metals and its EP toxicity characteristics.^{14, 15} The radionuclide inventory was ~90 Ci (~75 and 15 Ci of ⁹⁰Sr and ¹³⁷Cs, respectively, with traces of plutonium isotopes) with some samples containing 5.4×10^4 and 3.9×10^5 pCi/g of ¹³⁷Cs and ⁹⁰Sr, respectively. The volume of contaminated soil/sediment within the original pond area would be about 10^3 yd³ and about 6 times that if soil under the asphalt cap were removed to a depth of 10 ft.

The Old Hydrofracture Facility impoundment contains the largest radionuclide inventory of the ORNL impoundments. The estimated inventory is ~150 Ci and the sludge/sediment (on a dry-weight basis) would be classified as a Class C waste under Nuclear Regulatory Commission (NRC) regulations.^{13,16} High levels of ⁹⁰Sr (3.8×10^4 pCi/L) in ground water sampled from the well in the northwest berm indicate that considerable contamination is moving out of the impoundment. Surface soils down-gradient, as well as those between the pump house and impoundment, showed elevated rad levels, indicating considerable contamination of soils at this impoundment.¹⁶ These data indicate that estimates of surface-soil contamination may range to as high as 1.5×10^3 yd³ and about 0.5×10^3 yd³ of contaminated soil beneath the contaminated sludge contained in the impoundment.

1.4.7.4 Contaminated Sediments and Floodplain Soils

Most of the contaminated sediments in the ORNL area are in the Intermediate Pond, both White Oak Creek and Melton Branch weirs, White Oak Lake, and White Oak Lake Embayment of the White Oak Creek watershed. Contaminated floodplain soils are also located along tributaries of White Oak Creek.

The contaminated sediments and soils belong to WAG 2. The White Oak Creek drainage system has been exposed to a diversity of contaminants as a result of operation and waste disposal activities at ORNL during the past 47 years.

The Intermediate Pond was to serve as a settling basin for radionuclide-contaminated sediments released from ORNL and traveling down White Oak Creek toward White Oak Lake. The bed of the Intermediate Pond covers an area of about 8.3 acres, and the average depth of contaminated sediment is 1.6 ft.⁶ The volume of contaminated sediment

in the pond is about 2.1×10^4 yd³. Seven sediment samples taken at the area have ⁹⁰Sr (59–680 pCi/g), ⁶⁰Co (15–460 pCi/g), ¹³⁷Cs (68– 8.1×10^7 pCi/g), and minor amounts of ¹²⁵Sb (0.0–8.2 pCi/g) and TRU radionuclides.

The estimated area of contaminated sediments deposit above the White Oak Creek and Melton Branch weirs is 0.6 acres. The volume of contaminated sediments in the weirs is 2.9×10^3 yd³. Loar presented data from common radiological contaminants for the White Oak Creek and Melton Branch weirs.⁶ The average concentration of ¹³⁷Cs, ⁶⁰Co, and ⁹⁰Sr was 3.6×10^3 , 61.0, 177 pCi/g, respectively, in the White Oak Creek weir; and 50, 1.0×10^3 , 17.0 pCi/g, respectively, in the Melton Branch weir.

The current estimated surface area of White Oak Lake is 17 acres.¹⁷ The calculated volume of contaminated sediments in the lake is 5.6×10^4 yd³. Oakes et al., 1982, estimated the radiological contaminants in the White Oak Lake: 14.6 Ci ⁹⁰Sr, 152 Ci ⁶⁰Co, 704 Ci ¹³⁷Cs, and 1038 Ci ¹⁰⁶Ru.¹⁸

The area of the embayment at the summer pool level is about 8.3 acres. The estimated volume of contaminated sediments in the embayment is 5.2×10^3 yd³. The estimated inventory of radionuclides was 6.6 Ci ¹³⁷Cs and 0.06 Ci ⁶⁰Co with small amounts of ⁹⁰Sr, ²⁴¹Am, ²⁴⁴Cm, ^{238,240}Pu, and ^{234,235,238}U.¹⁹

Contaminated soils in the floodplain occupied an area of ~ 40 acres. The estimated volume of contaminated soil in the area is 6.3×10^4 yd³. Average activities of ¹³⁷Cs was 3×10^3 pCi/g.

The estimated total volume of contaminated sediments and floodplain soils is 1.5×10^5 yd³. The weight of the total sediment and soils is 3.3×10^8 lb. Inventory of sediment and soil weight was calculated by assuming a bulk density of 1.3 g/cm³.

1.4.8 Ground Water/Surface Water

This problem area includes all ground water and surface water within ORNL. Ground water includes the freshwater aquifer and deeper-saline aquifer systems for Bethel and Melton valleys. Surface water includes White Oak Creek and Melton Branch and their tributaries, White Oak Lake, and the embayment. Ground-water seeps, surface and subsurface storm flow, and water in the unsaturated zone are also included in this problem area.

Three WAGs are located within Bethel Valley: WAGs 1, 3, and 17; Melton Valley encloses WAGs 4, 5, 6, 7, 8, 9, and 10. WAG 2 surface water lies in both Bethel and Melton Valleys.

In addition to natural drainage, White Oak Creek has received treated and untreated effluents and reactor-cooling water from ORNL activities since 1943. Controlled releases include those from the Nonradioactive Wastewater Treatment Facility, the Sewage Treatment Plant, and a variety of process-waste holding ponds throughout the main plant area. It also receives ground-water discharge and surface drainage from WAGs 3, 4, 5, 6, 7, 8, 9, and 17. Major contaminants in White Oak Creek are ⁹⁰Sr, ⁶⁰Co, ¹³⁷Cs, ³H, and metals (e.g., mercury, zinc, and chromium).

White Oak Lake is a surface impoundment for radioactive and other hazardous wastes that drain ORNL via the White Oak Creek watershed. It also serves as a final settling basin for wastes released from ORNL operations and waste storage areas.

Ground water and surface water are contaminated from contact and leaching with subsurface wastes. The types and concentrations of contaminants vary; a summary list of contaminants is presented in Table 1.1.

The limited interaction between the freshwater/saline water interface is evidenced by the chemical (CaCO₃, NaHCO₃, and NaCl) stratification with depth. Additional

confirmation of limited interaction is the variation of tritium concentration with depth. Preliminary data shows that tritium is confined primarily to the shallow system.

1.4.9 Priorities

Priorities for remediating the site problem areas discussed in the preceding sections are presented in Table 1.5. The priorities were assigned on the basis of the potential for releases of contaminants to the environment. For the tanks soils/sediment, and ground water/surface water problem areas, two priorities were assigned to account for differences in the potential for release within a specific problem area.

Table 1.5. Remedial action site problem priorities

Site Problem	Priority^a	Comments
Buried waste	5	Primary source of releases
Pits and trenches	3	Releases already happened, contaminants locked up
Low-level waste tanks		
Gunite	5	Structural integrity questionable
Steel	3	Smaller volume/tanks intact
Soils and sediments		
Sediments	4	Moving off site
Soils	2	Remain in place
Ground water/surface water		
Seeps	5	Hot spots identified
Balance	2	
Buried pipelines	1	Not mobile or a major pathway
Impoundments	4	Some leaking contaminants
Hydrofracture		
Grout sheets/ injection wells	1	Migration not an issue

^aHighest priority designated by "5"

1.5 ORNL ROADMAP

1.5.1 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.²⁰ 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 comprehensive logic diagrams for RA of low-level, radioactive-mixed, hazardous, sanitary and industrial, and TRU wastes at the ORNL WAGs. The roadmapping process gives comparisons of the installation as it exists to the way the installation should exist under full compliance. The goal of roadmapping allows accurate and timely formulation of activities. The following information is excerpted from the *Strategic Roadmap for the Oak Ridge Reservation*.²⁰

1.5.2 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 at 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 FFAs; and (4) preparing a schedule that includes all commitments with all currently budgeted and forecasted activities.

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

A "Revised Roadmap Methodology Document" was issued in May 1993.

1.6 ORNL RA STRATEGY

The ORNL ER program addresses environmental contamination problems at ORNL consistent with the *Oak Ridge Reservation Site Management Plan for the Environmental Restoration Program*.²¹ The plan identifies approaches to meet the requirements of the FFA for the ORR. The approach promotes early remedy selections, flexibility for RA, and contingencies to react to new information discovered during investigations and is based on the following premises:

1. Operable units (OUs) consisting of remediation unit groupings have been initially identified for ORR. These OUs will proceed through the formal CERCLA process encompassing investigation field activities, the selection of the appropriate RAs, design and construction, and unit-monitoring activities. During the performance of the remedial investigation phase, the initial OUs may be further subdivided into additional OUs or combined to best expedite the identification and implementation of the remediation alternatives.
2. Removal actions will be undertaken to protect human health and the environment from an imminent threat in the short term (i.e., the planning period prior to initiation of action is less than 6 months). Interim RAs may also be taken to stabilize a site, prevent further degradation, or achieve significant risk reduction quickly [i.e., while the remedial investigation/feasibility study to support interim or final remedy selection is under way].
3. Unit characterization will be planned on the basis of optimizing field sampling and maximizing use of available data. In cases where sufficient historical data exist to support or eliminate potential remedies, these data on the OUs will be used to converge early on RAs based on probable unit conditions. Measures will be implemented to effectively manage the uncertainties where the unit has not been fully characterized.
4. A preliminary assessment/site inspection will be performed on units newly discovered or not already included in one of the existing OUs. Following the preliminary assessment/site inspection, these units will be classified as requiring no further investigation, requiring immediate action to stabilize the area and provide controlled access, or requiring further investigation (remedial investigation/feasibility study). Units requiring further investigation may be added to an existing OU or combined with other units to create a new OU.
5. Remediation of many ORR waste sites poses challenges unlike those encountered in cleanup of typical Superfund sites. For example, many of the sites have radioactive as well as hazardous contamination, which limits the commercially available treatment methods used at other Superfund sites. Excavating and treating some radioactive wastes may pose unacceptable risk, leading to the frequent use of consolidation and containment remedies. Thus, final remediation schedules will most likely be longer than those encountered at other Superfund sites and involve interim actions to reduce the risk to human health and the environment until the final remediation.

The current RA strategy at ORNL is oriented toward WAGs, which are consistent with OUs. The activities for each of these WAGs provide for

- a remedial investigation/feasibility study,
- interim corrective measures or removal actions, Record of Decision/Interim Record of Decision, and
- final site remediation for the WAG.

The remedial investigation/feasibility study process represents the methodology for characterizing the nature and extent of risks posed by WAGs and for evaluating potential remedial options. This approach is a dynamic, flexible process tailored to the specific circumstances of each of the WAGs. Due to the uncertainties inherent with each of the WAGs (e.g., site hydrogeology, extent of contamination), an "observational approach" workshop was conducted for each WAG. The observation approach workshop is a technique for recognizing and managing uncertainty and includes

- obtaining WAG data sufficiency rather than data completeness;
- focusing characterization efforts to support or eliminate potential remedies;
- converging early on RA alternative(s) based on probable conditions;
- identifying reasonable deviations from the RA alternative(s);
- preparing contingency plans; and
- monitoring the effectiveness of the RAs to protect the human health and environment.

Scoping is the initial-planning phase of the remedial investigation process, and begins with the collection of existing site data. Typical scoping activities include

- review and analysis of existing data for each of the WAGs;
- determining the RA objectives and identifying the data and other information needed to support those objectives;
- preparing the work plan, the sampling and analysis plan, and other project documentation; and
- determining overall project management strategy with the governmental agencies (e.g., EPA, TDEC, and DOE).

A scoping meeting will be held with the regulators prior to initiation of the remedial investigation to agree upon the sampling and analysis plan.

Site characterization activities are then initiated soon after, including field sampling and analysis. This data will be used to

- characterize the WAG,
- prepare a risk assessment that identifies the existing or potential risk posed to human health and the environment, and
- evaluate potential RA alternatives.

These alternatives are developed to address the contaminated medium (e.g., ground water), a specific area of the site (e.g., a waste lagoon or hot spot), or the entire WAG.

After the RA alternatives have been developed and assessed, the feasibility study and associated NEPA documentation will be prepared. During the feasibility study, the development of remedial alternatives are more fully analyzed and screened. The screening

process is based on the short- and long-term aspects of three broad criteria: effectiveness, implementability, and cost. The Proposed Remedial Action Plan and the Record of Decision are also prepared during the feasibility study.

Due to the size and complexity of these WAGs, they may be divided into OUs at the completion of the initial site characterization. Each OU will move through a remedial investigation (if required), a feasibility study, Record of Decision, and remediation as separate units. Coordination between OUs will be maintained at the WAG level so that remediation strategies for OUs will be compatible with remediation objectives for the WAG as a whole.

Prior to completion of final site remediation interim corrective measures or removal actions will be conducted if required to protect human health and the environment. Contamination resulting from releases of hazardous constituents from contaminated sites in the WAGs will be contained, removed, or treated.

Final site remediation activities for a WAG, if required, will include

- preliminary engineering,
- remedial design,
- RA,
- verification,
- long-term monitoring, and
- operation and maintenance.

1.6.1 Status of RA Activities at ORNL

ER activities for inactive contaminated sites at ORNL were initiated in 1985 under the auspices of the Remedial Action Program.⁴ As determined by the EPA, the regulatory driver for the RA Program was RCRA. RCRA requires implementation of (1) a compliance monitoring program, (2) a corrective action program, or (3) a detection monitoring as appropriate [40 Code of Federal Regulations (CFR), Part 264, Subpart F]. Consequently, the RA Program developed an approach that was consistent with RCRA yet reflected the uniqueness of the problems and physical setting of ORNL.

Initially, the RA Program established a strategy that was consistent with the various federal and state laws and regulations and DOE orders relevant to the remediation of contaminated sites at ORNL.⁴ Activities were initiated with a RCRA Facilities Assessment for ORNL followed by the development of the remedial feasibility investigation or the remedial investigation plan for each WAG established at ORNL. By 1989, most of the remedial feasibility investigations or the remedial investigation plans had been completed and submitted to EPA for approval. The remedial investigation Plans for WAGs 11 and 13 were completed and submitted to EPA in December 1990.

Subsequent activities affected the RA Program. First, DOE established a national ER Program, which was mirrored by Energy Systems' establishment of a centralized ER Program and the concurrent creation of an ORNL ER Program. The ORNL ER Program replaced the ORNL RA Program. The second activity was the establishment of an FFA between DOE, EPA, and TDEC effective January 1, 1992. This document formalized a procedural framework for developing, implementing, and monitoring appropriate response actions in accordance with CERCLA, the National Contingency Plan,⁵ RCRA, the NEPA, Tennessee State law, and appropriate guidance and policy. The framework for response actions at contaminated sites incorporates a range of potential activities identified in Section 1.5. Also, the FFA contains specific requirements for the low-level radioactive tank systems at ORNL.

A remedial investigation was performed for WAG 1 following EPA guidance developed to meet the requirements of CERCLA. Phase I field activities were initiated in December 1989 and three reports (Site Characterization Summary Report, Preliminary Risk Assessment Report, and Operable Unit Strategy Document) were submitted to EPA and TDEC for review and comment in September 1992.²² Based on these documents, a number of OUs have been identified, including the Gunitite and associated tanks OU, the surface impoundment OU and the shallow ground water OU. Remedial alternatives will be developed for the Gunitite and associated tanks OU and the surface impoundments OU. Because of their high priority, appropriate technologies are needed to address the current problems associated with these two OUs.

WAG 2, composed of White Oak Creek and its tributaries and associated floodplains, acts as a conduit for contaminants from up-gradient WAGs. Consequently, the WAG 2 Remedial Investigation Plan⁶ was developed and approved by EPA and TDEC that is based on short-term monitoring activities, followed by final remediation after the up-gradient areas or WAGs have been remediated. The objectives for the short term are as follows:

1. preliminary surveys and sampling to determine hot spots (discrete areas of significant contamination that may need interim corrective measures to protect the public or environment), identify areas where additional data are needed, fill data gaps for the first round of risk assessment, and clearly delineate the boundary of WAG 2; and
2. implementation of a multimedia environmental monitoring and characterization program to (a) define and monitor the input of contaminants from adjacent WAGs, (b) characterize the hydrology of the White Oak Creek system and support a mass-balance approach to determining sources, sinks and transport of contaminants in WAG 2, and (c) establish the basis for determining long-term trends in contaminant levels.

Long-term objectives of the WAG 2 remedial investigation include

1. definition of the nature and extent of contamination in WAG 2,
2. quantification of any risk to human health and the environment resulting from the contamination, and
3. preliminary evaluations of potential corrective measures and RA alternatives for the OUs in WAG 2.

A remedial feasibility investigation was implemented for WAG 6 to meet the RCRA Corrective Action Program schedule agreed upon by DOE, EPA, and TDEC for the remediation of WAG 6.⁷ The schedule called for completion of the remedial feasibility investigation by September 1991 and closure and final remediation of WAG 6 by 1997. Field activities for the remedial feasibility investigation commenced in December 1988 and were completed during the summer of 1990. The remedial feasibility investigation report was submitted for regulator review in September, 1991. Subsequently, a feasibility study/environmental assessment was prepared and accepted by EPA and TDEC. During a public hearing on the proposed remediation, strong objections were received related to the cost and temporary nature of the action. As a result, remedial activities have been delayed and a monitoring plan is being developed to monitor contaminant discharges in ground water from the WAG. Additionally, the development of technologies needed to address the remediation of buried wastes in WAG 6 have been expedited.

Except for the initial remedial investigation plan completed in 1988, ER remediation activities have not been scheduled for WAG 7. A technology demonstration of in situ

vitrification (ISV) is planned for a part of Pit 1 and a Treatability Study Work Plan is being prepared for submittal to EPA and TDEC.

The initial Remedial Investigation Implementation Plan for the WAG 10 remedial investigation was prepared in March 1990. The Sampling and Analysis Plan component of the Remedial Investigation Implementation Plan was revised based on regulatory review comments and resubmitted to EPA and TDEC in June 1992. Responses to regulatory comments on the revised Sampling and Analysis Plan were prepared and submitted in June 1993. The near term objective for the WAG 10 remedial investigation involves characterization of existing hydrofracture wells and bore holes. Information collected through this characterization work will be used to develop plugging and abandonment techniques for the various WAG 10 wells and bore holes.

A Remedial Investigation Work Plan was completed and submitted to EPA and TDEC for approval in 1990 for WAG 11. An interim RA has been implemented to collect, segregate, containerize, and remove the contaminated surface debris from the WAG. This action will be finalized with the issuance of a postconstruction report. At some time in the future, the remedial investigation leading to the final RA for the site will be initiated.

The Remedial Investigation Work Plan for WAG 13 was completed and submitted to EPA and TDEC in 1990. This WAG includes 13 cesium treatment plots used to simulate nuclear weapons fallout and four of the plots have been determined to emit elevated levels of gamma radiation, which poses a potential threat to human health and the environment. Consequently, an interim RA is being initiated to excavate cesium-contaminated soil and transport it to WAG 6. The final remediation of WAG 13 will be implemented at some time in the future.

1.6.2 Summary of Major Committed Milestones

ER milestones are negotiated annually with the regulators based upon DOE funding and priority considerations. These milestones reflect activities initiated in the past and support activities planned for the long-term. Major negotiated milestones for fiscal years 1994 and 1995 are shown in Table 1.6. Milestones are identified by site OUs and include monitoring plans, remedial investigation/feasibility study reports, designs, and postconstruction reports. The relationship between these milestones and remedial activities at the WAGs are discussed in Sect. 1.6.1.

**Table 1.6. Fiscal year milestones negotiated with TDEC^a
and EPA^b through FFA^c**

Site/OU ^d	Deliverable	Date
1994		
WAG ^e 1	RI/FS ^f Gunite and associated tanks OU	05/02/94
	Shallow GW ^g Monitoring Plan (RIWP ^h Addendum)	TBD
WAG 2	Annual monitoring (ERMA ⁱ Report)	09/30/94
	Site Sampling and Analysis Plan (Addendum)	09/30/94
WAG 6	Monitoring plan	TBD
WAG 7	Treatability study	TBD
WAG 11	Postconstruction report	05/31/94
WAG 13	Postconstruction report	02/28/94
Ground water	RI work plan	01/30/94
Active LLLW ^j tanks	Secondary containment design cat. B	03/31/94
	Status report	09/30/94
1995		
WAG 1	Proposed plan Gunite and associated tanks OU	04/19/95
	RI/FS surface impoundments OU	02/11/95
WAG 2	Annual monitoring (ERMA Report)	09/30/95
	Site Sampling and Analysis Plan (Addendum)	09/30/95
WAG 5	RI report	03/31/95
	Feasibility study	09/27/95
WAG 6	Annual monitoring report	06/30/95
		09/30/95
Active LLLW Tanks	Struct. integ. assess. cat. C tanks	09/30/95
	Struct. integ. assess. cat. C pipelines	09/30/95
	Status report	09/30/95

^a TDEC = Tennessee Department of Environment and Conservation

^b EPA = U.S. Environmental Protection Agency

^c FFA = Federal Facilities Agreement

^d OU = operable unit

^e WAG = waste area grouping

^f RI/FS = remedial investigation/feasibility study

^g GW = ground water

^h RIWP = remedial investigation work plan

ⁱ ERMA = environmental restoration monitoring and assessment

^j LLLW = liquid low-level waste

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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 RA problems that have been identified at ORNL. The technology listings in the diagrams were judged to have some reasonable prospect for application at ORNL. In a few cases the prospects are limited, however.

The K-25 Site TLD has been used whenever possible.

2.2 STAFFING FOR THE TLD

The formulation of the ORNL TLD was led by the same teams that formulated and published the *Oak Ridge K-25 Site Technology Logic Diagram*,¹ 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 from personnel associated with 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. 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.

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.

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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: clean up legacy waste, 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; 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, 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 a subelement-specific (see below) list 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.² 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 these various subelements for D&D, RA, and WM.

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

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

Table 2.1. Subelement categories in the Technology Logic Diagram

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

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 is addressed. 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 and technology 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 priority and status of each technology and its application is used to communicate separate information about the following:

- 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).
- Significance of site problem to which the technology is applied (1–5 is the scale of lowest importance to highest importance).
- Time required to bring the technology to the state of acceptable for application at large scale (commercial or mature state) at the site. This is expressed in number of years and depends on the state of its development.
- The cost for bringing the technology from its present state to acceptable for use commercially or at large scale. 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 relative to final application 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	Any score	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. *Oak Ridge K-25 Site Technology Logic Diagram*, K-2073, Martin Marietta Energy Systems, Inc., K-25 Site, February 26, 1993.
2. T. W. Burwinkle, Decontamination and Decommissioning workshop, Oak Ridge National Laboratory, October 29, 1992.

3. Characterization

3. CHARACTERIZATION

3.1 INTRODUCTION

RA problem areas require several types of 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?

In some cases, identification of the chemical form of the contaminant is also needed to design treatment schemes. Characterization technologies are used to locate buried wastes and contaminated ground-water seeps and to define contaminant migration boundaries in soils and sediments in burial grounds and outside of tanks, pipelines, buildings, and other structures. It is required to meet regulatory requirements, to permit risk assessment, and to guide remedial treatments. The technologies involve, for the most part, the analysis of soils, sediments, sludges, water, and air in the field and laboratory. The main contaminant groups of concern are radioactive elements, heavy metals, and organic compounds or mixtures of organic compounds (e.g., PCBs or fuels). Pathogenic organisms also are screened.

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

3.2 TECHNOLOGY OPTIONS

3.2.1 Characterization Technology Options

Characterization technology options for RA at ORNL are listed in Table 3.1 of Sect. 3.5, along with their rankings. All technologies are not required for each EM problem, and many of the technologies for a given constituent are optional. Many of these technologies are broadly applicable to a variety of constituents and RA 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., buried waste, soils and sediments, impoundments, and pits and trenches). Under this general heading, the technologies are grouped as the following alternatives: sampling design, sample collection, sample preparation, detection and measurement—field methods, and detection and measurement—laboratory methods. Technologies specific to a group of constituents are then listed in the TLD 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 highly common characterization technologies, such as for pH measurements are omitted for simplicity in this compilation. Following these general listings are specific ORNL problems to which technologies are particularly relevant.

3.2.1.1 Sampling Design

The main technologies needed under this alternative are statistical designs or approaches for planning sample collection. For example, the large number of samples called for by a conventional full-factorial sampling design applied to burial grounds can be reduced to a more manageable number by statistical considerations without sacrificing information value.

3.2.1.2 Sample Collection

Sample collection methods exist for most of the RA problems at ORNL, but many are inadequate or expensive, and technology improvements are needed. Examples are the collection of soils and sediments by EPA methodology for VOCs analysis and the collection of representative samples from liquids and sludges from underground nuclear waste storage tanks. The constraints of handling radioactive materials or working in radioactive fields severely hamper sampling methods. The DOE as low as reasonably achievable (ALARA) principle is the guiding factor for adaptation and development of such technologies. Solid-phase in situ sampling or extraction technologies are an attractive alternative to current methods.

Perhaps the most difficult sample collection problem is the collection of truly representative samples from heterogeneous wastes. This would include many of the wastes buried in drums and boxes in the burial grounds. The contents of the former may range from bottles, gloves, wipes, and shoe covers to broken, damaged, or contaminated equipment and apparatus. Technology needs include not only statistical designs for directing the sample collection but also the physical means for obtaining the samples.

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 regulatory leaching procedures. Current methodologies have not been able to meet regulatory requirements in some applications. High-pressure ashing methods are critically needed to prepare samples for inorganic radiochemical analyses.

3.2.1.4 Detection and Measurement—Field Methods

Measurement technologies for field use are needed to define areas and boundaries of contamination or to locate buried waste. They can also screen samples in the field so that only those with appreciable contamination are returned to the laboratory for more extensive and expensive characterization. Field-method technologies are also discussed below under specific contaminant group alternatives. In this alternative, major technology needs are fieldable technologies for locating buried waste by seismic, magnetic, ultrasonic, tomographic, or other methods. 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. 5) of this volume.

3.2.1.5 Detection and Measurement—Laboratory Methods

Laboratory-based technologies capable of inorganic and organic component determinations are listed in 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 and 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, data bases, 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.

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 RA programs and the need to minimize costs and wastes. A particularly important technology need is the development and validation of inductively coupled plasma—mass spectrometry (ICP-MS) 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. ICP-MS can also determine nonradioactive metals.

3.2.1.9 Inorganics—Field Methods

Technologies for determining inorganic composition in the field 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. Glow discharge ionization mass spectroscopy may also be fieldable, with some development work.

3.2.1.10 Inorganics—Laboratory Methods

There are many established, accepted laboratory methods for inorganic analyses. Adapting and upgrading these technologies to meet the special requirements of radioactive samples is required. A particularly useful technology is ICP-MS.

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 also immunoassay-based field test kits for selected organic compounds or mixtures such as PCBs are high-priority technologies.

3.2.1.12 Organics—Laboratory Methods

Technologies that determine regulated organic and DOE-unique (e.g., chelators or chelated radionuclides) compounds are required. Improvements that reduce secondary waste generation, increase analytical speed and efficiency, or to address DOE-unique compounds (e.g., chelators) are needed. Supercritical fluid extraction as a virtually waste-free sample preparation method and liquid chromatography-mass-spectrometry for nonvolatile analytes are examples of technologies whose development and deployment would greatly support site remediation.

3.2.1.13 Physical—Field Methods

Technologies for locating contaminated ground-water seeps and determining ground-water flows and directions are needed.

3.2.1.14 Physical—Laboratory Methods

Characterization of particles and other materials is a small technology need.

3.2.1.15 Pathogens—Laboratory Methods

Remediation of biological wastes will require surveillance for pathogenic organisms as a part of worker protection as well as waste treatment.

3.2.2 Crosscutting Technologies

An important area of technology crosscutting is robotics and automation. This is particularly relevant in three areas of characterization: sample collection in situations too hazardous or remote for direct human participation (as during the retrieval and sampling of highly radioactive buried wastes), preparation of highly radioactive samples for analysis (as for nuclear wastes), and robotic automation of measurements (as in radiation surveys of large areas such as burial grounds). These crosscutting technologies are discussed in Chap. 5 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 technologies may require some development work, such as the determination of extractants or chelators by derivatization-gas chromatography.

Other technologies will require basic R&D. The specific needs are explained in the data sheets that are included in Vol. 3, Pt. A. For example, basic advances in technology are needed for sampling heterogeneous wastes, both in sampling strategy as well as in the physical method and equipment used to take the representative sample(s).

3.4 IMPLEMENTATION NEEDS

Implementation needs, like science and technology needs, range from none to considerable. Instruments and protocols already exist for the determination of many regulated organics and inorganics using EPA protocols. These technologies have essentially no implementation needs and are ready as is for samples that can be handled in nonzoned laboratories. 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 of field and laboratory analytical technologies is a part of the technology quality assurance and is included in the implementation costs. Other technologies are not available on site and 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 and mixed wastes that require shielding or containment and for which current facilities are inadequate.

3.5 TECHNOLOGY RANKINGS

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

Table 3.1. Rankings of characterization technologies for remedial action

Alternative	Data sheet code numbers	Technology	Ranking ^a
General applicability to all remedial action problems			
Sampling design	CHAR-252-OL	Sequential sampling plans	M-3-.5 (\$.1M;\$0.5Kam ^b)
	CHAR-71-OL	Optimization of sampling designs	H-5-.5 (\$.1M;N)
	CHAR-228-OL	Sampling program configuration management system	E-5-1 (\$0.5M;\$50Kam)
Sampling collection	CHAR-270-OL	Sampling of heterogeneous wastes	H-5-3 (\$2.8M;N)
	CHAR-210-OL	In situ solid phase microextraction of organics	H-5-1 (\$.25M;\$200)
	CHAR-81-OL	Sampling and mixing methods	E-5-1 (\$.25M;N)
	CHAR-256-OL	Soil/sediment sampling for volatile organics analysis	H-4-1 (\$.1M;\$50)
	CHAR-257-OL	Sampling underground storage tanks for volatile organics	H-5-1 (\$.26M;\$500)
	CHAR-254-OL	Solid sorbent sampling for airborne organics	H-5-1 (\$.2M;\$50)
	CHAR-55-OL	Membranes for sample collection and concentration	M-5-1 (\$.25M;\$50)
	CHAR-276-OL	Sediment sampling from restricted access locations	M-5-2 (\$.45M;N)
	CHAR-64-OL	Multangle drilling for depth profiling of contaminants	M-4-1 (\$.2M;N)
Sample preparation	CHAR-205-OL	Radioactive sample preparation	H-4-1 (\$.1M;N)
	CHAR-208-OL	Supercritical fluid extraction of organics	M-5-1 (\$.33M;\$100)
	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	E-5-1 (\$.45M;N)
	CHAR-19-OL	Microwave digestion	H-5-1 (\$.2M;\$100)
	CHAR-67-OL	Metallographic sectioning and preparation	M-4-0 (\$0M;<\$500)
	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)
	CHAR-264-OL	Ion mobility mass spectrometry	M-5-2 (\$1M;\$50)

Table 3.1 (continued)

Alternative	Data sheet code numbers	Technology	Ranking ^a
Detection/measurement —field methods (continued)	CHAR-23-OL	Immunoassay detection	H-5-3 (\$1M;\$50)
	CHAR-84-OL	Portable Raman spectrometer	M-5-2 (\$1M;\$10)
	CHAR-27-OL	Optical absorption spectroscopy	H-5-1 (\$.6M;\$50)
	CHAR-59-OL	Air monitoring	E-5-0 (\$.25M;\$500)
	CHAR-18-OL	Infrared spectroscopy (wavelength dispersion)	M-5-1 (\$.5M;\$100)
	CHAR-52-OL	Personnel monitoring	H-5-1 (\$.2M;N)
	CHAR-60-OL	Tomographic seismic monitoring	M-5-N (N;N)
	CHAR-123-OL	Ultrasonic ranging and data system	H-5-0 (\$0;N)
	CHAR-124-OL	Ground-penetrating radar	H-5-0 (\$.03M;N)
	CHAR-125-OL	Electrical and electromagnetic detection of ground and geologic features	H-5-1 (\$.2M;N)
	CHAR-126-OL	Seismic methods (refraction, profiling, reflection)	M-5-1 (\$.2M;N)
	CHAR-127-OL	Microgravity methods	M-5-1 (\$.2M;N)
	CHAR-128-OL	Magnetics	M-5-1 (\$.2M;N)
	CHAR-92-OL	Portable luminescence detection	M-5-1 (\$.5M;\$10)
	CHAR-10-OL	Electrochemical methods	M-4-2 (\$.5M;\$100)
Detection/measurement —laboratory methods	CHAR-204-OL	Contamination control—analytical equipment	H-5-2 (\$.5M;N)
	CHAR-8-OL	Fourier transform infrared spectroscopy	M-5-1 (\$.2M;\$50–\$500)
	CHAR-48-OL	Isotopic dilution mass spectrometry	M-5-0 (\$0M;\$100–\$1000)
	CHAR-11-OL	Nuclear magnetic resonance	M-5-1 (\$.2M;\$200–\$500)
	CHAR-3-OL	Secondary ion mass spectroscopy	H-5-0 (\$0M;\$400)
	CHAR-9-OL	Ultraviolet/visible spectroscopy	H-5-0 (<\$.1M;\$50–\$200)

Table 3.1 (continued)

Alternative	Data sheet code numbers	Technology	Ranking ^a
Detection/measurement —laboratory methods (continued)	CHAR-4-OL	Laser ionization mass spectrometry	M-5-0 (\$0M;\$300-\$500)
Data analysis/ management	DISM-151-OL	Project information access services	E-5-1 (\$.5M;\$100Kam)
	DISM-152-OL	Network architecture with integrated workstations	E-5-1 (\$5M;\$60Kam)
	DISM-153-OL	Client/server access to standards and regulatory guidelines	E-5-0.5 (\$.25M;\$25Kam)
	DISM-154-OL	Data access services	E-5-1 (\$.5M;\$200Kam)
	DISM-181-OL	Geographic information system for DOE sites	E-5-1 (\$1M;\$200Kam)
	DISM-155-OL	Automated scanning and conversion of engineering drawings	E-5-2 (\$2M;\$300Kam)
	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)
	DISM-171-OL	Simulated walk-through facility for robotics task sequence analysis	E-5-1 (\$.3M;\$60Kam)
	DISM-191-OL	Computer-based training systems	E-5-1 (\$.3M;\$100Kam)
	DISM-172-OL	Computer-aided task analysis and procedure preparation	E-5-1 (\$.5M;\$150Kam)
	DISM-157-OL	Client/server/architecture for data base access	E-5-1 (\$.5M;\$200Kam)
	DISM-158-OL	Hypertext information systems	E-5-1 (\$.3M;\$150Kam)
	CHAR-253-OL	Spatial sample and data analysis plans	H-3-.5 (\$.1M;\$.5Kam)
	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	E-5-1 (\$.5M;\$80Kam)

Table 3.1 (continued)

Alternative	Data sheet code numbers	Technology	Ranking ^a
Data analysis/ management	CHAR-222-OL	Multisensor fusion measurement systems	H-3-1 (\$.5M;\$.25/ measurement)
	CHAR-223-OL	Detection and measurement systems with feature extraction	M-4-2 (\$1M;\$1/image scanned)
	CHAR-225-OL	Fractals used to select models for material transport in porous media	M-2-2 (\$.5M;\$20Kam)
	CHAR-229-OL	Configuration management system	E-5-1 (\$.5M;\$50Kam)
	CHAR-242-OL	Stored material neural net identification system	E-5-2 (\$1M;\$100/ container analyzed)
	CHAR-45-OL	Subsurface complexation model	
	CHAR-255-OL	Dynamic modeling of material transport	H-5-2 (\$.3M;\$10Kam)
	DISM-159-OL	Electronic catalog descriptions and source locations of site historical data	E-5-2 (\$2M;\$150Kam)
Radioactive elements—field methods	CHAR-108-OL	Proportional counter for alpha and beta activity	H-5-0 (\$.1M;\$100)
	CHAR-102-OL	Passive monitors for weak beta radionuclides	M-4-2 (\$.6M;\$20)
	CHAR-103-OL	Thermoluminescence dosimeter array for spatial characterization of alpha contamination	M-4-3 (\$.6M;\$20)
	CHAR-65-OL	Long-range alpha detector	M-4-1 (\$.4M;\$100)
	CHAR-216-OL	Bubble dosimeters for neutron flux	M-4-1 (\$.2M;\$15)
	CHAR-269-OL	Advanced radiation monitors	M-4-2 (\$.4M;\$50)
	CHAR-95-OL	Electret passive surface alpha monitor	H-4-1 (\$.3M;\$15)
	CHAR-96-OL	Alpha track etch detectors for surface alpha contamination	H-4-1 (\$.4M;\$10)
	CHAR-263-OL	Portable gamma-ray scintillometers	H-4-0 (\$0M;\$100)

Table 3.1 (continued)

Alternative	Data sheet code numbers	Technology	Ranking ^a
Radioactive elements—laboratory methods	CHAR-107-OL	Neutron activation	H-4-1 (\$.2M;\$300)
	CHAR-106-OL	Sodium iodine-germanium gamma spectroscopy	H-4-0 (\$0M;N)
	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)
	CHAR-266-OL	Neutron activation analysis	H-4-1 (\$.2M;\$300)
	CHAR-268-OL	Gamma-ray spectrometry	H-5-0 (\$.1M;\$100)
	CHAR-267-OL	Liquid scintillation counting	H-5-0 (\$.1M;\$100)
Inorganics—field methods	CHAR-76-OL	Atomic emission spectroscopy	M-5-1 (\$.2M;\$N)
	CHAR-6-OL and CHAR-219-OL	Portable X-ray fluorescence	H-5-1 (\$.2M;\$25)
Inorganics—laboratory methods	CHAR-78-OL	Inductively coupled plasma—mass spectroscopy	H-4-2 (\$1M;\$200)
	CHAR-77-OL	Inductively coupled plasma spectroscopy	H-4-0 (\$1M;\$200)
	CHAR-76-OL	Atomic emission spectroscopy	H-4-0 (\$1M;\$200)
	CHAR-50-OL	Ion chromatography	H-4-0 (\$.1M;\$100)
	CHAR-37-OL	Electron diffraction	M-4-0 (\$0M;\$100)
	CHAR-36-OL	Wavelength dispersive X-ray spectroscopy	M-4-0 (\$0M;\$100)
	CHAR-35-OL	Energy dispersive X-ray spectroscopy	M-4-0 (\$0M;\$100)
	CHAR-34-OL	Transmission electron microscopy	M-4-0 (\$0M;\$100)
	CHAR-33-OL	Scanning electron microscopy	M-4-0 (\$0M;\$100)
	CHAR-17-OL	Particle-induced X-ray emission	M-4-0 (\$0M;\$100)
	CHAR-56-OL	Glow discharge ionization mass spectroscopy	H-4-1 (\$.5M;N)

Table 3.1 (continued)

Alternative	Data sheet code numbers	Technology	Ranking ^a
Inorganics— laboratory methods (continued)	CHAR-24-OL	Cold vapor (mercury) analysis	H-4-0 (\$0M;\$100)
	CHAR-266-OL	Neutron activation analysis	H-4-1 (\$.2M;\$200)
	CHAR-31-OL	Powder X-ray diffraction	M-4-0 (\$0M;>\$100)
	CHAR-1-OL	Electron spectroscopy for chemical analysis	M-4-0 (\$0M;\$200-\$600)
	CHAR-2-OL	Auger electron spectroscopy	M-4-0 (\$0M;\$300-\$800)
Organics— field methods	CHAR-100-OL	Portable gas chromatograph/electron capture detection for analyzing PCBs ^d	H-4-0 (\$.25M;\$50)
	CHAR-5-OL	Portable volatile organic compound detectors	H-5-0 (\$.25M;\$10)
	CHAR-90-OL	Direct sampling ion trap mass spectrometry	H-5-2 (\$.2M;\$50)
	CHAR-101-OL	Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	M-4-1 (\$.2M;<\$50)
	CHAR-262-OL	Gas chromatography in the field	H-5-0 (\$.25M;\$50)
Organics— laboratory methods	CHAR-206-OL	Analytical methods for chelators and decontamination agents	H-5-1 (\$.25M;\$500-\$1000)
	CHAR-207-OL	Capillary zone electrophoresis	M-5-1 (\$.25M;\$300)
	CHAR-115-OL	On-line supercritical fluid extraction—multidetector gas chromatography	H-5-1 (\$.25M;\$300)
	CHAR-66-OL	Gas chromatography-Fourier transform infrared spectroscopy	H-5-2 (\$.5M;\$400)
	CHAR-89-OL	Liquid chromatography—mass spectrometry	H-5-1 (\$.34M;\$500)
	CHAR-88-OL	Gas chromatography—mass spectrometry	E-5-0 (\$0M;\$200-\$800)
	CHAR-101-OL	Synchronous fluorescence screening for polycyclic aromatic hydrocarbons	M-5-1 (\$.2M;\$10)
	CHAR-94-OL	Gas chromatography	E-5-0 M;\$0M;\$300)

Table 3.1 (continued)

Alternative	Data sheet code numbers	Technology	Ranking ^a
Organics— laboratory methods (continued)	CHAR-211-OL	Solid phase microextraction analysis method	H-5-1 (\$.3M;\$500)
	CHAR-258-OL	In situ ground-water flow meter	H-5-0 (\$.4M;\$1-3K)
	CHAR-259-OL	Ground-water discharge location	H-5-0 (\$0M;\$50K)
Physical— laboratory methods	CHAR-26-OL	Particle size analysis	M-5-0 (\$0M;\$1000)
	CHAR-32-OL	Optical microscopy	H-5-0 (\$0M;\$100-\$800)
Pathogens— laboratory method	CHAR-215-OL	Pathogen surveillance	E-5-1 (\$.25M;\$50-\$250)
Buried waste remedial action problem only			
Sample collection and field methods	CHAR-273-OL	SEAMIST inverted membrane	H-5-1 (\$.6M;\$15K)
	CHAR-25-OL	Fiber-optic chemical sensors	H-5-1 (\$1M;\$3.3M)
Hydrofracture remedial action problem only			
Sample collection and field methods	CHAR-274-OL	Hydrofracture ground-water monitoring	H-1-2 (\$.5M;\$3.3M)

^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 energy dispersive X ray 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 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 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 UV spectroscopy
		CH101101	H	Mobile ICP atomic emission spectroscopy
		AL213204	M	Robotics to include AES
		AL221108	M	Uses AES for chromium
		CH114101	M	Center for Advanced Technical Development and Toxicology Information Program: 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 Spect
Infrared spectroscopy	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
		AL123101	H	EPA SW-846 for mixed waste
Ultrasonic extraction	CHAR-20-OL	RF121204	L	Ultrasonic cleaning at Rocky Flats Plant

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	IR fiber-optic spectrophotometer
		Many more		Widely pursued technology
Optical absorption spectroscopy	CHAR-27-OL	OR101101	M	Fiber-optic version
		SF211203	H	Fiber-optic differential abs spectrometer
Scanning electron microscopy	CHAR-33-OL	OR121115	M	One example of widely used technology
		Many More		
Transmission electron microscopy	CHAR-34-OL	OR121115	M	Example. Mature tech. 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	Uranium 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	Electromag. tomography (esp 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	NA	Much work directed at soil
Membranes for sample collection and concentration	CHAR-55-OL	OR111204	M	High-efficiency particulate air 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 Savannah River Integrated Demonstration (SRID)
		AL221123	M	Underground imaging (resistance)
		CH221101	M	Seismic wave measurement of clay at Savannah River (SR)
		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 methods	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
ICP spectroscopy	CHAR-77-OL	CH101101	H	Mobile ICP-AES development
		Many		Widely used technology
ICP—mass spectroscopy	CHAR-78-OL	OR111105	M	Direct sampling ion-trap mass spectrometer
		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
		RL401206	M	Use raman sensing in hot cell
		SF211203	H	Development raman sensor for RL401206
IR 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	NA	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 halogenated organic compounds (HOCs)
		SR132002	H	Used on cesium extraction project
Direct sampling ion-trap mass spectrometry	CHAR-90-OL	OR101102	H	Development
		OR101103	H	Development and application
		OR101105	H	Use with army toxic materials
		OR121103	H	Use at SRID Project
		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 non-Arid
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; ICP; AES	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 fractures	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 SR
		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	Environmental management (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 rad. 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
XRF 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
Fiber-optic systems for measuring multiple physical variables	CHAR-248-OL	SF213203	H	Microsensor systems development

Table 3.2 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Quality control for measurement processes	CHAR-250-OL	CH013101	H	Analytical management-quality assessment program (Environmental Measurements Laboratory)
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	CHAR-256-OL	Many	H	Widely found
In situ ground-water flow meter	CHAR-258-OL	OR121104	H	Colloidal bore scope
Ground-water discharge location	CHAR-259-OL	Many	H	Accepted and widely used
Waste drum gamma activity monitor	CHAR-261-OL	SF223203	H	Waste facilities operation & sorting technology
		SR113201	H	SR robotics, waste facilities operations
Gas chromatography in the field	CHAR-262-OL	ALTTPMSA	M	Mobile sample analysis laboratory
Portable gamma-ray scintillometers	CHAR-263-OL	AL112101	L	Field screening studies
		SF223203	M	Used in waste facilities operations
Surface-enhanced Raman scattering	CHAR-265-OL	OR121101	H	Spectroelectrochemical sensors
		SF211203	M	Adv. fiber-optic spectroscopy for inorganic contaminants
Neutron activation analysis	CHAR-266-OL	AL131004	M	Multispectral neutron logging
		AL931001	H	Multispectral neutron logging
Liquid scintillation counting	CHAR-267-OL	AL931102	L	Chemical barriers demonstration
		ORNL-DOSAR Facility	H	Uranium 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	M	Real time emission monitor
		ID111701	M	Fiber-optic thermoluminescence dosimeter monitor development
		ID121210	M	BWID contamination control
Sampling of heterogeneous wastes	CHAR-270-OL	AL123101	M	Adapted SW-846 methods for mixed waste analysis

Table 3.2 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
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
Isotope dilution ICP mass spectrometry	CHAR-275-OL	CH101103	M	ICP/mass spectrometry dev.
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.

4. Remedial Action

4. REMEDIAL ACTION

4.1 INTRODUCTION

In Chap. 1, environmental contamination at ORNL was grouped according to source and media into the following site problem areas:

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

A technical team was organized to assess the RA needs and technologies for each problem area. Each team conducted an initial workshop with multiorganizational and multidisciplinary experts to define the problem area and identify candidate remedial technologies. Each team focused on defining the status, science and technology needs, and implementation needs of the identified technologies. Each team then gave rankings for development of the identified technologies (see Chap. 2 explanation). The approach taken by most teams was to identify technologies for the RA subelements: containment and isolation, in situ treatment, retrieval, and ex situ treatment. Technical teams coordinated activities and cross-referenced data sheets (Vol. 2). In several instances it was necessary to prepare more than one data sheet for an individual technology due to differences in the status of development and needs associated with individual problem areas (e.g., ISV).

This chapter is organized into sections discussing the technologies considered, science and technology needs, implementation needs, and technology rankings. Each section is in turn subdivided into the individual site problem areas.

4.2 DESCRIPTION OF TECHNOLOGIES CONSIDERED

4.2.1 Introduction

Technologies considered in each area are described and listed below. In all, this included more than 120 technologies, but even this is not a complete list. The list is the result of a selection by the experts who work in each area. The list includes technologies for interim, as well as permanent solutions, to the problem in each area. Some technologies may play an important role but may not be able to solve entire problems by themselves. For instance, some technologies can remove or destroy only one contaminant, and other technologies are only useful for retrieval of contaminated soil, wastes, etc. New technologies are likely to be conceived and developed in the future that are not covered.

4.2.2 Buried Wastes

Systematic evaluation of alternatives for buried waste sites resulted in three systems approaches: in situ hydrologic isolation or containment, in situ treatment, and retrieval followed by treatment. Each of the three systems entails a series of interrelated activities (see Fig. 4.1), each of which is essential for the success of the system. The in situ isolation/containment system includes definition of the design basis, which encompasses the design life, health/safety standards, structural criteria, environmental parameters, waste-form requirements, and cost limitations; site characterization; structural stabilization; actual isolation technologies; monitoring; and support activities (transportation, health & safety, decontamination of equipment, etc.). The in situ treatment system includes definition of the design basis; characterization of waste and site, and treatment technologies; verification of treatment effectiveness; site closure and monitoring; and support activities. The retrieval system includes definition of the design basis; waste and site characterization; retrieval; staging/storage; segregation/sorting/packaging; treatment/recycle/recovery/decontamination; disposal or recycle of residue; and support activities. Since other sections of the TLD examine technology development and support needs for characterization and monitoring, waste storage, site closure, and disposition of treatment residues, this section focuses on technology needs to support structural stabilization, containment and isolation, in situ treatment, retrieval, segregation/sorting/repackaging, and ex situ treatment.

Specific technologies that were evaluated for application to ORNL's buried waste problems are listed, along with their ranking, in Table 4.1 of Sect. 4.5. Data sheets for these technologies are available in Vol. 3, Pt. B.

Many of the technologies applicable to buried waste (e.g., barrier technologies) were also considered for remediation of contaminated solid and sediments and impoundments. In addition, many decontamination techniques (e.g., CO₂ blasting) could potentially be applied to retrieved waste.

Fig. 4.1. Potential buried waste remediation systems.

4.2.3 Low-Level Waste Tanks

Remedial alternatives considered for the inactive low-level waste tanks include removal of the tank contents, in situ treatment via fixation or sorption, removal of the tank shells, hydrogeologic containment or isolation of the tanks, and treatment of the tank contents via chemical methods. Data sheets are available for the technologies that accomplish the first two alternatives. Technologies supporting the last three alternatives are covered in other core groups and are discussed in more detail below.

- *Removal of the tank contents (liquid alone, or both liquid and sludge)*—Specific technologies included in this alternative are mechanical excavation, pneumatic removal, and hydraulic removal (sluicing/slurry pumping). The use of cryogenics to freeze and thereby facilitate removal of the contents has been suggested; however, this technology was not pursued further because of concern over potential for cracking or breaching the tank shells.
- *In situ treatment of tank contents*—Specific fixation technologies include cement grouting, silicate-based stabilization, vitrification, chemical grouting, and thermoplastic encapsulation; in situ sorption was also discussed as a physical separation treatment.
- *Removal of the tank shells (Gunitite and steel)*—Specific technologies are discussed by the dismantlement team in Vol. 1, Pt. A, Chap. 4.
- *Hydrogeologic containment or isolation of the tanks using walls or barriers or combinations of capping and drains*—Examples of wall or barrier technologies are grout curtains, slurry walls, sheet-pile walls, and cryogenic barriers. Examples of capping are intruder barriers and multilayer caps, and examples of drains are french drains and horizontal wells. Specific technologies are discussed in Sect. 4.2.2.
- *Treatment via chemical methods*—Examples of chemical treatments are dissolution, neutralization, and radiochemical separation and recovery. Specific ex situ chemical treatment technologies are discussed in Vol. 1, Pt. C, and Vol. 3, Pt. C. Potential in situ chemical treatments have not been identified nor referenced.

For many of these alternatives, access to the inside of the tanks with special equipment will be necessary. However, due to the radiation hazard inside the tanks, the remediation equipment that enters the tanks must be operated remotely. The robotics and automation (see Chap. 5) addresses the different types of equipment that can be used remotely in hazardous environments.

4.2.4 Pits and Trenches

Remedial alternatives considered for the pits and trenches include containment, in situ treatment, retrieval, ex situ treatment, and disposal. Data sheets are available for the following technologies: capping/barrier overview—containment; ISV, grouting, and extraction—in situ treatment; remote excavation—retrieval.

Ex situ treatment and disposal technologies are available in other RA problem areas and the WM Volumes. Additional containment technologies (such as cryogenic barriers and slurry walls) and in situ technologies (such as freezing and heating) are available in other RA problem areas.

4.2.5 Soils and Sediments

Technologies considered for the management of ORNL contaminated soils and sediments are broadly divided into containment and isolation and treatment processes. Because the contamination of soils and sediments at ORNL often includes a variety of contaminants (organic compounds, toxic metals, and an almost unlimited list of radionuclides), the application of both types of processes to many of the soils may be required. For example, the prevailing ORNL management strategy for contaminated soils is containment in low-level radioactive waste burial grounds. One alternative would be treatment to achieve volume reduction, which would lower containment costs. The selection of a technology for the management of contaminated soils and sediments is highly dependent on the type of contaminant(s), its distribution in the soils and sediments (both in terms of depth within the profile and distribution among particle-size fractions), and its chemical form. Knowledge of these properties requires extensive characterization. Because of the lack of characterization data and the potential presence of a wide variety of contaminants in many of the soils and sediments of ORNL, the descriptions of treatment technologies are also varied.

Contaminated soils and sediments must be managed at ORNL because of one of two actions: (1) soils and sediments accumulated from construction, facilities already in need of remediation (e.g., leaking pipelines, impoundments, waste area), or of other activities, and (2) soil and sediment remediation projects already specified. In the near term, most of the needs for the development, demonstration, and implementation of the required technologies will center on the soil and sediments generated from actions other than soils and sediments remediation *per se*. For example, remediation of underground storage tanks, leaking pipelines, and waste lagoons commands higher priority than soils and sediments. These facilities are generally the source term of soil contamination. The careless selection of technologies to remediate these facilities could generate large volumes of soils and sediments requiring remediation. From this stand point, an important soil remediation technology is one that does not generate contaminated soil and sediment.

In the near term, soil remediation needs at ORNL will be directly associated with remediation of pipelines and waste tanks (most of which contain radioactive wastes). From this standpoint, the major objective is volume reduction of soils and sediments to lower the need for containment in a burial ground. In the long term, specific areas may require remediation, such as sediments of White Oak Lake, residual soils resulting from the excavation of waste lagoons or waste burial grounds, and surface soils, where spills of hazardous/radioactive wastes have contaminated soils. The technologies required to address near- and long-term needs in soil and sediment remediation are often similar; however, their priorities in implementation differ due to their degrees of maturity and confidence in expected deliverables. Because near-term needs are related primarily to contaminated soils resulting from remediation of pipelines and waste tanks, the emphasis was placed on the description of technologies involving *ex situ* treatment over containment. In the case of long-term needs, the emphasis on *in situ* treatment and containment technologies generally prevailed.

The following technologies were evaluated:

Treatment

- *Soil washing/extraction*—Soil washing/extraction is a broad term that involves size segregation of soil fractions using water as solvent to selectively extract specific contaminants (organic compounds, metals, and/or radionuclides) and using a variety of chemical leaching media. The major objective is volume reduction, when water is used, and the transfer of contaminants from the soil phase to a liquid phase, when specifically designed extraction media are used.
- *Thermal desorption*—For soils containing VOCs, ex situ vapor-extraction techniques or thermal desorption processes could be readily applied. These technologies would be beneficial in the removal of RCRA volatile compounds from mixed wastes prior to containment in a burial ground.
- *Stabilization/fixation by grouting*—The primary purpose in the grouting of soils is to stabilize and reduce the mobility of contaminants in soil scheduled for disposal in landfills. The major detriment of grouting soils for disposal is the added volume. For most soils, grouting would be conducted using particulate-based grouting materials in commercially available mixers and blenders. Portland cements, because of their low cost, would be the predominant cementing agent. In certain instances, additives would be used for sorption or complexation of specific contaminants, depending on the mobility characteristics of the contaminant. In special cases, chemical-based grouting materials might be preferred because they do not add substantially to the volume of soil to be disposed of. However, their higher costs will generally preclude widespread use unless some low-cost chemical grouting materials are developed.
- *Soil-Vapor Extraction*—For soils containing VOCs, in situ soil-vapor extraction, thermally enhanced soil-vapor extraction, and soil-vapor extraction with radio frequency (RF) heating were evaluated. The latter two technologies are enhancements of soil-vapor extraction.
- *High-Temperature Destruction*—Several technologies (including incineration, molten glass combustor, chem char process, plasma arc furnace, and cement kiln incineration) were considered for destruction of organic compounds in soil and sediments.
- *Chemical Separation*—Solvent extraction, chemical oxidation/reduction and electrokinetics were considered for removal of organics, metals, and radionuclides from soils and sediments.
- *In Situ Vitrification*—Encapsulation of metals and radionuclides in a durable glass and crystalline product by extreme heat.
- *Biotreatment*—This technology includes a wide range of biological processing options that rely on microbial transformation of organic compounds to remediate soils and sediments.

Retrieval

- *Entombed Clamshell*—Modified clamshell bucket used to dredge contaminated sediments.

Containment

- *Capping/barrier installation*—This technology involves the placement of a hydraulic barrier over and around contaminated soil. Materials used in this technology vary from flexible membrane liners to clay grouts. The major objective is to stop infiltrating rainwater and ground water and inhibit the intrusion of plant roots and burrowing animals.

4.2.6 Buried Pipelines

Buried pipes exist throughout the ORNL area, many in the main laboratory area. Some of these pipes have carried radioactive wastes to underground storage tanks or to treatment facilities in the past. Many of the pipes have deteriorated, and most are no longer in use. Most pipes are relatively near the surface, and the levels of radioactivity and other hazards do not appear excessively hazardous. Only two technologies were considered for treating the pipes themselves—excavation and fixation (probably with cement-based grout). Where the pipes have leaked considerably, there may be significant amounts of contaminated soil around pipes. Although such contamination may have to be removed or contained, treatment of contaminated soils around piping will be covered by soils and sediments core groups.

4.2.7 Impoundments

Impoundments are areas where contaminated waters have been discharged into ponds or diked areas that prevent run-off. The soil in impoundments often can be treated with technologies discussed in Sect. 4.2.5, Soils and Sediments, but the localized concentration in impoundments requires special technologies. These special technologies, not the more general soil treatment technologies, are discussed below.

Containment and Isolation

- *Capping*—This technology involves the placement of a hydraulic barrier over and around the contaminated impoundment.
- *Drains*—French drains, biopolymer drains, and horizontal wells aid in hydraulic isolation of the impoundments.
- *Walls/Barriers*—Grout Curtains, slurry walls, sheet pile walls, clay bentonite additives and cryogenic barriers were considered for hydraulic isolation of the impoundments.

Treatment

- *Physical Separation*—Soil washing and in situ soil flushing were considered for removal of metals and radionuclides from impoundments. Sludge drying was also considered for removal of water from impoundment sediments as a pretreatment for storage/disposal.
- *Fixation*—In situ fixation using silicates, cements or polymers and ISV were considered for immobilizing contaminants in impoundment sediments.

Retrieval

- *Excavation*—Mechanical excavation, vacuum loading, and dredging to retrieve contaminated impoundment sediments were considered.

Note that some technologies (sludge drying and soil washing) are *ex situ* treatment technologies that require mechanical excavation or vacuum loaders (technologies listed for waste retrieval), prior to processing. Similarly, cryogenic barriers are an *in situ* treatment that retain the contamination temporarily (perhaps for relatively long times) until radioactivity has decayed or until permanent treatment plans are complete.

Several technologies aim to restrict the entry of water into the impoundment area. These include slurry walls, sheet-pile walls, grout curtains, french drains, capping, and biopolymer drains. These may be considered permanent or temporary solutions, depending upon the lifetime of the retention and the lifetime of the contaminant. These technologies can also be useful for preventing pollutant migration while the contaminated region is being treated.

Other impoundment technologies are *in situ* treatment for permanent solutions to the problems. These technologies may be of more interest for impoundments than for most soil contamination because impoundments are more likely to contain high local concentrations of contaminants that can be immobilized by solidification of relatively small volumes of soil.

4.2.8 Hydrofracture

Due to the depths and lateral extent of the injected wastes, only containment alternatives were considered for remediation of the hydrofracture problem area. Plugging and abandonment was considered for the well bores. Three containment technologies—water proofing cave with hydraulic cage, deep rock drainage curtain, and chemical grout—were considered for the grout sheets. A brief description of each technology follows.

- *Plug and abandon*—Conventional plugging of well bores using drilling rigs to place concrete plugs above and below injection zones in the well bore.
- *Water proofing cave with hydraulic cage*—Deep-rock hydraulic curtain at the periphery of the contamination zone. The contaminated zone is surrounded by a series of interconnected wells that equalize the pressure in the rock mass, thereby reducing any seepage to less than 1% of the original flow through the rock mass.
- *Deep rock drainage curtain*—A circular array of vertical drill holes serve as a drainage gallery for any mobile wastes in the contaminated zone.
- *Chemical grouting*—Polymer is injected to fill in any cracks or fissures in the host rock at the edge of the contaminated zone.

4.2.9 Ground Water and Surface Water

Processes for removal of contaminants from ground water and surface waters can be carried out in either of two general methods: *in situ* or aboveground. Some of the technologies considered have been practiced widely in the chemical process industries and can be designed with confidence for aboveground application. When such technologies (e.g., ion exchange) are considered for *in situ* application, uncertainties arise concerning the control of flow distribution and rate and monitoring concentrations and

associating them with flow rates so that mass balances are closed properly. No experience is available to indicate efficiencies that may be expected when such materials must be replaced.

For radionuclides and heavy metals, the technologies evaluated were adsorption, ion exchange, precipitation, and artificial wetlands. For hydrocarbons, VOCs, and PCBs, the technologies evaluated were adsorption, biological oxidation, chemical oxidation, artificial wetlands, and air and steam stripping. For nitrates, the technologies evaluated were biological denitrification and artificial wetlands.

Adsorption requires that the water be contacted intimately with a solid sorbent, such as activated carbon, so that the containment distributes preferentially onto the solid phase. Usually such contacting is done in a tower filled with the sorbent (in the form of small pellets), providing a large surface area for mass transfer. Sorbents have been prepared from immobilized algae, which are said to be highly specific for certain contaminants. After the sorbent bed is fully loaded (exhausted), it may or may not be regenerated for reuse depending on process economics. Ion-exchange operations are quite similar to adsorption except that the contaminant must be an ionized species that replaces another ion carried by the fresh exchanger in the solid phase.

Precipitation of heavy metals and radionuclides can be enhanced by various reagents, iron hydroxide and aluminum hydroxide being the most common. Precipitation is carried out in the ORNL Process Waste Treatment Plant and is an accepted technology. Artificial wetlands have been used for treating domestic sewage and coal mine runoff. Therefore, this technology has the potential to destroy organics and immobilize heavy metals. Application to ORNL ground water and surface waters would require development work.

Biological oxidation is used routinely to degrade water-soluble organics, as in the ORNL Storage Treatment Plant. More refractory contaminants, such as chlorinated solvents, may require specially designed treatment systems. Laboratory-scale tests have shown that higher-chlorinated PCBs can be dechlorinated anaerobically, and that lower-chlorinated PCBs can be dechlorinated aerobically. Chemical oxidation of organic contaminants has been demonstrated with potassium permanganate, ozone, and hydrogen peroxide.

For VOCs in water, air stripping has been promulgated a "best available technology." The operation is usually done by passing the water down a packed-column countercurrent to a rising air stream. The effluent air carrying organics may require treatment. The use of steam rather than air is a well-established industrial technology. The advantage of steam is that it can be condensed, which eliminates the problem of treating the effluent gas.

4.3 SCIENCE AND TECHNOLOGY NEEDS

4.3.1 Introduction

This section highlights some of the R&D needed to make the technologies available for RA at ORNL. For accepted technologies and even for some demonstrated technologies, there may be no science and technology needs. However, the soils and other conditions at Oak Ridge are unusually complex, and some testing, perhaps only treatability studies, may be needed, even for technologies that have been in common use elsewhere.

4.3.2 Buried Wastes

The majority of the structural stabilization technologies have been demonstrated and are available. Science and technology needs include testing to determine material compatibility for structural caps and solidification. Other needs include field tests with full-scale dynamic compaction equipment.

Needs for isolation/containment technologies include methods to minimize waste generation during application, guidance systems for grout injection/tunnelling, and development of waste-resistant materials for capping.

The applicability of thermal destruction technologies for buried wastes and the characteristics of the treated residue need to be determined. Methods for treating off-gas from thermal destruction are also needed.

Science and technology needs for fixation technologies include development of new chemical mixtures and application/injection equipment. This is especially critical to ensure and verify that containers are ruptured and grout/polymer has mixed with contents for in situ technologies. The development of compaction methods is needed to prevent flashing/overpressurization of waste during ISV.

Testing is needed to estimate the effectiveness and identify additives for freeze purification and thermal desorption. Soil simulation methods to promote conductivity for fractured air stripping are needed.

Methods are needed to safely and effectively segregate buried waste during and after retrieval. The development of remotely controlled/robotic retrieval technologies needs to be continued.

4.3.3 Low-Level Waste Tanks

With regard to tank contents removal (particularly sludge removal), the principal science and technology needs are the development of retrieval and transport devices or systems. Retrieval equipment must be capable of removing hard salt cake, sludges of varying consistencies, tank hardware, and foreign objects. Conveyance systems must be capable of handling dislodged or mobilized wastes and tank hardware, and, in some cases, it must be capable of transporting the slurry over long distances with negligible solids separation or in-line clogging. Special emphasis is being placed in the Integrated Demonstration projects of DOE's Office of Technology Development on robotics-integrated retrieval equipment (e.g., articulated and remotely operated mechanical arms). Because the equipment must be versatile, this work is technically difficult. If scheduled implementation time is short, large expenditures in terms of dollars and manpower will be needed for development.

Another principal science and technology need is for a detailed characterization of the waste matrix that will determine the suitability of the solidifying agent for specific tanks. This is a necessary first step in development of in situ fixation methods. Better understanding of immobilization mechanisms and the chemistry of these solidified waste forms can lead to improved performance and better predictions about their durability. It is important also to note that high confidence in the long-term effectiveness of these fixation techniques is not universal. More careful demonstrations and operations are needed to create a higher level of confidence in the long-term performance of the fixation techniques. Long-term assessments of the ability of the fixation technologies to retain and contain the contamination would be useful. The assessments would address, for example, whether the cement grout and silicate-based formulations maintain the pH necessary to prevent migration and whether the polymer grout and thermoplastic formulations retain their stability in high-radiation environments.

One of the most promising in situ fixation methods is vitrification. ISV needs two significant technology developments to make it acceptable for ORNL underground storage tanks. The problem of off-gas pressurization and splattering during ISV of underground tanks seems to be caused by the absence of lateral and subsurface porosity when the tank is sealed on top by molten material of high temperature. As an ISV melt proceeds, molten glass can pressurize confined gas or liquids within the underground tank resulting in the rapid burping of off-gas and associated splattering. This problem could be largely overcome by in situ compaction of the tank prior to ISV or by filling the tank space with earthen material (or other contaminated soil or waste) that would be incorporated into the final product. Specific tank contaminants and materials would need to be tested for compatibility with such earthen materials during vitrification.

4.3.4 Pits and Trenches

For long-term containment of pits and trenches, radionuclide source-term identification and long-term performance testing of materials and construction methods are needed.

A principal science and technology need for in situ grouting is the development of delivery, mixing, and dispersion systems. Grout-waste compatibility, as well as long-term performance modeling under field weathering, would also need to be determined.

In situ extraction requires the development of fluid extractants that could mobilize the radionuclides of concern. Technology for injection, disposal, and recovery of extractants in the pits and trenches would also be needed.

In situ vitrification is the most promising technology for the pits and trenches. The most significant technology need is the modification of off-gas handling techniques to deal with volatilization of cesium during vitrification.

4.3.5 Soils and Sediments

One of the most important science and technology needs is an accurate and complete characterization of the contaminated soils and sediments. It is a gamble selecting the most appropriate remediation technology if properties of the contaminant and the soils and sediments are unknown. In many instances, the distribution and chemical form of the contaminant within particle-size fractions of the soils and sediments is important in determining the success or failure of a specific technology.

Near-term science and technology needs at ORNL should be directed at determining how to reduce the volume of contaminated soils being disposed of in ORNL's low-level

radioactive waste burial grounds. Bench-scale studies should be initiated to investigate the potential advantages of volume reduction methods such as size classification and soil washing/extraction, using soils presently on hand and stored at SWSA 5 but designated for burial in SWSA 6. Other near-term science and technology needs include investigations relating to how much more efficiently vapor extraction of VOCs from ORNL impermeable soils can be conducted. The effectiveness of chemical oxidation processes to destroy organic contaminants in these same high-silty and -clayey soils also needs to be investigated.

Long-term science and technology needs at ORNL involve the identification and testing of methods to remediate large volumes of soil that contain relatively low levels of radionuclides and/or other hazardous contaminants. These include sediments contained in White Oak Lake and adjacent to many of the waste lagoons at ORNL and the contaminated soils along waste lines and in the low-level burial grounds. The first need is to thoroughly characterize these soils and sediments and evaluate the potential environmental and health risk associated with a "no remediation action" scenario. If an unacceptable risk is involved, bench-scale studies should be aggressively pursued. However, because of the time involved in making a risk analysis and in obtaining a regulatory approval of "no remediation action," it may be beneficial to start up (on a limited scale) some bench-scale testing of the more promising technologies.

4.3.6 Buried Pipelines

Both of the previously described technologies considered for treated buried piping are considered accepted, and there are not believed to be significant science and technology development needs. Only in the unexpected event that radioactivity or toxic hazard is sufficient to prevent direct participation of personnel with protective clothing would robotic or other new equipment be required.

4.3.7 Impoundments

All of these technologies are accepted or have been demonstrated on somewhat similar sites. Usually the most important science and technology need is a sufficient understanding of the soil properties in the impoundment. In situ vitrification, in particular, needs an understanding of the behavior of all components during high-temperature treatment, such as volatilization, decomposition of organic compounds, and leachability of contaminants from the product glass. Although there is more experience with fixation of contaminants with cement-based grouts, this technology also needs treatability testing to confirm that all contaminants of interest are adequately contained within the grout.

Most of the in situ technologies, including the different types of barrier construction, have been used or demonstrated in soils that are far less complex than those in the Oak Ridge area. For instance, the complex flow patterns in the highly fractured soils at Oak Ridge make placement of barriers more complicated than in simpler and more nearly homogeneous sandy soils.

4.3.8 Hydrofracture

The circulating fluid used for conventional well plugging and abandonment could become contaminated and pose a potential health risk to workers during plugging and abandonment. Technology to develop remotely controlled equipment is needed to minimize worker health risk.

The geologic and hydrologic characteristics of the rock formations need to be characterized for both the deep rock drainage curtain and water proofing cave with hydraulic cage technologies. Modeling is also needed to evaluate the sensitivity of waste movement to pore pressures. Because deep-drilling costs are a key to the economic viability of these technologies, cost-effective drilling techniques are needed.

The impact of radioisotopes and saline ground water on the long-term properties of cured polymers is needed to evaluate the feasibility of chemical grouting of the hydrofracture grout sheets.

4.3.9 Ground Water and Surface Water

Chemical process operations are normally fine-tuned to operate at optimal conditions on the feed stream. A primary consideration concerning ground water and surface water treatment is the variation in flow rates and contaminant concentrations that may be encountered. These variations are presently unknown, and determining them is a key factor in minimizing treatment costs. For aboveground treatment, consideration should be given to accumulating a feed reservoir to average out fluctuations in flow rates and concentrations.

For in situ technologies, the extent of the contaminated ground water and its variation with climatological conditions must be identified, and this flow must be directed through the treatment zone. Subsurface structures to control ground-water flow must be demonstrated and costs established. Instrumentation for monitoring flow rates and contaminant levels for in situ applications is needed.

4.4 IMPLEMENTATION NEEDS

4.4.1 Introduction

This section highlights some of the problems that must be overcome to use the technologies at ORNL. These could include establishment of treatment limits and regulatory acceptance of the final treatment product. Some technologies do not solve the problems completely but are important single steps in the solution. In these cases, it will be necessary to have the other technologies available to complete the job. One particular group of technologies does not provide permanent solutions to the problems but provides containment of the pollutant, sometimes for long periods. Use of such technologies requires regulatory acceptance of delayed permanent treatment and development (perhaps future development) of permanent treatment technologies.

4.4.2 Buried Wastes

Dynamic compaction and surcharging need to be demonstrated for the soil and hydraulic conditions at ORNL prior to implementation. Field tests are needed to determine the long-term effectiveness of different materials for use as barrier walls or in fixation applications. Cold-test facilities are needed to check guidance systems for grout delivery prior to implementation.

Significant permitting and trial burn efforts are needed to establish the effectiveness of thermal destruction technologies and to obtain regulatory approval for implementation. Safety, product-quality, and field-process operations all need to be established.

Field testing of retrieval technologies under actual conditions is needed to demonstrate safety and precision.

4.4.3 Low-Level Waste Tanks

If the contents are removed from the tanks (removal of either the liquid alone or the liquid and sludge), facilities will be needed to receive the waste. Review of the waste in the inactive low-level waste tanks indicates that the supernates (liquid) could generally be transferred to the active liquid low-level waste system. This means that the liquid would probably be concentrated in the liquid low-level waste evaporator and then transferred to the Melton Valley Storage Tanks for long-term storage. Two tanks are known to contain significant organic layers and could not be sent directly to the active liquid low-level waste system. Additional studies will be required before recommendations can be made for these tanks. Only a small percentage of the supernates (~1%) could be discharged directly to the Process Waste Treatment Plant. The other 99% of the supernates exceed the Process Waste Treatment Plant waste acceptance criteria for such indicators as cesium, strontium, and gross beta, and sometimes for cobalt and gross alpha (Th, U, and Pu). A fairly complicated pretreatment system (e.g., mixed-bed ion-exchange columns, zeolite ion-exchange columns, and precipitation) would be necessary to treat these waste acceptance criteria-exceeding supernates for discharge to the Process Waste Treatment Plant. The time required to perform development studies and build such a pretreatment facility precludes considering this as a viable option for the near future.

The storage volume currently available in the Melton Valley Storage Tanks is limited and is insufficient for all of the tank supernatants. Periodic campaigns to solidify a portion of the supernatant have allowed continued operation of the liquid low-level waste system in the past, but this is undesirable in many ways and is only a temporary

measure. DOE and ORNL's WM group is working together to acquire and implement additional storage tanks and/or treatment facilities. Long-term options for liquid low-level waste storage and treatment generally include building the Waste Handling and Packaging Plant at ORNL to process and repackage liquid low-level waste for eventual disposal at the planned Waste Isolation Pilot Plant in New Mexico.

The tank supernatants are non-TRU, while about two-thirds of the tank sludges are TRU waste. After the liquids are removed from the tanks, the sludges may also be removed to the active liquid low-level waste system or processed in other ways, such as in situ treatment. According to DOE Order 5820.2A, stored TRU sludges must be removed from the tanks and disposed of at the Waste Isolation Pilot Plant unless another alternative is fully justified. If the TRU sludges are solidified and stabilized in situ, the treatment would probably be temporary, and final disposition of the tank contents may be required at a later date. The degree to which in situ fixation options facilitate final disposition of the tank contents should be analyzed carefully. For example, significant cement grouting of the tanks may make final contents disposition difficult. An option would be to partially fill a tank with grout so tank accessibility is not limited.

Basic implementation needs for both retrieval or in situ fixation alternatives include the following:

- Support platforms that straddle tanks. Because the structural strengths of the Gunitite tank domes are suspect, all equipment to be mounted above the tanks should be supported on a platform that straddles the tanks.
- Access to the tanks for in situ solidification or retrieval of the contents.
- Use of minimal in-tank equipment (i.e., ancillary equipment should be located outside the tank) to improve system reliability and accessibility.
- Specially designed remote equipment. ES&H considerations may mandate that in-tank equipment be remotely operated; such equipment may need to be specially designed.
- Closed-circuit TV and remote control equipment.
- Areas to provide for wash-down, minor maintenance, and waste load-out in preparation for equipment relocation.

With regard to the in situ treatments, the necessary equipment and expertise are needed to properly blend and mix the constituents and manage the operation. This is especially true for polymer grouting, where some of the grouting polymers are toxic. It is important that the polymers react with the tank contents; if they do not react and instead become free liquids in the tanks, they become future candidates for migration. Processing controls are necessary to ensure that the grouting and tank contents are mixed correctly and proportionately to promote solidification of the mixture.

A critical implementation need for ISV is field-scale tests to demonstrate that off-gas pressurization and splattering problems can be eliminated via compaction or by filling the void spaces with an appropriate material. Existing pilot-scale ISV equipment could be used to perform demonstrations that would require about two years and an estimated three million dollars to complete. Successful deployment of the ISV technology for underground tanks would then require fabrication of site-dedicated hardware (about 6 million dollars and two years of effort) and contractual arrangements with a private sector corporation to operate that equipment. All underground tanks at ORNL would require many years to treat by ISV, but only a few years (i.e., three) would be required to treat selected higher-activity units that present the greatest risk for exhumation and redisposal.

4.4.4 Pits and Trenches

Capping implementation needs center on characterizing of the site to determine the exact areas to be contained and identifying potential lateral and subsurface recharge areas that would require hydrologic separation. In situ grouting implementation needs include establishing grout mixing and compatibility at a projected field scale. Due to the relatively higher-radiation fields at the pits and trenches, remote operations, including auger change, repair, and abandonment within the waste, would likely be required during in situ grouting.

In situ vitrification implementation needs center only on providing a field-scale operation to demonstrate implementability. In situ extraction implementation needs are largely indeterminate because the specific in situ process and extractants cannot be identified.

4.4.5 Soils and Sediments

Pilot-scale testing of soil remediation technologies is needed before full-scale use. Presently, ORNL does not have facilities to conduct pilot-scale tests for soil remediation technologies, such as soil washing/extraction, chemical oxidation/reduction, thermal desorption, or incineration. Because of the potential to contaminate private vendor's equipment, contracting pilot-scale studies is not a cost-effective option. Contracting often restricts flexibility in design of experiments and in many cases does not offer a total systems approach. For example, many of the soil remediation technologies are based on separation processes of a contaminant from the soil (e.g., soil-vapor extraction, thermal desorption, soil washing/extraction, and electrokinetics) and treatment of the contaminant (using a destruction or containment process) is addressed separately. Accessibility to pilot-scale facilities at ORNL would be cost effective, provide greater utility in technology evaluation, and ensure the correct scale-up to full-fledged treatment facilities.

To meet long-term science and technology objectives in soil remediation at ORNL, a determined program that evaluates potential environmental and health risks associated with large bodies of soils and sediments that contain relatively low levels of radionuclides and/or toxic hazardous constituents, needs to be implemented. This program should include a major task in soil characterization that determines fate and transport of contaminants contained in the soils and sediments of concern. The program should be formed in such a manner so that the EPA and state of Tennessee regulatory agencies can actively participate. Goals should be established with a realistic timetable, dealing with expected dates of promulgation and cleanup levels. Implementation of a successful program along these lines would aid significantly (in cost as well as time) in the selection of the most appropriate soil remediation technology for ORNL sites.

4.4.6 Buried Pipelines

Both of these technologies and the expected means of application are accepted. No unusual implementation needs are expected.

4.4.7 Impoundments

Since some technologies considered for impoundments are temporary measures, their implementation obviously requires methods and plans for subsequent permanent treatment. Although short half-life radioactivity may decay during the retention period, other contaminants may remain. The potential temporary measures include most of the barrier concepts. The ability to leave the contaminants in-place but contained may depend upon an agreement of the regulators to accept institutional control of the site for several years. In a similar manner, excavation methods depend upon the availability of ex situ treatment methods.

Other technologies considered produce a solid mass that retains the contamination. It is acceptable to leave a solidified mass in place. Although this mass would not support plant life as the original soil, it would be more like large rocks.

4.4.8 Hydrofracture

Field demonstration sites and flow modeling are needed for the deep rock drainage curtain and water proofing cave with hydraulic cage. Facilities for leachate treatment from these deep-rock drainage curtains are also needed.

Laboratory testing, to determine the site-specific impacts of radioisotopes/saline water on the chemical grout, is needed.

4.4.9 Ground Water and Surface Water

Ion-exchange and adsorption operations carried out aboveground have been done on a large scale for many years. Costs for these operations can be estimated with considerable confidence. In commercial applications a range of \$1-\$2/1000 gal of water treated would be typical. For applications that treat water containing nuclear materials, the cost is much higher because of the required nuclear waste storage, additional permitting, etc., and \$5-\$10/1000 gal is a better estimate.

In situ adsorption and ion exchange operations and the control of ground water have not been demonstrated. Materials must be contained so that they are accessible to ground water but removable after exhaustion. These same ground-water control considerations apply to other in situ operations that might be done using a trench-and-fill concept, such as precipitation and chemical oxidation.

Costs for aboveground precipitation for heavy metals, cesium and strontium should cost about \$100/1000 gal of water and about \$1000/1000 gal for cobalt and technetium. Cost for aboveground biological oxidation of organics are about \$10/1000 gal, typical of storage treatment plants. For chemical oxidation, costs are expected to be about \$100/1000 gal. For nitrate destruction, biological denitrification is expected to cost less than \$200/1000 gal.

Separation of volatile organics by air stripping aboveground will cost between \$0.60 and \$4.10/1000 gal, depending on the scale of operation and whether the organics are recovered from the air. Steam stripping would cost about \$8/1000 gal.

4.5 TECHNOLOGY RANKINGS

4.5.1 Introduction

The rankings of RA technologies are presented in the following sections. The criteria listed in Chap. 2, Sect. 2.4, were used to rank the technologies. It should be noted that the development and projected unit operating costs are rough order-of-magnitude estimates. Their validity is limited to the relative comparison of costs between technologies.

4.5.2 Buried Wastes

Table 4.1 summarizes the rankings of each technology addressed by the buried waste group. The rankings are briefly discussed by systems approach in the following sections.

4.5.2.1 Containment and Isolation Technologies

Challenges to hydrologic isolation of buried waste in the ORNL setting have been ranked in this study with direct-surface infiltration having the highest impact, near-surface storm-water flow of secondary impact, and deeper ground-water flow of least impact. Accordingly, technologies to prevent direct infiltration were ranked higher than technologies providing isolation from deeper ground water.

Among the structural stabilization technologies, dynamic compaction was ranked high, partly due to its effectiveness of surface caps at relatively low cost and its applicability to many trench areas at ORNL. High ranking was also assigned to horizontal-mixing-in-place technology, due to its potential for penetration of containers, which effectively stabilized nonhomogeneous wastes. While this technology has been demonstrated for contaminated soil, the effectiveness of the delivery system for buried waste needs further evaluation and demonstration.

In the evaluation of isolation technologies, vertical barriers were determined ineffective in Oak Ridge's geology, which does not provide an impermeable bottom seal. Higher priority was assigned to caps that prevent direct infiltration, and drains that divert shallow storm flow from buried waste areas. An exception was the high ranking of the slurry wall with HDPE screen, which can serve as a leachate collection/drainage/leak-detection system or possibly as a hydrobarrier to prevent contaminant migration through the wall down-gradient of contaminants.

4.5.2.2 In Situ Treatment

High priority was assigned to ISV, due primarily to its robustness and potential effectiveness in converting radionuclides to an excellent waste form, while destroying all organic hazards and combustible materials. Although ISV has been successfully demonstrated for contaminated soil, the challenges of off-gas pressurization and fluid pressurization within ambient containers must be addressed (possibly by in situ compaction) prior to application of this technology to buried waste.

Table 4.1. Rankings of remedial action technologies

Alternative	Data sheet code number	Technology	Contaminants	Ranking ^a
Buried waste group				
Containment and isolation				
Structural stabilization	REMA-1	Dynamic compaction	LLW ^b , organics, metals	H-5-1 (\$0.5M;\$1.50/ft ²)
	REMA-81	Horizontal mixed in-place	LLW, organics, metals	H-5-2 (\$1.5M;\$275/yd ³)
	REMA-96	Structural caps	LLW, organics, metals	M-5-1 (\$.5M;\$1M/acre)
	REMA-82	Surcharge	LLW, organics, metals	M-5-1 (\$0.25M;\$25/yd ³)
	REMA-5	In situ solidification	LLW, organics, metals	M-5-2 (\$0.5M;\$150/yd)
	REMA-97	Thermal set resin impregnation	LLW, organics, metals	L-5-10 (>\$1M;<\$50/ton)
Capping	REMA-94	Intruder barriers	LLW, organics, metals	H-5-1 (≤\$.5M;\$0.5M-\$7M/acre)
	REMA-46	Capping	LLW, organics, metals	H-5-1 (≤\$.5M;\$0.5M-\$7M/acre)
Bottom seals	REMA-87	Vibrated plastic tube bottom seal	LLW, organics, metals	L-5-3 (\$0.5M;\$200-\$300/ft ²)
	REMA-86	Microtunneled high-density polyethylene liner	LLW, organics, metals	L-5-5 (\$3M;>\$500/ft ²)
	REMA-85	Jet grouting	LLW, organics, metals	L-5-1 (\$0.8M;\$150-\$300/ft ²)
Barriers	REMA-58	Cryogenic barriers	LLW, organics, metals	L-5-3 (≤\$1M;~\$100/ft ²)
Drains	REMA-44	Biopolymer drains	LLW, organics, metals	H-5-1 (≤\$1M;\$15-\$20/ft ²)
	REMA-43	French drains	LLW, organics, metals	H-5-1 (≤\$1;\$50-\$100/ft ²)
	REMA-45	Horizontal wells	LLW, organics, metals	H-5-1 (≤\$1M;\$150/ft)
Walls	REMA-84	Hydromill	LLW, organics, metals	M-5-3 (≤\$1M;\$30/ft ²)
	REMA-42	Grout curtains	LLW, organics, metals	M-5-1 (≤\$1M;\$30-\$40/ft ²)
	REMA-40	Slurry walls	LLW, organics, metals	M-5-1 (≤\$1M;\$15-\$20/ft ²)
	REMA-83	Slurry walls with high-density polyethylene insert	LLW, organics, metals	H-5-2 (\$2M-\$3M;~\$40/ft ²)
	REMA-41	Sheet pile walls	LLW, organics, metals	M-5-2 (≤\$1M;\$30-\$40/ft ²)
	REMA-88	Soil saw	LLW, organics, metals	L-5-2 (\$0.8M;\$70-\$80/ft ²)

Table 4.1. (continued)

Alternative	Data sheet code number	Technology	Contaminants	Ranking ^a
<i>In situ treatment</i>				
Destruction	REMA-99	In situ heating	Organics	L-5-8 (>\$1M;<\$50/ton)
	REMA-110	In situ biodegradation (buried waste)	Organics	L-5-5 (≤\$1M;<\$50/ton)
Fixation	REMA-3	In situ particulate grouting	LLW, organics, metals	M-5-2 (>\$1M;\$40-\$60/yd ³)
	REMA-2	In situ chemical grouting	LLW, organics, metals	M-5-2 (≤\$1M;\$60-\$100/yd ³)
	REMA-100	In situ vitrification (buried waste)	LLW, organics, metals	H-5-5 (\$3M;\$60-\$100/yd ³)
Separation	REMA-89	Fracted air stripping	Organics	M-5-4 (\$2M;\$50-\$75/ton)
<i>Retrieval</i>				
Excavation	REMA-123	Overshot drilling	HFIR ^c control plates	H-5-4 (\$5M/6 HFIR ^b holes)
	REMA-126	Bulk item exhumation	Large equipment	H-5-2 (≤\$1M;<\$50/ton)
	REMA-125	Wireline basket recovery	HFIR control plates	H-5-4 (\$8M/6 HFIR holes)
	REMA-101	Vacuum loader (buried waste)		L-5-2 (≤\$1M;<\$50/ton)
	REMA-4	Borehole mining (super soil stabilization management)	LLW, organics, metals	L-5-3 (≤\$1M;\$50-\$100/yd ³)
	REMA-10	Solidify and mine (freeze and mine)	LLW, organics, metals	L-5-8 (≤\$1M;<\$50/ton)
	REMA-90	Precision excavation	LLW, organics, metals	H-5-1 (≤\$.5M;<\$50/ton)
	REMA-122	Modular excavation	LLW, organics, metals	M-5-8 (>\$1M;<\$50-\$100/ton)
	REMA-38	Remote excavation	LLW, organics, metals	H-5-2 (≤\$.5M;\$203-\$244/ft ³)
<i>Ex situ treatment</i>				
Separation	REMA-93	Shredding and magnetic separation	LLW, metals	L-5-1 (\$1M;\$0.2M/yr/system)
	REMA-121	Physical sorting	LLW, metals	M-5-1 (N:N)
	REMA-92	Thermal desorption	Organics	L-5-3 (≤\$1M;\$35-\$120/ton)
	REMA-91	Freeze purification	LLW, organics, metals	L-5-5 (≤\$.5M;<\$50/ton)
	REMA-8	Gravity sorting	LLW, metals	L-5-3 (≤\$1M;\$0.35-\$1/lb)

Table 4.1. (continued)

Alternative	Data sheet code number	Technology	Contaminants	Ranking ^a
Ex situ treatment (continued)				
Separation (continued)	REMA-55	Soil washing (contaminated soil/sediment)	LLW, organics, metals	L-5-3 (<\$5M;\$70-\$150/ton)
Fixation	REMA-9	Cementitious solidification	LLW, organics, metals	H-5-3 (<\$5M;\$200-\$360/yd ³)
	REMA-112	Thermoplastic encapsulation	LLW, organics, metals	H-5-3 (<\$5M;\$25/ft ³)
	REMA-113	Thermoset encapsulation	LLW, organics, metals	H-5-3 (<\$1M;\$30/ft ³)
	REMA-114	Sulfur polymer cement encapsulation	LLW, organics, metals	H-5-10 (<\$1M;\$25/yd ³)
	REMA-115	Polymer-impregnated concrete/polymer-modified concrete	LLW, organics, metals	M-5-8 (>\$1M;<\$50/ton)
	REMA-117	Vitrification	LLW, organics, metals	M-5-6 (>\$1M;\$400-\$500/ton)
	REMA-116	Ceramic encapsulation	LLW, organics, metals	L-5-10 (N;N)
Destruction	REMA-95	Incineration	Organics, metals	H-5-1 (<\$1M;>\$100/ton)
	REMA-98	Calcining/sintering	LLW, organics, metals	L-5-10 (>\$1M;<\$50/ton)
	REMA-7	Low-temperature ashing	LLW, organics, metals	H-5-6 (>\$1M;<\$50/ton)
Recovery/conversion	WPRO-111	Smelting	Metals	M-5-1 (\$3M;\$2/lb.)
	REMA-127	Transmutation	LLW, TRU ^d	M-5-4 (<\$1M;<\$50-\$100/ton)
Tanks core group				
Contents removal	REMA-27	Tank contents removal using mechanical mining		H-5-3 (>\$4M;N)
	REMA-28	Tank contents removal using pneumatic techniques		H-5-0 (\$4M;N)
	REMA-29	Tank contents removal using hydraulic techniques		H-5-0 (>\$4M;N)
Fixation	REMA-25	In situ solidification using cement-based grouting		M-5-2 (>\$5M;>\$70/m ³)

Table 4.1. (continued)

Alternative	Data sheet code number	Technology	Contaminants	Ranking ^a
Tanks core group (continued)				
Fixation (continued)	REMA-26	In situ solidification using silicate-based formulations		M-5-2 (>\$5M;>\$70/m ³)
	REMA-30	In situ treatment using in situ vitrification		M-5-2 (\$3M;<\$50-\$100/ton)
	REMA-32	In situ solidification using polymer grouting		M-5-2 (>\$5M;>\$100/m ³)
	REMA-33	In situ solidification using thermoplastic techniques		L-5-3 (>\$5M;>\$70/m ³)
Physical separation	REMA-31	In situ solidification using sorbents		M-5-1 (>\$1M;>\$50/m ³)
Pits and trenches				
Containment	REMA-36	Capping (pits/trenches)		H-3-1 (L, \$0.5-\$7M/acre)
In situ treatment	REMA-35	In situ vitrification (pits/trenches)		H-3-1 (>\$1M;\$25/ft ³)
	REMA-37	In situ grouting (pits/trenches)		M-3-2 (<\$1M;\$75/ft ³)
	REMA-39	In situ extraction		L-3-10 (>\$1M;\$244/ft ³)
Retrieval	REMA-38	Remote excavation		M-3-2 (<\$0.5M;\$203-\$244/ft ³)
Soils and sediments				
Containment	REMA-46	Capping	LLW, organics, metals	M-4-1 (<\$0.5M;\$0.5-\$7M/acre)
	REMA-58	Cryogenic barriers	LLW, organics, metals	M-4-3 (<\$1M;\$200-\$300/ft ²)
Physical separation	REMA-55	Soil washing (contaminated soils/sediments)	LLW, organics, metals	H-4-2 (<\$0.5M;\$70-\$150/ton)
	REMA-13	Low-temperature thermal treatment	Volatile organics	M-4-2 (\$1M;\$100-\$800/ton)
	REMA-11	Vapor extraction with radio frequency heating	Volatile organics	H-2-4 (<\$1M;<\$100/ton)
	REMA-16	Thermal desorption	Volatile organics	H-2-2 (<\$1M;\$35-\$120/ton)
	REMA-78	Soil vapor extraction	Volatile organics	H-2-3 (<\$1M;\$50-\$75/ton)
	REMA-80	Thermally enhanced soil vapor extraction	Volatile organics	H-2-3 (<\$1M;\$50-\$100/ton)
	REMA-119	Soils treatment using solvent extraction	Organics, metals	M-2-3 (\$3M-\$5M;\$200-\$300/ton)
Chemical separation	REMA-120	Soils treatment using oxidation or reduction	Organics, metals	M-2-3 (\$3M-\$5M;\$100-\$200/ton)
	REMA-19	Electrokinetic removal	Organics, metals	L-2-4 (\$1M-\$10M;>\$100/ton)

Table 4.1. (continued)

Alternative	Data sheet code number	Technology	Contaminants	Ranking ^a
Soils and sediments (continued)				
Destruction	REMA-118	Soils treatment using bioremediation	Organics	M-2-3 (\$3M-\$5M;\$100-\$200/ton)
	REMA-12	Incineration	Organics	M-4-2 (\$1M-\$2M;\$100-\$800/ton)
	REMA-15	Molten glass combustor	Organics, PCBs ^f	M-2-3 (≤\$1M;>\$200/ton)
	REMA-20	Chem char process	Organics, PCBs	L-2-4 (\$1M;<\$50-\$100/ton)
	REMA-17	Plasma arc furnace	Organics, PCBs	M-2-3 (\$10M;<\$50-\$100/ton)
	REMA-14	Incineration, cement kiln	Organics, PCBs	M-2-3 (≤\$1M;<\$50/ton)
Fixtation	REMA-18	In situ vitrification	LLW, organics, metals	M-4-3 (≤\$.5M;\$390/ton)
	REMA-59	In situ vitrification (impoundments)	LLW, organics, metals	M-4-2 (≤\$1M;\$75/ft ³)
Retrieval	REMA-124	Entombed clamshell	LLW, organics, metals	H-4-0 (≤\$.5M;<\$25-\$50/yd ³)
Pipeline group				
Excavation	REMA-53	Pipeline excavation	LLW	H-1-0 (\$0;>\$25/yd ³)
Fixtation	REMA-52	In situ grouting (pipeline)	LLW	H-1-1 (\$0;~\$25-\$70/yd ³)
Hydrofracture group				
Containment—well bores	REMA-22	Well plugging and abandonment		H-1-2 (\$0;\$10-\$20M total cost)
Containment—grout sheets	REMA-21	Waterproofing cave with hydraulic cage		M-1-5 (\$3M;\$30-\$40M total cost)
	REMA-24	Deep rock drainage curtain		M-1-4 (\$3M;\$30-\$40M total cost)
	REMA-23	Hydrofracture grouting		L-1-2 (\$3M;\$30-\$40M total cost)
Impoundments				
Capping	REMA-46	Capping	LLW, organics	H-4-1 (≤\$.5M;\$0.5-\$7M acre)
Drains	REMA-43	French drains	LLW, organics	H-4-1 (≤\$1M;\$50-\$100/ft ²)
	REMA-44	Biopolymer drains	LLW, organics	H-4-2 (≤\$1M;\$15-\$20/ft ²)
	REMA-45	Horizontal wells	LLW, organics	H-4-3 (≤\$.5M;~\$150/ft ²)
Walls/barriers	REMA-58	Cryogenic barriers	LLW, organics	M-4-3 (≤\$1M;\$200-\$300/ft ²)

Table 4.1. (continued)

Alternative	Data sheet code number	Technology	Contaminants	Ranking ^a
Impoundments (continued)				
Walls/ barriers (continued)	REMA-42	Grout curtain	LLW, organics	M-4-2 ($\leq \$1M; \$30\text{--}\$40/\text{ft}^2$)
	REMA-40	Slurry walls	LLW, organics	M-4-3 ($\leq \$1M; \$15\text{--}\$20/\text{ft}^2$)
	REMA-41	Sheet pile walls	LLW, organics	M-4-2 ($\leq \$1M; \$30\text{--}\$40/\text{ft}^2$)
	REMA-60	Clay/bentonite additives	LLW, organics	L-4-1 ($\leq \$0.5M; \$0.55/\text{ft}^2$)
Physical separation	REMA-51	Soil washing (impoundments)	LLW, organics, metals	M-4-2 ($\leq \$0.5M; \$70\text{--}\$150/\text{ton}$)
	REMA-47	In situ soil flushing	LLW, organics, metals	M-4-3 ($\leq \$0.5M; < \$50/\text{ton}$)
	REMA-56	Sludge drying	Organics	M-4-3 ($\leq \$1M; < \$50/\text{ton}$)
Fixation	REMA-57	In situ fixation	LLW, organics, metals	H-4-1 ($\leq \$1M; \$50\text{--}\$75/\text{yd}^3$)
	REMA-59	In situ vitrification (impoundments)	LLW, organics, metals	M-4-3 ($\leq \$0.5M; \$25/\text{yd}^3$)
Excavation	REMA-50	Mechanical excavation	LLW, organics, metals	H-4-1 ($\leq \$0.5M; < \$50/\text{ton}$)
	REMA-49	Vacuum loaders	LLW, organics, metals	H-4-1 ($\leq \$0.5M; < \$50/\text{ton}$)
	REMA-48	Dredging	LLW, organics, metals	H-4-1 ($\leq \$0.5M; < \$50/\text{ton}$)
Ground water and surface water				
Physical separation	REMA-65	Ion exchange	Radionuclides, inorganics	H-5-1 ($\$1M; \$5\text{--}\$10/1000\text{ gal}$)
	REMA-34	Precipitation	Radionuclides, inorganics	M-5-1 ($\$1M; \$100\text{--}\$1000/1000\text{ gal}$)
	REMA-73	Adsorption on biomedica	Inorganics	M-2-2 ($\$2M; N$)
	REMA-66	Activated carbon	Organics, inorganics	H-2-1 ($\$1M; \$5\text{--}\$10/1000\text{ gal}$)
	REMA-76	Air stripping	VOCs ^g	H-2-0 ($\$0; \$6\text{--}\$4.10/1000\text{ gal}$)
	REMA-77	Steam stripping	VOCs	H-2-0 ($\$0; \$8/1000\text{ gal}$)
Destruction	REMA-68	Biological oxidation	Organics	H-2-1 ($\$1M; \$10/1000\text{ gal}$)
	REMA-72	Chemical oxidation	Organics	M-2-2 ($\$2M; \$100/1000\text{ gal}$)
	REMA-69	Anaerobic dechlorination	PCBs	L-2-5 ($\$5M; N$)
	REMA-75	Biological denitrification	Nitrates	M-2-1 ($\$1M; \$200/1000\text{ gal}$)

Table 4.1. (continued)

Alternative	Data sheet code number	Technology	Contaminants	Ranking ^a
<i>In situ processes</i>				
Physical separation	REMA-64	In situ ion exchange	Radionuclides, inorganics	L-5-3 (\$3M;N)
	REMA-62	In situ precipitation	Radionuclides, inorganics	L-5-3 (\$3M;N)
	REMA-74	In situ bioremedia adsorption	Inorganics	L-2-3 (\$3M;N)
	REMA-67	In situ activated carbon	Organics, inorganics	L-2-3 (\$3M;N)
	REMA-70	In situ biological oxidation		M-2-3 (\$2M;N)
Fixation	REMA-63	Artificial wetlands	Organics, inorganics	M-2-3 (\$3M;N)
	REMA-79	Cryogenic immobilization		H-5-2 (\$2M;N)
Destruction	REMA-61	In situ chemical oxidation	Organics	M-2-2 (\$2M; a few\$/1000 gal)
	REMA-71	In situ anaerobic dechlorination	PCBs	M-2-5 (\$5M;N)
	REMA-75	In situ biological denitrification	Nitrates	M-2-3 (\$3M;N)

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

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

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

^b LLW = low-level waste

^c HFIR = High Flux Isotope Reactor

^d TRU = transuranic

^e RFH = radio frequency heating

^f PCBs = polychlorinated biphenyls

^g VOCs = volatile organic compounds

4.5.2.3 Retrieval and Ex Situ Treatment

Three technologies were ranked in waste retrieval. Excavation technologies, including precision excavation, were selected because they are already highly developed and readily adaptable to retrieval of low-activity waste. The development/demonstration needs for precision excavation focus on contamination control. Also given a high ranking for development/demonstration was bulk item exhumation because of the need to remove large buried objects safely. Overshot drilling for high-activity applications, such as the retrieval of reactor plates for auger holes, is also given a high ranking.

Segregation/sorting technologies ranked lower than other subelements for two reasons. First, the need for segregation will be driven by the primary treatment technology, which is undefined. Second, the buried waste is not characterized well enough to determine relative proportions of different treatment groups (e.g., metals). The highest ranking technology in this area was physical sorting, because it is already used for newly generated waste and because it provides for segregation into a larger number of treatment categories.

A group of thermal treatment technologies and a group of solidification technologies were ranked high in ultimate treatment. Incineration, vitrification, and low-temperature ashing were selected because of their effectiveness, robustness, and tremendous waste-reduction effects. Low-temperature ashing has the potential of providing better control of semi-volatile contaminants. Technology development/demonstration needs focus on off-gas treatment and development of a final waste form. High-ranking solidification technologies included cement solidification, thermoplastic encapsulation, thermoset encapsulation, and sulfur polymer cement encapsulation.

4.5.3 Low-Level Waste Tanks

Table 4.1 also summarizes the rankings for each technology addressed in the tank's core group. Those technologies with the highest ranking (mechanical excavation, pneumatic removal, and hydraulic removal or sluicing) were identified for the contents removal alternative. One of the reasons for the high ranking for the contents removal technologies is that they comply in part with DOE policy of TRU wastes removal. Two of the technologies, pneumatic and hydraulic removal, are technically mature and well demonstrated at ORNL and Hanford. However, based on lessons learned from past experience with these two technologies, their removal efficiency (historically up to 90%) could be improved by upgrading the in-tank equipment and through careful selection of tools appropriate for the particular tank waste. The technology with the potential for the highest removal efficiency, at least for the Gunitite tanks, may be mechanical excavation. DOE's Office of Technology Development is already helping develop this technology through its Integrated Demonstration Programs for robotics and the underground storage tanks. The parallel robotics developments are useful because robotics is a crosscutting technology that enables remote deployment of equipment, tools, and sensors in the hazardous-tank environment.

4.5.4 Pits and Trenches

The rankings for each technology addressed by the pits and trenches group are in Table 4.1. In situ vitrification and capping were the highest ranked technologies. Both technologies have been demonstrated and shown effective. In situ grouting was ranked

as a medium priority because of uncertainties of its effectiveness and its implementation costs/schedule. Although remote excavation does not require significant development, it was ranked medium because of uncertainty in the disposal of excavated material. In situ extraction was ranked low due to the lack of an extractant, uncertainties in implementability/effectiveness, and need for delivery/recovery systems.

4.5.5 Soils and Sediments

Table 4.1 provides rankings of soils and sediments technologies. Soil washing was ranked a high priority because of its demonstrated ability to selectively remove radionuclides, the major contaminant of concern. Other physical separation technologies, such as thermal desorption and soil-vapor extraction (including thermally enhanced and RF heating), were also given high priority. It should be noted, however, that since the effectiveness of these technologies is limited to volatile and semi-volatile organics, their site-problem ranking is lower.

The rankings in the systems approach for soil remediation technologies are expected to change over time. Near-term priorities focus on ex situ treatment because of the early implementation in important remediation projects, such as the removal of leaking tanks and pipelines and the remediation of spills. Longer-term priorities are expected to focus on in situ treatments and containment for large volumes of contaminated sediments and soils, such as those contained in White Oak Lake and the burial grounds.

4.5.6 Buried Pipelines

Both technologies evaluated for remediation of buried pipelines were given high rankings (see Table 4.1). Both technologies are currently used for remediation of buried pipelines and their effectiveness at ORNL has been demonstrated.

4.5.7 Impoundments

Technologies receiving the highest rankings (see Table 4.1) included all excavation and capping and drainage technologies since these are likely to be the most critical for remediation of impoundments. In situ fixation was also rated high, primarily for its demonstrated ability to immobilize wastes. The other technologies were ranked lower due to their limited applicability and limited effectiveness for the site conditions at ORNL.

4.5.8 Hydrofracture

Plug and abandon was ranked the highest since it has been demonstrated as effective and is versatile and will not require a long development period or cost. The deep-rock drainage curtain was ranked as medium since it is a well-established technique for seepage control below high-head dams. Chemical grouting and water proofing cave with hydraulic cage were ranked low, primarily due to the development required and uncertainty of the effectiveness. Due to the nature of the problem, all technologies (with the exception of plug and abandon) were estimated to be of high cost ($\geq \$100M$) to develop and implement.

4.5.9 Ground Water and Surface Water

The technology receiving the highest rankings for inorganics (e.g., heavy metals) and radionuclides was aboveground ion exchange. For organics and inorganics the highest ranked were aboveground adsorption on activated carbon. Aboveground biological oxidation, for organics; aboveground air or steam stripping, for VOCs; and cryogenic immobilization, for tritium, were given high rankings as well.

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 RA technologies listed in Table 4.1. A search of available information on programs funded in FY 1992 and FY 1993 was performed to identify possible matches with this list of RA technologies. The results of this search are presented in Table 4.2. Those FY 1993 projects described by TTPs and determined to be potentially relevant and beneficial are listed under the corresponding RA technology code and 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. RA technologies for which no matches were found are omitted from the table. The relevance column indicates the degree of overlap between the listed RA technologies and active TTP projects. The TTP's comprising the search data base are listed in the appendix.

Table 4.2. Remedial action technologies under development by DOE

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
In situ chemical grouting	REMA-2-OL	AL231008	H	In situ containment
		CH321101	H	In situ containment
		RL331002	H	In situ containment
In situ particulate grouting	REMA-3-OL	CH321101		
In situ solidification	REMA-5-OL	RL311103	L	In situ remediation
Soil washing	REMA-6-OL	CH331002	M	Cost-to-benefit analysis
		NV031001	M	Plutonium separation
		PE031001	H	Centrifugal jig
		SR121105	M	Extraction/leaching
Cementitious solidification	REMA-9-OL	ID132012	L	Acceptance criteria
Solidify and mine (freeze and mine)	REMA-10-OL	ID121203	M	Ground freezing
		SR121104	H	Integrated demonstration
Vapor extraction with radio frequency (RF) heating	REMA-11-OL	AL221121	H	RF heating
		RL311104	M	In situ soil heating
		SF211104	H	RF heating
		SR121106	M	RF heating
		SR121107	M	Integrated demonstration
		ID121701	M	Biofiltration
		SR121104	H	Integrated demonstration
		SR131001	H	In situ heating
Incineration	REMA-12-OL	ID132011	M	Arc melter vitrification
		RL321211	L	Plasma torch and furnace
Low-temperature thermal treatment	REMA-13-OL	AL221121	H	Vapor extraction system
		RL311103	L	In situ heating
		RL311104	H	Six-phase soil heating
		RL331003	H	Six-phase soil heating
		SR131001	H	In situ heating
Thermal desorption	REMA-16-OL	ID121114	H	Volatile organic compound (VOC) recycle and recovery
Plasma arc furnace	REMA-17-OL	ID132011	H	Arc melter vitrification
		PE033502	H	Plasma centrifugal furnace
		RL321211	H	Direct Current (DC) arc plasma furnace

Table 4.2 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
In situ vitrification (ISV)	REMA-18-OL	ID132010	H	Thermal kinetic processes
		RL332009	H	Pilot-scale ISV system
		OR101201	M	Data and engineering analyses
Electrokinetic removal	REMA-19-OL	AL221122	M	Electrokinetic remediation
		AL231009	M	Electrokinetic remediation
		ID121211	M	Electrokinetic remediation
Water proofing cave with hydraulic cage	REMA-21-OL	AL223305	M	International Technology Exchange Program (ITEP) activities
		AL231008	M	Flowable grout technologies
Tank contents removal using hydraulic techniques	REMA-29-OL	RL332006	H	Waste dislodging and conveyance
In situ treatment using in situ vitrification	REMA-30-OL	ID132010	H	Thermal kinetic processes
In situ solidification using polymer grouting	REMA-32-OL	CH321201	H	Polyethylene encapsulation
In situ solidification using thermoplastic techniques	REMA-33-OL	CH321201	H	Polyethylene encapsulation
Precipitation	REMA-34-OL	ID121204	L	Biological destruction
		RL431001	M	In situ chemical treatment
In situ vitrification - pits and trenches	REMA-35-OL	OR101201	H	Pilot-scale demonstration
Capping - pits and trenches	REMA-36-OL	AL121125	L	Postclosure monitoring
		AL131001	L	Barrier selection software
In situ grouting - pits and trenches	REMA-37-OL	AL121125	L	Postclosure monitoring
Remote excavation	REMA-38-OL	AL232006	M	Buried Waste Integrated Demonstration (BWID)
		ID121203	H	BWID waste retrieval demo
		ID121210	M	BWID contamination control
		ID132007	M	BWID retrieval technologies
		ID332004	H	BWID remote excavation demo
		ID413200	M	Robotics technology
		ID431001	H	Uranium in Soils Integrated Demonstration (USID) remote excavation demo
		SF213205	M	Robotics technology
		OR113202	M	Robotics technology
Slurry walls	REMA-40-OL	AL121125	L	Barrier evaluations

Table 4.2 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Sheet pile walls	REMA-41-OL	ID132007	M	BWID retrieval technologies
Horizontal wells	REMA-45-OL	AL221114	M	Moisture logging system
		RL421103	H	Drilling technology development
		SR121106	M	Air stripping
		SR134101	L	Air stripping
Capping	REMA-46-OL	AL221111	H	Effects on contaminant transport
		AL321002	H	Air-enhanced dry barrier
		CH331001	M	Subterranean vertical barrier
In situ soil flushing	REMA-47-OL	AL201101	M	Ground-water flow sensor
		RL311103	M	In situ soil flushing
Mechanical excavation	REMA-50-OL	NO031001	L	Rotomill excavator testing
Soil washing	REMA-51-OL	AL1312R1	M	Heap leaching
		NV031001	M	Plutonium separation
		SR121105	M	Extraction/leaching
Stabilization/fixation by grouting	REMA-54-OL	CH321101	H	Advanced grouting materials
Soil washing	REMA-55-OL	CH331002	M	Cost-to-benefit analysis
		NV031001	M	Plutonium separation
		PE031001	H	Centrifugal jig
		SR121105	M	Extraction/leaching
In situ fixation	REMA-57-OL	CH321101	H	Advanced grouting materials
Cryogenic barriers	REMA-58-OL	AL121125	M	Barrier evaluation
		ID132007	M	Ground freezing
In situ vitrification - impoundments	REMA-59-OL	RF101201	L	Microwave solidification
		RL332009	M	Vitrification studies
Clay/bentonite additives	REMA-60-OL	AL231008	L	Bentonite-paraffin material
In situ chemical oxidation	REMA-61-OL	ID121217	L	Supercritical water oxidation
		OR121206	M	Supercritical water oxidation
In situ precipitation	REMA-62-OL	RL331002	L	Chemically enhanced barriers
		RL431001	M	In situ chemical treatment
In situ ion exchange	REMA-64-OL	PE021104	L	Technology screening
		RL321204	M	Inorganic sorbent exchangers

Table 4.2 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Ion exchange	REMA-65-OL	AL232004	M	Titanate ion exchangers
		OR111102	L	Liquid-phase decontamination
		OR111203	L	NaNO ₃ + radioactivity
		PE021104	L	Resource recovery
		RL321203	M	Cesium recovery on resin
		RL421102	L	Decontaminated ground water
Biological oxidation	REMA-68-OL	ID111701	H	Methanotropic biofiltration
Anaerobic dechlorination	REMA-69-OL	RL321102	H	Bimolecular probe analysis
		OR121110	H	Bioremediation of PCBs
In situ biological oxidation	REMA-70-OL	RF101205	L	Incineration alternatives
In situ anaerobic oxidation	REMA-71-OL	SR121106	H	Methane monooxygenase treatment
Biological denitrification	REMA-75-OL	ID121204	L	Destruction of tank wastes
		OR111203	L	Destruction of tank wastes
Air stripping	REMA-76-OL	RF121204	M	Feasibility study
Thermally enhanced soil vapor extraction	REMA-80-OL	AL221121	H	Extraction system
		R311104	H	Six-phase soil heating
Jet grouting	REMA-85-OL	AL231004	H	Linear and rotating jet grouting
Shredding and magnetic separation	REMA-93-OL	AL124103	H	Magnetic separation Cooperative Research and Development Agreement (CRADA)
Calcining/sintering	REMA-98-OL	RL421216	H	Tank waste treatment
		RL432004	H	Calcine residue leaching
In situ vitrification (buried waste)	REMA-100-OL	ID132010	H	Thermal kinetic processes
		ID132011	H	Arc melter vitrification
		OR101201	H	Issues evaluation
In situ biodegradation	REMA-110-OL	OR123302	H	Biodegradation
		SR121104	H	Integrated demonstration
In situ biological denitrification	REMA-111-OL	OR111203	L	Aqueous sodium nitrate
Thermoplastic encapsulation	REMA-112-OL	RF111203	H	Polymer development
Thermoset encapsulation	REMA-113-OL	RF111203	H	Polymer development
Sulfur polymer cement encapsulation	REMA-114-OL	CH331001	L	Bench-scale evaluations
		ID132012	L	Performance criteria

Table 4.2 (continued)

Technology	Code	1993 TTP ^a	Relevance ^b	Focus of TTP
Sensors for monitoring entombment integrity	REMA-118-OL	CH111203	M	Sensor technology implementation plan
Solvent extraction	REMA-119-OL	RL322101	M	Development of advanced processes
		OR121204	H	TRUEX® extraction process
Concrete-based solidification/stabilization	REMA-120-OL	CH321101	M	Advanced grouting materials

^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.

5. Robotics and Automation

5. ROBOTICS AND AUTOMATION

5.1 INTRODUCTION

There are a number of reasons why robotics/automation would be used for RA activities, including (1) to perform a task more efficiently than by direct human involvement or (2) to remove the humans from the hazardous environment and minimize the danger level to the humans. Both of these reasons are encountered in RA activities.

For the purpose of identifying the robotics/automation technologies applicable to RA, the RA activities have been grouped into six problem areas, as follows:

- buried waste,
- low-level waste tanks,
- impoundment,
- soils,
- ground water, and
- buried pipes.

Some of these problem areas will require very little involvement by robotics/automation while others may require extensive involvement, at least until the hazard level associated with the activity has been better defined. Further, each of these problem areas requires a somewhat different mix of robotics/automation technologies. It should also be noted that, in general, robotics/automation supports those other technological activities—including characterization, retrieval, and treatment—necessary to perform the actual remediation tasks.

5.2 TECHNOLOGY OPTIONS

The robotics/automation technologies that are applicable to RA activities are listed in Table 5.1 (an X indicates which technologies are applicable to specific RA problem areas). As shown in the table, the robotics/automation technologies are grouped into nine functional categories. The technologies listed for RA tasks are primarily those required (1) to locate, characterize, and retrieve buried wastes, including buried pipes, (2) to sample and remove contaminated soil, and (3) to sample and remove the wastes from low-level waste storage tanks. Robotics/automation will have fewer applications in impoundment or ground-water treatment applications.

Generally, it will be necessary to combine a number of these robotics/automation technologies into integrated systems before a particular RA task can be performed effectively. For example, having a remotely operable vehicle (ROBA-2-OL) available to locate or characterize buried waste would not be particularly useful unless appropriate detection sensors (ROBA-47-OL), operator interfaces (ROBA-38-OL), and data/signal transmission devices (ROBA-13-OL) are also available. In setting priorities for needed R&D, consideration was also given to integrated robotics/automation systems.

Table 5.1. Relationship of robotics/automation technologies to remedial action problems

Data sheet code number	Remedial action problem area					
	Buried waste	LLW ^a tanks	Impoundment	Soil	Ground water	Buried pipes
Mechanical—mobility						
ROBA-1-OL	X ^a		X	X	X	X
ROBA-7-OL			X			
ROBA-9-OL		X				
ROBA-10-OL	X		X	X	X	X
ROBA-11-OL	X			X		
ROBA-12-OL	X			X		X
ROBA-13-OL	X		X	X	X	X
Mechanical—manipulation						
ROBA-16-OL	X	X				X
ROBA-19-OL	X	X				X
Mechanical—mechanisms						
ROBA-21-OL		X				X
ROBA-22-OL	X	X				X
Mechanical—end-of-arm tooling						
ROBA-23-OL	X	X				X
ROBA-24-OL	X	X				X
ROBA-25-OL	X	X				X
ROBA-26-OL	X	X				X
Controls—algorithms						
ROBA-27-OL	X	X		X		X
ROBA-28-OL	X			X		X
ROBA-29-OL	X			X		X
ROBA-30-OL	X	X				X
ROBA-31-OL		X				
ROBA-32-OL	X	X		X		X
ROBA-33-OL		X				
ROBA-34-OL	X	X				X
ROBA-35-OL	X	X		X		X
ROBA-37-OL	X	X	X	X	X	X

Table 5.1 (continued)

Data sheet code number	Remedial action problem area					
	Buried waste	LLW ^a tanks	Impound- ment	Soil	Ground water	Buried pipes
Controls—human/machine interface						
ROBA-38-OL	X	X	X	X	X	X
ROBA-39-OL	X	X		X		X
ROBA-40-OL	X	X		X		X
ROBA-41-OL		X				X
ROBA-42-OL	X	X	X	X	X	X
Sensors—perception						
ROBA-43-OL	X	X	X	X	X	X
ROBA-44-OL		X				
ROBA-45-OL		X				
ROBA-46-OL	X	X		X		X
ROBA-47-OL	X			X		X
Sensors—control						
ROBA-48-OL	X	X		X		X
ROBA-50-OL	X	X				X
ROBA-51-OL		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	X	X	X	X	X	X
ROBA-56-OL	X	X	X	X	X	X
ROBA-57-OL	X	X	X	X	X	X
ROBA-58-OL	X	X	X	X	X	X
ROBA-59-OL	X	X	X	X	X	X

^aLLW = low-level waste^bAn X indicates that a technology is applicable to an RA problem area.

5.3 SCIENCE AND TECHNOLOGY NEEDS

Specific needs, with short explanations of the reasons why additional R&D is required, are given below for each of the RA problem areas.

5.3.1 Buried Wastes and Buried Pipes

Many of the records showing the location and the contents of buried-waste fields have either been lost or destroyed, or accurate records were never kept. Similar problems exist for some of the buried pipes that have carried radioactive fluids in the past. Also, since the hazards associated with these waste fields are not well defined and may exceed those to which humans can be exposed, the surveys necessary to characterize these burial grounds will be performed remotely using teleoperated or robotic vehicles to deploy the detection sensors. Needs related to this activity are included in the following sections:

5.3.1.1 Remotely Deployable, Nonintrusive Sensors (ROBA-47-OL)

Present sensors have limited usefulness. Ground-penetrating radar has limited range in the soil encountered on ORR, particularly if clay caps have been placed on the waste field. Conductivity probes can be disrupted by the metallic signature of the robotic vehicle used to deploy the probes. Radioactivity meters and organic gas detectors cannot indicate the burial depth or the quantity of buried materials. Efforts to improve the capabilities of sensors are required, and it is assumed this technology need will be addressed by characterization programs. The integration of these various types of sensors onto a remotely deployed vehicle is also a technology need that requires additional R&D. Addressing this need will minimize potential interference between the sensors and other systems on the deployment vehicle.

5.3.1.2 Low-Metallic Content, Remotely Driven Vehicle (ROBA-1-OL)

A vehicle of this type is needed to minimize interference with the detection sensors carried by the vehicle. Some work in this area is presently being conducted by the Office of Technology Development Robotics Program, with a technical demonstration planned for later in this calendar year.

5.3.1.3 Tool Caddies (ROBA-21-OL)

Methods of stowing various tools where they are easily accessible to a manipulator arm is a technology need that has not been adequately addressed in previous robotics/automation programs. The present approach is to move the manipulator away from the work site to a tool storage area when tool changes are necessary. Having an on-board tool caddy would greatly increase the efficiency of the remote operations and would be particularly useful in the repair or replacement of buried pipes where frequent tool changes may be necessary.

5.3.1.4 Navigation of Robotics Vehicles on Waste Sites (ROBA-29-OL)

In the surveying of waste sites, relatively precise information on the position of the vehicles conducting the survey is required to relate data from the detection instruments to burial site location. Although several instruments to provide this information are available commercially (e.g., Ultrasonic Ranging and Data System), they generally require line-of-sight between the detectors and the vehicle and may not be applicable to many of the terrains encountered on the ORNL waste sites.

5.3.2 Low-Level Waste Storage Tanks

The condition of storage tanks at ORNL varies from active tanks that are in reasonably good shape but nearing capacity (Melton Valley Storage Tanks) to storage tanks in which the domes are in danger of collapsing (Gunitite storage tanks). Generally, the radioactivity levels in these tanks are sufficiently high. Therefore, remediation tasks will have to be performed remotely using robotics/automation technologies. The highest priority science and technology needs to perform these tasks are summarized in the following sections.

5.3.2.1 Long-Arm Deployed Robotic Platforms (ROBA-9-OL)

Many of the storage tanks are quite large and have limited penetrations, making the remediation activities difficult. A reasonably compact, long-reach arm capable of entering the existing top-of-the-tank penetrations and accessing the lower periphery of the vessel is a high priority. The length of the arm and its inherent flexibility present control and stability problems that must be addressed in the R&D program.

5.3.2.2 Support and Stabilization Platforms (ROBA-22-OL)

Methods of supporting long-arm deployed robotic platforms, particularly for the remediation of deteriorated tanks, where no additional load can be placed on the dome of the vessel, is a technology need that is only recently being addressed in other programs. Ideally this platform could be used on a variety of vessels, regardless of their size.

5.3.2.3 Force-Limiting and Compliant End-of-Arm Mechanisms (ROBA-26-OL)

The development of a method of remotely adjusting and limiting the force that an arm or tool can exert on a surface, such as a tank wall, is also a technology need for robotics/automation. Although force reflecting manipulators are commercially available, these units depend on the ability of an operator to sense forces transmitted back through the control system and are not sufficient to prevent damage during remote operations.

5.3.3 Soils

Rather large quantities of contaminated soils are present at ORNL. Although surface soils probably are not sufficiently contaminated to require remote operations, soils adjacent to buried wastes, buried and leaking pipes, and leaking low-level waste storage tanks may be highly contaminated and will require removal by remote means. There is also an economic incentive to minimize the amount of soil removed for treatment or waste

disposal. The science and technology needs required for robotics/automation for soil remediation are summarized below.

5.3.3.1 Front-End Loaders and Backhoes for Minimum Soil Removal (ROBA-2-OL)

A remotely operated, heavy-duty vehicle with sufficient sensors to control the depth of soil removal is a high priority science and technology need for robotics/automation. There is presently a jointly funded Department of Defense and DOE Office of Technology Development Robotics Program to develop the first prototype of a vehicle with these capabilities, and a technical demonstration is planned for late in calendar year 1993. This program should be continued to the point so that the technology can be turned over to a private company for commercial deployment.

5.3.4 Impoundment

At the present time confinement of contaminants in sediments has been effectively controlled by coffer dams. In the future, however, if migration of the contaminants occurs, it may be necessary to consider techniques to remove the sediments from the impoundment areas.

5.3.4.1 Specialized Robotic Deployment Platforms (ROBA-7-OL)

Use of available techniques for sediment removal (e.g. surface dredging) would result in a significantly greater release of contaminants during the treatment period. Methods of deploying equipment to remove sediments with minimal disturbance of the surrounding material are required. Underwater deployment of sediment removal equipment, using remotely operated submersibles, would be one method of accomplishing this task.

Remotely operated submersibles have been used for some time for off-shore oil rigs and ocean exploration. However, for shallow water operations in freshwater impoundments, experience has shown that the primary difficulty is the limited visibility. This is particularly true when the bottom sediment is being disturbed or, during warm weather months, when algae growth is at a maximum. In addition to specialized robotic deployment platforms, specialized sensors (ROBA-43, -44, and -45-OL) may also be required for these robotic applications.

5.4 IMPLEMENTATION NEEDS

For RA activities high-priority implementation needs are cold-test beds where the effectiveness of robotic systems to detect, characterize, sample, and remove buried wastes, buried pipes and soils can be demonstrated prior to performing the actual remediation effort. Similar facilities are needed for the development and testing of the robotic devices that would be used to recover residual wastes from low-level waste tanks.

An additional implementation need is quantitative information on the anticipated physical and radiological characteristics of the various waste materials, particularly those that are likely to be encountered in buried waste sites and as residual materials in the low-level waste tanks. Without this information, it will be very difficult to determine the required capabilities of the robotic systems used to deploy the sensors and tools needed for the remediation efforts.

5.5 TECHNOLOGY RANKINGS

The rankings of the robotics/automation technologies required for RA activities are given in Table 5.2. It should be noted that the criteria used for ranking are biased toward those technologies that are commercially available. Hence, a one-for-one comparison between the rankings and the science and technology needs identified in Sect. 5.3 is not possible (i.e. commercially available devices generally require little additional R&D). It should also be noted that several of the criteria suggested for ranking 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 5.2 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 5.2. Rankings of robotics/automation technologies for remedial action

Data sheet code number	Technology	Ranking ^a
Mechanical—mobility		
ROBA-1-OL	Wheeled/tracked vehicles	E-5-2 (\$3M;N)
ROBA-7-OL	Specialized robotic deployment platforms	M-4-3 (\$5M;N)
ROBA-9-OL	Long-arm deployed robotic platform	M-5-3 (\$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 methods for mobile platforms	M-3-1 (\$0.5M;N)
ROBA-13-OL	Data/signal transmission	E-5-1 (\$0.5M;N)
Mechanical—manipulation		
ROBA-16-OL	Dexterous manipulators	E-5-1 (\$1M;N)
ROBA-19-OL	Compact, high-capacity manipulators	H-5-1 (\$1M;N)
Mechanical—mechanisms		
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	H-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)

Table 5.2 (continued)

Data sheet code number	Technology	Ranking ^a
Controls—human/machine interface (continued)		
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)
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	E-5-1 (\$0.5M;N)
ROBA-54-OL	Radiation hardening	M-3-2 (\$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-5-2 (\$1M;N)
ROBA-59-OL	Sample preparation	E-5-1 (\$1M;N)

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

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

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

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 robotics/automation technologies listed in Table 5.2. A search of available information on programs funded in FY 1992 and FY 1993 was performed to identify possible matches with the complete set of robotics/automation technologies listed in the TLD, Vol. 1, Pts. A, B, and C. The results of this search as presented in Table 5.3 include, but are not limited to, robotics/automation technologies listed in Table 5.2. 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 searchers (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 Vol. 1, Pts. A, B, and C, and active TTP projects. The TTPs comprising the search data base are listed in the appendix.

Table 5.3. 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	Demonstr. 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 development	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 of 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 and 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 change out mechanisms	ROBA-24-OL	SR123201	M	Robotics for D&D

Table 5.3 (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
Detection instruments	ROBA-47-OL	OR113203	M	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 5.3 (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

^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.

6. Regulatory Compliance

6. REGULATORY COMPLIANCE

6.1 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. ER of these facilities is currently focusing on D&D of facilities and RA for contaminated soils, ground water, and surface water. A related issue is WM of any wastes generated by these activities, as well as those wastes related to daily performance.

ORR was proposed by the EPA for placement on the National Priorities List under CERCLA on July 14, 1989 [54 *Federal Register (FR)* 29820], with final National Priorities Listing on Nov. 21, 1989, effective Dec. 21, 1989 (54 *FR* 48184). As a result of this listing, DOE, EPA, and TDEC (formerly the Tennessee Department of Health and Environment) have signed an FFA for the ER ORR (effective Jan. 1, 1992). This FFA is an Interagency Agreement required by §120 of CERCLA. FFA §IV discusses the coordination between RCRA and CERCLA, and states that corrective actions previously established under DOE's current RCRA permit [Hazardous and Solid Waste Amendments (HSWA) of 1984 TN 001] and the TDEC RCRA permit (TN1 890 090 003) will be supplemented with response actions under CERCLA to ensure comprehensive remediation ORR. Because ORR is on the National Priorities List, most RA activities and technologies will be legally subject to CERCLA regulation, and the FFA will govern the scheduling and character of such activities.

An effort is under way to incorporate into the FFA all inactive facilities that are known or suspected to contain significant quantities of residual hazardous materials. These facilities would be added to project lists under the FFA, and would subsequently undergo remediation pursuant to CERCLA or RCRA. Facilities that remain listed as D&D activities would be closed under the D&D program, subject to the regulatory drivers detailed in Vol. 1, Pt. A, Chap. 7. The scope of this chapter will address regulatory drivers for remedial activities proceeding under RCRA and CERCLA.

Further, DOE has entered into a number of signed agreements with state and federal parties, as well as appraisals and audits that define committed milestones for ER and WM activities. Some of these major committed milestones impacting ORNL RA activities include the *FFA for the ORR*, the *Tennessee/DOE Monitoring and Oversight Agreement (TOA)*, and the *Compliance Agreement Between the U.S. DOE - Oak Ridge Reservation and the EPA, Region IV (LDR-FFCA/ORR)*.

The FFA among DOE, EPA Region IV, and TDEC focuses on resolving compliance issues associated with ER ORR. The agreement sets up a procedural framework and schedule for developing, implementing, and monitoring response actions conducted in compliance with RCRA, CERCLA, NEPA, Tennessee laws/regulations, and other applicable and appropriate requirements.

The TOA details the obligations and agreements between DOE and TDEC with respect to the DOE provision for technical and financial support of state environmental activities. These activities include participation in the FFA, covering ER ORR, oversight, monitoring, accessing, and emergency response initiatives. Such activities are designed to ensure compliance with applicable federal, state, and local laws and regulations concerning ORR and its environs.

The LDR-FFCA/ORR was signed June 12, 1992 in order to bring mixed-waste generation and storage facilities at ORR into compliance with the RCRA land disposal restrictions (LDRs) for mixed waste. The LDR-FFCA/ORR allows DOE ORR facilities to continue to generate and store mixed wastes while addressing LDR mixed-waste compliance issues. The mixed wastes covered under the LDR-FFCA/ORR include flammable and corrosive liquids, solvents, paint waste, waste oils and organics, and solid-mixed wastes. The LDR-FFCA/ORR is addressed in more detail in Sect. 6.4.2.

In addition to the above signed agreements, other agreements are pending, including one that would allow for the continued storage of PCBs at ORNL.

The Federal Facility Compliance Act (FFCA) of 1992 (Public Law 102-386, October 6, 1992) will also impact on committed milestones for RA activities. This Act amends §6001 of the Solid Waste Disposal Act (SWDA) to waive immunity of the United States with respect to substantive and procedural requirements regarding control, abatement, or management of solid or hazardous waste and is discussed in detail in Sect. 6.4.2.

DOE has also published its strategy for development of a national compliance plan for DOE mixed waste (57 FR 57170, December 3, 1992). DOE's National Compliance Plan will integrate ER and D&D activities with the development of appropriate mixed-waste treatment, storage and disposal capacity.

A second group of milestones, not considered commitments, are derived primarily from DOE's annual *Five Year Plan*, *Current Year Work Plans*, and *Activity Data Sheets*.

All of the above milestones, both committed and uncommitted, currently serve as regulatory drivers for RA activities in addition to applicable promulgated regulations triggered under CERCLA. This chapter will only define regulatory drivers for D&D and RA activities proceeding under CERCLA (i.e., FFA ER sites). These RA activities will address contaminated soil, ground water, burial grounds, point and line sources of contamination, and pond-waste sludges. Regulatory drivers for those D&D activities that only involve decontamination and dismantling of buildings or structural components (i.e., sites that will not be listed under the FFA as ER sites) are addressed in Vol. 1, Pt. A, Chap. 7.

In addition to regulatory issues pertaining to RA, any wastes generated under any regulatory umbrella must be managed according to prescribed WM procedures. Vol. 1, Pt. C, Chap. 7, will address federal, state, and local codes, DOE orders, Interagency Agreements and Federal Facility Compliance Agreements as they apply to WM practices at ORNL.

6.2 OVERVIEW OF ENVIRONMENTAL LAWS AFFECTING RA ACTIVITIES

As DOE begins RA at some of its ORNL facilities, special attention must be given to the environmental laws that will impact on these activities. These laws were promulgated to protect public health and the environment. The requirements of these environmental laws will dictate how the RA activities are to be carried out. This section gives a general overview of the major environmental regulations that will affect DOE RA activities.

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. It is also concerned with the promotion of resource recovery techniques to reduce waste volume. The HSWA both expanded the scope of RCRA and increased the level of detail in many of its provisions.

CERCLA as amended by Superfund Amendments and Reauthorization Act (SARA) of 1986, was passed in response to a growing national concern about the release of hazardous substances into the environment. CERCLA provides for liability, compensation, clean up, and emergency response for hazardous substances released into the environment and the clean up of inactive hazardous-waste disposal sites. The intent of CERCLA is to provide for response to, and cleanup of, environmental problems that are not covered by the permit programs of the many other environmental laws.

CERCLA specifies that RA for clean up of hazardous substances must comply with requirements or standards under federal or more stringent state environmental laws that are applicable or relevant and appropriate to the hazardous substances or particular circumstances at a site. Inherent in the interpretation of ARARs is the assumption that protection of human health and the environment is ensured. The National Oil and Hazardous Substances Pollution Contingency Plan was amended to reflect changes made by SARA. In particular, Subpart E, "Hazardous Substance Response," contains a detailed plan of authorized activities involved in abating and remediating releases or threats of releases of hazardous substances, including compliance with all ARARs. If remedial activities proceed under RCRA, compliance with all legally applicable federal and state regulations must be assured; under CERCLA, compliance is also required with regulations that meet the definition of "relevant and appropriate" as defined in the National Contingency Plan.

Despite the completion of RAs to clean up a release of a hazardous substance, a natural resource such as land, fish, wildlife, biota, air, water, ground water, or drinking water supplies may suffer residual damages (i.e., the natural resource is not returned to the position it was in before the injury). In these situations, under the authority of CERCLA §122(j), a Natural Resource Trustee is authorized to conduct a natural resource damage assessment (NRDA). CERCLA authorized the Department of the Interior to promulgate regulations at 43 CFR 11 outlining the NRDA process. Because DOE caused the release, it becomes the responsible party and is liable to the Natural Resource Trustee(s) for financial compensation for the irreparable harm done to the natural resource. The NRDA process includes collecting, compiling, and analyzing information, statistics, or data through prescribed methodologies to determine damages for injuries to natural resources.

As a result of ORR's listing on the National Priorities List, DOE, EPA, and TDEC have signed a FFA for the ER ORR. This FFA is an Interagency Agreement required by §120 of CERCLA. FFA §IV discusses the coordination between RCRA and CERCLA, and states that corrective actions established under DOE's current RCRA permit and the TDEC

RCRA permit will be supplemented with response actions under CERCLA to ensure comprehensive remediation at ORR. Because ORR is on the National Priorities List, most RA activities and technologies will be legally subject to CERCLA regulation, and the FFA will govern the scheduling and character of such activities. Following is a summary of all federal laws and regulations that may be legally applicable to cleanup of ER sites that are grouped in the FFA under the umbrella of CERCLA.

The Clean Air Act (CAA) of 1970 is the major federal law regulating process and facility air emissions. The objectives of the CAA are to protect and enhance the quality of the nation's air resources and to protect public health and welfare, while fostering a beneficial productive capacity. This is accomplished through National Ambient Air Quality Standards, National Emission Standards for Hazardous Air Pollutants, air permits, and other standards and requirements set forth under the CAA. The CAA amendments of 1990 established a list of 189 hazardous-air pollutants for which technology-based emission standards must be set. Depending on the type of activity or technology proposed, RA might be subject to any one or all of these CAA standards.

The Clean Water Act of 1972 (CWA) is the major water-related statute affecting D&D activities. The objectives of CWA include prohibition of toxic discharges, protection of fish and wildlife, and availability of federal funds for public-waste treatment works. All DOE facilities that discharge wastewaters to either a surface-water body or a publicly owned treatment system must ensure compliance with the CWA.

The Safe Drinking Water Act (SDWA) of 1974 is an environmental statute that protects drinking water resources. Primary drinking water standards promulgated under the SDWA apply to drinking water "at the tap" as delivered by public water supply systems. As such, the standards are directly applicable to those DOE facilities that meet the definition of a public water supply system. Of equal significance to DOE is the fact that these drinking water standards are used to determine ground-water protection regulations under a number of other statutes.

The Atomic Energy Act (AEA) of 1954 delegates authority to DOE, NRC, and EPA to control nuclear energy. NRC has the authority to issue licenses for use of radioactive materials at certain types of facilities and can promulgate rules regulating that use. DOE is exempt from NRC's authority under the AEA. Although NRC regulations are not legally applicable to DOE sites, DOE addresses the regulation of radioactive materials in its DOE orders that are binding on all DOE sites. Standards outlined in the DOE orders reiterate, for the most part, the standards promulgated under NRC regulations.

The Toxic Substances Control Act (TSCA) of 1976 is a comprehensive act governing toxic substances. TSCA protects human health and the environment by requiring that specific chemicals be tested and that regulations restricting their processing and use be implemented. The objectives of TSCA include development of adequate data to determine the health and environmental effects of chemicals and control of any chemicals that present an unreasonable risk of injury. RA activities involving PCBs and asbestos-contaminated materials, in particular, would be regulated under this act.

The Hazardous Materials Transportation Act (HMTA) of 1975, as amended, is the major transportation-related statute affecting DOE. The objective of the HMTA is "to improve the regulatory and enforcement authority of the Secretary of Transportation to protect the nation adequately against risks to life and property which are inherent in the transportation of hazardous materials in commerce." Any transportation of hazardous or radioactive materials off site from an RA site would be regulated under HMTA.

The Occupational Safety and Health Act (OSHA) of 1970 is concerned with providing employees with a safe and healthy working environment. Under OSHA, rules have been promulgated to protect employees involved with 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. All OSHA requirements apply to all DOE ER activities. DOE 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 Government-Owned, Contractor-Operated Facilities*), and 5480.9 (*Construction Safety and Health Program*), and it is understood that DOE will comply with these Orders. The DOE orders related to occupational safety are not addressed in this chapter unless they specifically apply to RAs.

NEPA establishes national policies and goals for protection of the environment. The purposes of NEPA include encouraging harmony between people and the environment, promoting efforts to prevent or eliminate damage to the environment and the biosphere, and encouraging the understanding of ecological systems and natural resources important to the country. NEPA ensures that federal agencies take into account the environmental impact of their actions through a procedure and detailed statement known as an Environmental Impact Statement. DOE Order 5440.1D (*National Environmental Policy Act Compliance Program*) mandates DOE compliance with the requirements of NEPA. Further, DOE Order 5400.4 [*Comprehensive Environmental Response, Compensation, and Liability Act Requirements (CERCLA)*] calls for integration of NEPA and CERCLA requirements for DOE RAs at CERCLA sites. This issue has been reaffirmed in the FFA §I(A)(3) and §III(A)(2) and Secretary of Energy Notice of Feb. 5, 1990 (SEN-15-90), which was issued to ensure that DOE's NEPA activities are carried out in a centralized and uniform manner.

The Endangered Species Act of 1973 and the Fish and Wildlife Coordination Act of 1958 are major federal statutes designed to protect plant and animal resources from adverse effects of development projects. Both acts require consultation with wildlife authorities before committing resources to certain types of projects. The Endangered Species Act provides for the designation and protection of invertebrates, wildlife, fish, and plant species that are in danger of becoming extinct and mandates conservation of the ecosystems on which such species depend. The Fish and Wildlife Coordination Act was enacted because the goals of water-related projects may at times conflict with the goal of conserving fish and wildlife resources. This act ensures that fish and wildlife resources receive equal consideration with other factors during the planning of development projects that affect water resources.

The Federal Insecticide, Fungicide, and Rodenticide Act of 1947 regulates pesticides. Its purpose is to control the use of pesticides by requiring that all pesticides be registered with the EPA. Under Federal Insecticide, Fungicide, and Rodenticide Act, EPA conducts inspections to ensure compliance with Federal Insecticide, Fungicide, and Rodenticide Act, (e.g., having pesticides labeled and stored properly). The act regulates the proper disposal of pesticides, which may impact on RA activities involving pesticides or pesticide-contaminated materials.

It should be noted that all the major environmental laws also specify designated test methods and detailed sampling and analysis protocols that must be followed when testing materials or substances or verifying the applicability of a particular law to a given situation, substance, or material.

DOE has issued orders, as discussed above, addressing many of the activities regulated under the above-mentioned environmental statutes. These DOE orders are binding between DOE and its contractors, in this case, Martin Marietta Energy Systems,

Inc., which operates the facilities in Oak Ridge, Tennessee. Pertinent DOE orders will be considered throughout the chapter as they relate to ER activities at DOE facilities.

Environmental laws enacted by the state of Tennessee generally correlate to their federal counterparts. The differences that arise between the state and federal laws will be pointed out throughout the chapter.

Specific requirements and standards promulgated under each of the above laws are discussed in detail in the following sections. This regulatory summary 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 Regulations are grouped into four major areas: (1) *chemical-specific* regulations—standards or limits based on the particular contaminant or pollutant present; (2) *radiation protection* standards—regulations governing radioactivity, promulgated to protect the public health and environment; (3) *action-specific* regulations—performance or design standards or restrictions that set limits or controls based on the kind of activity planned at a site or designed into a particular technology; and (4) *location-specific* regulations—restrictions placed on pollutant concentrations or activities solely because they are in a particular location.

6.3 CHEMICAL-SPECIFIC REGULATIONS

Chemical-specific regulations set health- or risk-based concentration limits or discharge limitations in various environmental media for specific hazardous substances, pollutants, or contaminants. These requirements generally set protective cleanup levels for the chemicals of concern in a designated medium or indicate a safe level of discharge that may be incorporated when considering a specific remedial activity.

Although limited in number, chemical-specific standards have been established under several statutes, including RCRA, SDWA, CWA, TSCA, OSHA, CERCLA, and the CAA. Designated test methods and sampling/analysis protocols are delineated under each regulation for determining applicability of chemical-specific standards. These methods and protocols must be followed exactly as outlined in the regulation.

6.3.1 Ground Water and Surface Water

Table 6.1 lists available chemical-specific standards that have been promulgated under federal law for ground water, surface water, and air. The regulations for air are listed in the table and described in Sect. 6.3.2.

All ground water at ORR is scheduled to be cleaned up under CERCLA as part of the ER Program. As stated in the National Contingency Plan (55 *FR* 8666, March 8, 1990), the goal of EPA's approach to cleanup of contaminated ground water is to return usable ground water to its beneficial use within a given time frame that is reasonable for the particular circumstances at a CERCLA site. Ground water at ORR has not been given an EPA classification. Although not legally applicable unless promulgated, EPA guidance on ground-water classification should be used to determine whether ground water at ORR falls within Class I, II, or III. Classes I and IIA represent current sources of drinking water of varying value, Class IIB represents potential sources of drinking water, and Class III ground water is not considered a potential source of drinking water and is of limited beneficial use. Restoration time periods vary, depending on the use classification of the ground water, and may range from 1 year to several decades.

In the National Contingency Plan, EPA states the preference for SDWA maximum contaminant levels (MCLs) and nonzero maximum contaminant level goals (MCLGs) or other health-based standards, criteria, or guidance for cleanup of Class I and Class II ground water at CERCLA sites (55 *FR* 8732). Alternate concentration limits may also be used when active restoration of the ground water to MCLs or nonzero MCLGs is not practicable (55 *FR* 8754). For Class III ground waters, EPA establishes remediation levels based on specific site conditions, the beneficial use of the ground water, and environmental receptors (55 *FR* 8732). Final determination of applicable standards for site-specific cleanup of ground water at ORR will depend on the chosen ground-water classification.

The state of Tennessee has issued draft ground-water classification rules that classify ground water as: (1) Class A—current or future sources of drinking water; (2) Class B—not a current or future source of drinking water but protected for other beneficial uses; (3) Class C—not protected for drinking water or for other beneficial uses; and (4) Surface Water Recharge—ground water that recharges surface waters.

Class A ground waters are listed by aquifers; two are identified for East Tennessee—Cambrian-Ordovician Carbonate Aquifer and Crystalline Rock Aquifer. Final promulgation of this ground-water classification rule is projected for mid-1993.²

Table 6.1. Chemical-specific federal regulations for protection of human health^a

Chemical	RCRA ^b MCLs ^c (µg/L)	Safe Drinking Water Act MCLs (µg/L)	Safe Drinking Water Act MCLGs ^d (µg/L)	Clean Air Act NAAQS ^e (µg/m ³)
Acrylamide ^f		TT ^g	0	
Adipates [di(ethylhexyl)adipate] ^h		400	400	
Alachlor ^f		2	0	
Aldicarb ⁱ		3	1	
Aldicarb sulfone ⁱ		2	1	
Aldicarb sulfoxide ⁱ		4	1	
Antimony ^h		6	6	
Arsenic ^j	50	50		
Asbestos (fibers >10µm) ^f		7 ^k	7 ^k	
Atrazine ^f		3	3	
Barium ⁱ	1,000	2,000	2,000	
Benzene ^m		5	0	
Benzo(a)pyrene ^h		0.2	0	
Beryllium ^h		4	4	
Cadmium ⁿ	10	5	5	
Carbofuran ^f		40	40	
Carbon monoxide				40,000 (1-h) ^o 10,000 (8-h) ^o
Carbon tetrachloride ^m		5	0	
Chlordane ^f		2	0	
Chromium (total) ⁿ	50	100	100	
Copper		TT ^p	1,300	
Cyanide ^h		200	200	
Dalapon ^h		200	200	
1,2-Dibromo-3-chloropropane ^f		0.2	0	
o-Dichlorobenzene ^f		600	600	

Table 6.1 (continued)

Chemical	RCRA ^b MCLs ^c (µg/L)	Safe Drinking Water Act MCLs (µg/L)	Safe Drinking Water Act MCLGs ^d (µg/L)	Clean Air Act NAAQS ^e (µg/m ³)
<i>p</i> -Dichlorobenzene ^m		75	75	
1,2-Dichloroethane ^m		5	0	
1,1-Dichloroethylene ^m		7	7	
<i>cis</i> -1,2-Dichloroethylene ^f		70	70	
<i>trans</i> -1,2-Dichloroethylene ^f		100	100	
Dichloromethane (methylene chloride) ^h		5	0	
2,4-Dichlorophenoxyacetic acid (2,4-D) ⁿ	100	70	70	
1,2-Dichloropropane ^f		5	0	
Dinoseb ^h		7	7	
Diquat ^h		20	20	
Endothall ^h		100	100	
Endrin ^h	0.2	2	2	
Epichlorohydrin ^f		TT ^g	0	
Ethylbenzene ^f		700	700	
Ethylene dibromide ^f		0.05	0	
Fluoride ^g		4,000	4,000	
Glyphosate ^h		700	700	
Heptachlor ^f		0.4	0	
Heptachlor epoxide ^f		0.2	0	
Hexachlorobenzene ^h		1	0	
Hexachlorocyclopentadiene ^h		50	50	
Lead	50	TT ^p	0	1.5 (90-day) ^r
Lindane (<i>gamma</i> -HCCH) ⁿ	4	0.2	0.2	
Mercury ⁿ	2	2	2	
Methoxychlor ⁿ	100	40	40	
Monochlorobenzene ^f		100	100	

Table 6.1 (continued)

Chemical	RCRA ^b MCLs ^c (µg/L)	Safe Drinking Water Act MCLs (µg/L)	Safe Drinking Water Act MCLGs ^d (µg/L)	Clean Air Act NAAQS ^e (µg/m ³)
Nickel ^h		100	100	
Nitrate (as N) ⁿ		10,000	10,000	
Nitrite (as N) ^f		1,000	1,000	
Nitrate + Nitrite (as N) ^f		10,000	10,000	
Nitrogen dioxide				100 (1-year) ^s
Ozone				235 (1-year) ^{o,t}
Oxamyl (Vydate) ^h		200	200	
Particulate matter				260 (24-h) ^o 75 (1-year) ^u
Pentachlorophenol ^l		1	0	
Phthalates [di(ethylhexyl)phthalate] ^h		6	0	
Picloram ^h		500	500	
Polychlorinated biphenyls ^f		0.5	0	
Selenium ⁿ	10	50	50	
Silver ^v	50			
Simazine ^h		4	4	
Styrene ^f		100	100	
Sulfate ^w		400,000/500,000	400,000/500,000	
Sulfur oxides				365 (24-h) ^o 80 (1-year) ^s
Tetrachloroethylene ^f		5	0	
Thallium ^h		2	0.5	
2,3,7,8-Tetrachlorodibenzo-p-dioxin (Dioxin) ^h		0.00003	0	
Toluene ^f		1,000	1,000	
Toxaphene ⁿ	5	3	0	

Table 6.1 (continued)

Chemical	RCRA ^b MCLs ^c (µg/L)	Safe Drinking Water Act MCLs (µg/L)	Safe Drinking Water Act MCLGs ^d (µg/L)	Clean Air Act NAAQS ^e (µg/m ³)
1,2,4-Trichlorobenzene ^h		70	70	
1,1,1-Trichloroethane ^m		200	200	
1,1,2-Trichloroethane ^h		5	3	
Trichloroethylene ^m		5	0	
Trihalomethanes (total) ^{j,x}		100		
2,4,5-Trichlorophenoxy-propionic acid (2,4,5-TP) ⁿ	10	50	50	
Vinyl chloride ^m		2	0	
Xylenes (total) ^f		10,000	10,000	

^aFederally promulgated regulations under RCRA, SDWA, and the CAA are included in this table. Clean Water Act regulations are listed in Tables 6.4 and 6.5. Tennessee state drinking water MCLs/MCLGs (Chap. 1200-5-1 of the Rules of the TDEC) are identical to the federal.

^bRCRA = Resource Conservation and Recovery Act (40 CFR 264.94).

^cMCL = maximum contaminant level; RCRA MCLs are properly termed "maximum concentration limits."

^dMCLG = maximum contaminant level goal.

^eNAAQS = National Ambient Air Quality Standards (40 CFR 50.4, 50.6, 50.8 and 50.9-50.12).

^f56 FR 3526 (January 30, 1991). Effective July 30, 1992.

^gTT = treatment technology.

^h57 FR 31776 (July 17, 1992). Effective January 17, 1994 except for the MCL/MCLG for Endrin which becomes effective August 17, 1992.

ⁱEffective date for aldicarb compounds, originally set for January 1, 1993, is postponed indefinitely pending further study (57 FR 22178, May 27, 1992).

^j40 FR 59570 (December 24, 1975).

^kMillion fibers per liter.

^l56 FR 30266 (July 1, 1991). Effective January 1, 1993.

^m52 FR 25690 (July 8, 1987).

ⁿThe final MCL/MCLG was set for this chemical (56 FR 3526, January 30, 1991) and supersedes the original interim SDWA MCL. Effective July 30, 1992; interim MCLs remain in effect until that time.

^oMaximum concentration not to be exceeded more than once per year.

^pTT= treatment technology; 56 FR 26460 (June 7, 1991, effective December 7, 1992). When the "action level" of 15 or 1300 µg/L, for lead or copper, respectively, measured in the 90th percentile at the consumer's tap, is exceeded for lead or copper, corrosion control study and treatment requirements are triggered. However, an OSWER memorandum (dated June 21, 1990) recommends that a final cleanup level of 15 µg/L for lead in ground water usable for drinking water is protective of sensitive subpopulations; this is guidance, not an ARAR.

Table 6.1 (continued)

Chemical	RCRab MCLsc (µg/L)	Safe Drinking Water Act MCLs (µg/L)	Safe Drinking Water Act MCLGsd (µg/L)	Clean Air Act NAAQSe (µg/m ³)
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^qMCL - 51 FR 11396 (April 2, 1986); applies to community water systems only. MCLG - 50 FR 47141 (November 14, 1985).

^rThree-month maximum arithmetic mean concentration.

^sAnnual arithmetic mean concentration.

^tHydrocarbon emissions are controlled as part of the ozone NAAQS strategy.

^uAnnual geometric mean.

^vThe interim SDWA MCL was revoked for this chemical (56 FR 3526, January 30, 1991) and a secondary MCL established instead (see Table 6.2). Effective July 30, 1992; interim MCL of 50 µg/L remains in effect until that time.

^wThis is a *proposed* MCL/MCLG only (55 FR 30370, July 25, 1990). EPA has deferred setting a final MCL/MCLG for sulfate pending further study (57 FR 31776, July 17, 1992).

^xTotal trihalomethanes refers to the sum of the concentration of chloroform, bromodichloromethane, dibromochloromethane, and bromoform.
Source: Etnier et al., 1993.

6.3.1.1 Resource Conservation and Recovery Act

Subtitle C of RCRA lists maximum concentration levels for 14 chemicals; the concentration of these chemicals in ground water at the plant boundary of a RCRA-permitted treatment, storage, and disposal facility may not exceed the stated maximum concentration level. In addition, background concentrations or alternate concentration limits are established in 40 CFR 264.94 as ground-water protection standards. Table 6.1 lists RCRA maximum concentration levels; however, as mentioned above, EPA has specified SDWA MCLs and nonzero MCLGs for cleanup of Class I and Class II ground-water and site-specific remediation levels for Class III ground waters. This approach is consistent with the substantive requirements of RCRA maximum concentration levels, alternate concentration limits, or background limits (53 FR 51433). The newly promulgated regulations for municipal landfills (56 FR 50978, October 9, 1991) establish all SDWA MCLs by reference, and alternate concentration limits, or background concentrations as ground-water protection standards (40 CFR 258.55). Although not legally applicable to RAs found at ORR, these regulations may prove relevant and appropriate for cleanup of ground water at some of the sites. Alternate concentration limits may be calculated for chemicals without an MCL, using a risk-based approach (56 FR 51026).

Under the present RCRA Subtitle C hazardous-waste identification regulations, solid wastes ("solid wastes," as defined under RCRA, can be solid, liquid, semisolid, or contain gaseous material) generated during the D&D process would be subject to RCRA regulation under the following conditions: (1) if they are identified as RCRA-listed or RCRA-characteristic hazardous wastes pursuant to 40 CFR Part 261; (2) if they are a "mixture" of solid waste and listed hazardous waste "derived from" a listed hazardous waste, or (3) if they have a listed hazardous waste "contained in" the waste (40 CFR 261.3). Wastes are "characteristically hazardous" under RCRA if they (1) exhibit ignitability, corrosivity, reactivity, or toxicity, (2) meet certain toxicity criteria, or (3) contain certain toxic constituents (40 CFR 261.10-24). Currently, listed wastes remain hazardous unless they are "delisted" according to procedures set forth in 40 CFR 260.20 and 260.22.

In an attempt to address instances where regulation of listed hazardous waste under the jurisdiction of RCRA Subtitle C would cease without the need for a delisting petition, EPA proposed two alternative approaches for identifying a waste as a RCRA hazardous waste ("Hazardous Waste Identification Rule," 57 FR 21450, May 20, 1992). However, this proposed rule was withdrawn due to a large number of policy and technical issues. Congress has charged EPA with promulgating rules to address the "derived from" and "mixture" issues by October 1994.³

6.3.1.2 Safe Drinking Water Act

EPA has promulgated primary and secondary drinking water regulations applicable to public water systems that have at least 15 service connections or serve an average of at least 25 people daily at least 60 days of the year. National Primary Drinking Water Standards are established in 40 CFR 141 and include MCLs and MCLGs. New drinking water standards promulgated for eight synthetic organic chemicals (52 FR 25690, July 8, 1987) added a new category of suppliers referred to as noncommunity, nontransient systems that regularly serve at least 25 people for 6 months of the year. Table 6.1 lists SDWA MCLs and MCLGs.

MCLs are enforceable standards that take into consideration human health effects, available treatment technologies, and costs of treatment. MCLGs are strictly health-based standards that disregard cost or treatment feasibility and are not legally enforceable. MCLs are legally applicable to water "at the tap" but are not applicable to cleanup of ground water or surface water. However, they may be considered as relevant and appropriate in situations where ground water or surface water may be used for drinking water. CERCLA §121(d)(2)(A) specifically mentions that RAs must require a level or standard of control that at least attains MCLGs and federal ambient water quality criteria (WQC) where such goals or criteria are relevant and appropriate under the circumstances of the release. Although MCLGs and WQC are nonenforceable guidelines, Congress elevated them to a higher status by specifically mentioning them in CERCLA. Therefore, promulgated MCLGs are listed in Table 6.1. At present, EPA is planning to use the SDWA MCLs for RA compliance for carcinogens that have an MCLG of zero and any nonzero MCLG for systemic toxicants (55 FR 8752).

EPA has revised its drinking water standards for lead and copper, eliminating the MCL and replacing it with a treatment technique requirement (56 FR 26460, June 7, 1991). If an "action level" of 15 or 1300 µg/L, for lead or copper, respectively, is exceeded at the tap, a state is required to analyze source water samples and to decide what treatment levels are necessary to minimize lead or copper levels delivered to users from the affected distribution system. In the instance of contaminated ground water, the action levels for lead and copper are neither legally applicable nor relevant and appropriate for cleanup; however, for copper, the MCLG of 1300 µg/L is relevant and appropriate. In addition, the EPA Office of Solid Waste and Emergency Response final cleanup level of 15 µg/L for lead in ground water usable for drinking water is protective of sensitive populations (Office of Solid Waste and Emergency Response memorandum dated June 21, 1990). This might be considered TBC guidance for remediation of lead-contaminated ground water (footnoted in Table 6.1) and will serve as guidance to ensure the precision of analytical detection limits. TDEC has proposed a cleanup criteria of 15 µg/L for lead in ground water (TDEC Rule 1200-1-13-.08, Table 8-2). When promulgated this criteria will be applicable to cleanup.

Chapter 1200-5-1 of the Rules of the TDEC lists MCLs for public water systems that are identical to the federal MCLs. Therefore, the state regulations are not repeated here.

National Secondary Drinking Water Standards regulate contaminants that affect the aesthetic qualities related to public acceptance of drinking water and are implemented in 40 CFR 143.3 as secondary maximum contaminant levels (SMCLs) (see Table 6.2). These regulations are not federally enforceable but are intended to serve as guidelines for use by states in regulating water supplies. Tennessee has promulgated SMCLs in Chap. 1200-5-1.12 of the Rules of the TDEC (see Table 6.2). These regulations are designed to provide water to the consumer, which is aesthetically pleasing, and they apply to all community water systems and to those noncommunity water systems "as may be deemed necessary" by TDEC. In that context, they would not be legally applicable to cleanup of ground water or surface water, but may be considered as relevant and appropriate in instances where these media may provide private drinking water sources. EPA has proposed National Secondary Drinking Water Standards for ten additional contaminants (54 FR 22062, May 22, 1989; 55 FR 30370 July 25, 1990); when these are promulgated, they will be incorporated into the TDEC secondary drinking water regulations.⁴ Therefore, they are included in Table 6.2 for completeness. EPA has published a final National Secondary Drinking Water Standards for aluminum and silver (56 FR 3526, January 30, 1991).

Table 6.2. Federal and Tennessee secondary drinking water regulations

Chemical	Federal SMCL ^a (mg/L)	Tennessee SMCL ^b (mg/L)
Aluminum	0.05–0.2 ^{c,d}	
Chloride	250	250
Color (color units)	15	15
Copper	1	1
<i>o</i> -Dichlorobenzene ^e	0.01	
<i>p</i> -Dichlorobenzene ^e	0.005	
Ethylbenzene ^e	0.03	
Fluoride	2.0	2.0
MBAS (methyl blue active substance)		0.5
Hexachlorocyclopentadiene ^f	0.008	
Iron	0.3	0.3
Manganese	0.05	0.05
Odor (threshold odor number)	3	3
Pentachlorophenol ^e	0.03	
pH	6.5–8.5	6.5–8.5
Silver	0.1 ^c	
Styrene ^e	0.01	
Sulfate	250	250
Toluene ^e	0.04	
TDS (total dissolved solids)	500	500
Xylene ^e	0.02	0.02
Zinc	5	5

^aFinal rule [44 FR 42198 (July 19, 1979)]. National Secondary Drinking Water Standards (NSDWS) are included in this table for completeness because they will be incorporated into the TDEC secondary drinking water regulations when they are revised.

^bChapter 1200-5-1.12 of the Rules of the TDEC.

^cNSDWS final rule [56 FR 3526 (January 30, 1991)]. Effective date July 30, 1992.

^dLevel recommended to prevent posttreatment precipitation in the distribution system.

^eProposed NSDWS (54 FR 22062, May 22, 1989). EPA has deferred setting final standards for these chemicals pending further study (56 FR 3572, January 30, 1991).

^fProposed NSDWS (55 FR 30370, July 25, 1990); EPA has deferred setting a final standard for this chemical pending further study (57 FR 31776, July 17, 1992).

6.3.1.3 Clean Water Act

CERCLA §121(d)(2)(A) specifically states that RAs shall at least attain federal ambient WQC established under the CWA if they are relevant and appropriate. In determining whether any WQC are relevant and appropriate, one must consider the “designated or potential use of the surface or ground water, the environmental media affected, the purposes for which the criteria were developed, and the latest information available” [CERCLA §121(d)(2)(B)]. Federal WQC are derived for the protection of freshwater aquatic organisms and for the protection of human health from the consumption of contaminated drinking water and/or aquatic organisms.

Table 6.3 lists federal ambient WQC for the protection of human health. EPA has derived WQC for ingestion of drinking water and aquatic organisms and for the ingestion of aquatic organisms alone. Since neither of these categories is relevant and appropriate for consideration of contaminated ground water, WQC derived for the ingestion of drinking water alone are also included in Table 6.3. The EPA Region IV Water Quality Standards Unit has adjusted WQC for human health based on recent human toxicity information [reference doses (RfDs) and carcinogen slope factors (CSFs)] obtained from the EPA *Integrated Risk Information System*⁵. The values presented in Table 6.3 reflect the EPA Region IV revised WQC and are current as of October 1991.⁶ They are intended to supersede all previous WQC. Federal WQC are not promulgated standards. They are intended to serve as guidelines for individual states to use in promulgating state water quality standards. When a state adopts federal WQC and promulgates them in their state regulations, then they become legally enforceable under that state's law.

As part of the federal requirement for a triennial review of state water quality standards, the TDEC Division of Water Pollution Control has promulgated amendments to Chaps. 1200-4-3 and 1200-4-4 of the Rules of the TDEC. TDEC has revised its water quality standards and promulgated the federal SDWA MCLs as WQC for domestic water supplies (effective date Aug. 30, 1991). Included in this revision are criteria for protection of recreational uses. These criteria are human health criteria derived to protect the consumer from consumption of contaminated fish; these criteria are similar to the federal WQC for the protection of human health from consumption of fish alone. However, they are based on a risk of 10^{-5} rather than the 10^{-6} risk on which the federal WQC are based. Tennessee WQC for human health are listed in Table 6.4.

Chapter 1200-4-3 of the Rules of the TDEC lists seven use-designation categories for Tennessee's surface waters and ground waters. Specific water quality standards are promulgated for each use category. Under the Tennessee Water Quality Control Act, the Tennessee Water Quality Control Board has classified the Clinch River for domestic water supply, industrial water supply, fish and aquatic life, recreation, irrigation, and livestock watering and wildlife uses (Chap. 1200-4-4 of the Rules of the TDEC). The tributaries to the Clinch River have various use classifications, that need to be analyzed on a site-specific basis. The standards also state that "all other streams, named and unnamed, which have not been specifically noted shall be classified for fish and aquatic life, recreation, irrigation, and livestock watering and wildlife uses." TDEC has promulgated a change in the use classification that adds recreation as a category for all segments of rivers and streams that are not currently classified as such (effective August 1991).

Table 6.5 lists federal WQC for the protection of freshwater aquatic life. EPA Region IV has also revised these WQC based on current toxicity and bioaccumulation data for aquatic organisms, and these appear in Table 6.5 as well. When the designated use classification requires protection of aquatic life or when environmental factors are being considered at an RA site, a WQC for the protection of aquatic life that is more stringent than the SDWA MCL may be appropriate for cleanup. TDEC has promulgated WQC for the protection of aquatic organisms, effective Aug. 30, 1991; these are identical, for the most part, to the federal WQC and are listed in Table 6.4.

6.3.2 Air Standards

Primary National Ambient Air Quality Standards for six chemicals appear in 40 CFR 50; these standards are based on the direct health effects of those chemicals to sensitive groups, with no economic factors considered. The National Ambient Air Quality Standards take into consideration all sources of exposure to a given chemical and establish ceilings that are not to be exceeded in the United States. Only major new

**Table 6.3. Federal ambient water quality criteria (WQC)
for the protection of human health (µg/L)**

Chemical	WQC for aquatic organisms and drinking water ^a	WQC for aquatic organisms alone ^a	WQC for drinking water alone ^b
Acenaphthene	20 (org) ^c	NA ^d	2,100
Acrolein	320	780	
Acrylonitrile	0 (0.059)	0 (0.67)	0 (0.065)
Aldrin	0 (1.3E-04) ^e	0 (1.4E-04)	0 (2.1E-03)
Anthracene	9,567.2	107,692	10,500
Antimony	14	4,308	14
Arsenic	0 (0.018)	0 (0.14)	0 (0.02)
Asbestos	0 (30,000 fibers/L)	NA	
Benzene	0 (1.18)	0 (71.28)	0 (1.2)
Benzidine	0 (1.2E-04)	0 (5.4E-04)	0 (1.5E-04)
Benzo(a)anthracene	0 (2.8E-03)	0 (0.031)	
Benzo(a)pyrene	0 (2.8E-03)	0 (0.031)	
Benzo(k)fluoranthene	0 (2.8E-03)	0 (0.031)	
3,4-Benzofluoranthene	0 (2.8E-03)	0 (0.031)	
Beryllium	0 (7.7E-03)	0 (0.13)	0 (8.1E-03)
Bromoform	0 (4.38)	0 (363.5)	0 (4.4)
Carbon tetrachloride	0 (0.254)	0 (4.42)	0 (0.27)
Chlordane	0 (5.8E-04)	0 (5.9E-04)	0 (0.03)
Chlorinated benzenes			
Monochlorobenzene	20 (org)	NA	700
1,2-Dichlorobenzene	2,667	17,432	3,150
1,3-Dichlorobenzene	400	2,600	
1,4-Dichlorobenzene	400	2,600	
1,2,4,5-Tetrachlorobenzene	38	48	
Pentachlorobenzene	74	85	
Hexachlorobenzene	0 (7.5E-04)	0 (7.7E-04)	
Chlorinated ethanes			
1,2-Dichloroethane	0 (0.38)	0 (98.6)	0 (0.38)
1,1,1-Trichloroethane	3,094	173,077	3,150
1,1,2-Trichloroethane	0 (0.605)	0 (41.99)	0 (0.61)
1,1,2,2-Tetrachloroethane	0 (0.172)	0 (10.8)	0 (0.175)
Hexachloroethane	0 (1.95)	0 (8.85)	0 (2.5)
Chlorinated phenols			
2-Chlorophenol	0.1 (org)	NA	175
2,4-Dichlorophenol	0.3 (org)	NA	105
2,4,5-Trichlorophenol	1.0 (org)	NA	
2,4,6-Trichlorophenol	0 (2.1)	0 (6.5)	0 (3.2)
Pentachlorophenol	0 (0.28)	0 (8.2)	0 (0.29)
3-Methyl-4-chlorophenol	3,000 (org)	NA	

Table 6.3 (continued)

Chemical	WQC for aquatic organisms and drinking water ^a	WQC for aquatic organisms alone ^a	WQC for drinking water alone ^b
Chloroalkyl ethers			
bis-(Chloromethyl) ether	0 (1.6E-04)	0 (0.077)	0 (1.6E-04)
bis-(2-Chloroethyl) ether	0 (0.031)	0 (1.42)	0 (0.032)
bis-(2-Chloroisopropyl) ether	1,389	174,400	1,400
Chlorodibromomethane	0 (0.412)	0 (34.2)	0 (0.417)
Chloroform	0 (5.67)	0 (470.8)	0 (5.74)
Chromium (III)	33,300	673,077	35,000
Chrysene	0 (2.8E-03)	0 (0.031)	
Copper	1,000 (org)	NA	
DDD	0 (8.3E-04)	0 (8.3E-04)	0 (0.15)
DDE	0 (5.9E-04)	0 (5.9E-04)	0 (0.103)
DDT	0 (5.9E-04)	0 (5.9E-04)	0 (0.103)
Dibenz(a,h)anthracene	0 (2.8E-03)	0 (0.031)	
3,3'-Dichlorobenzidine	0 (0.04)	0 (0.77)	0 (0.078)
Dichlorobromomethane	0 (0.27)	0 (22.1)	0 (0.27)
Dichlorodifluoromethane	0 (5.67)	0 (470.8)	
1,1-Dichloroethylene	0 (0.06)	0 (3.2)	0 (0.058)
Dichloropropanes/Dichloropropenes			
cis-1,3-Dichloropropene	10.4	1,691	10.5
trans-1,3-Dichloropropene	10.4	1,691	10.5
Dieldrin	0 (1.4E-04)	0 (1.4E-04)	0 (2.2E-03)
2,4-Dimethylphenol	400 (org)	NA	200
2,4-Dinitrotoluene	0 (0.11)	0 (9.1)	
1,2-Diphenylhydrazine	0 (0.041)	0 (0.54)	0 (0.044)
Endosulfan(a-,b-)	0.932	1.99	1.8
Ethylbenzene	3,120	28,718	3,500
Fluoranthene	295.5	374.6	1,400
Fluorene	1,275.6	14,358.5	1,400
Halomethanes	0 (5.67)	0 (470.8)	
Heptachlor	0 (2.1E-04)	0 (2.1E-04)	0 (8.1E-03)
Heptachlor epoxide	0 (1.0E-04)	0 (1.0E-04)	0 (3.8E-03)
Hexachlorobutadiene	0 (0.45)	0 (49.7)	0 (0.45)
Hexachlorocyclohexanes (HC-CH)			
Alpha-HCCH	0 (0.004)	0 (0.013)	0 (5.5E-03)
Beta-HCCH	0 (0.014)	0 (0.046)	0 (0.02)
Gamma-HCCH	0 (0.019)	0 (0.063)	

Table 6.3 (continued)

Chemical	WQC for aquatic organisms and drinking water ^a	WQC for aquatic organisms alone ^a	WQC for drinking water alone ^b
Hexachlorocyclopentadiene	1 (org)	NA	245
Indeno(1,2,3-cd)pyrene	0 (2.8E-03)	0 (0.031)	
Isophorone	0 (8.42)	0 (599.7)	0 (8.5)
Mercury	0.151	0.153	
Methyl bromide	48	4,020	49
Methyl chloride	0 (5.67)	0 (470.8)	
Methylene chloride	0 (4.65)	0 (1,578)	0 (4.7)
Nickel	607	4,584	700
Nitrobenzene	17.3	1,863	17.5
Nitrophenols			
2,4-Dinitrophenol	69.7	14,264	70
2-Methyl-4,6-dinitrophenol	13.4	765	
Nitrosamines			
<i>n</i> -Nitrosodimethylamine	0 (6.9E-04)	0 (8.12)	0 (6.8E-04)
<i>n</i> -Nitrosodiphenylamine	0 (4.95)	0 (16.2)	0 (7.1)
<i>n</i> -Nitrosopyrrolidine	0 (0.016)	0 (91.9)	
Pentachlorobenzene	74	85	
Phenol	300 (org)	4,615,385	21,000
Phthalate esters			
Butylbenzyl phthalate	2,984	5,202	7,000
Diethylphthalate	22,631	118,019	10,500
Dimethylphthalate	313,000	2,900,000	
Di- <i>n</i> -butylphthalate	2,715	12,100	3,500
Bis-2-ethylhexylphthalate	0 (1.8)	0 (5.9)	0 (2.5)
Polychlorinated biphenyls (1016, 1221, 1242, 1254, 1260)	0 (4.4E-05)	0 (4.5E-05)	0 (4.5E-03)
Polynuclear aromatic hydrocarbons	0 (2.8E-03)	0 (3.11E-02)	
Pyrene	956.7	10,769.2	1,500
2,3,7,8-Tetrachlorodibenzo- <i>p</i> -dioxin	0 (1.3E-08)	0 (1.4E-08)	0 (2.2E-07)
1,2,4,5-Tetrachlorobenzene	38	48	
Tetrachloroethylene	0 (0.8)	0 (8.9)	
Thallium	13	48	
Toluene	6,764.8	201,294	70,000
Toxaphene	0 (7.3E-04)	0 (7.5E-04)	0 (0.032)
Trichloroethylene	0 (2.7)	0 (80.7)	
Trichlorofluoromethane	0 (5.67)	0 (470.8)	
Vinyl chloride	0 (2)	0 (525)	
Zinc	5,000 (org)	NA	

^aThe criterion value of zero for all potential carcinogens is listed in the table. Concentrations in parentheses for potential carcinogens correspond to a risk of 10⁻⁶.

^bThese adjusted criteria, for drinking water ingestion only, are estimated using a reference dose or carcinogen potency factor and a body weight of 70 kg and water ingestion rate of 2 L/day.

^cCriteria designated as organoleptic are based on taste and odor effects, not human health effects. Health-based WQC are not available for these chemicals.

^dNA = not available.

^eRead as 1.3 × 10⁻⁴.

Source: U.S. Environmental Protection Agency, Region IV Criteria Charts, October 1991.

**Table 6.4. Tennessee water quality criteria for
designated water uses (µg/L)^a**

Chemical	Domestic Water Supply	Recreation ^b	Fish and Aquatic Life	
			CMC ^c	CCC ^d
Acenaphthylene	NA ^h	0.3	NA	NA
Acrolein	NA	780	NA	NA
Acrylonitrile	NA	6.7	NA	NA
Aldrin	NA	0.0014	3	NA
Anthracene	NA	0.03	NA	NA
Antimony	NA	4310	NA	NA
Arsenic (III)	NA	NA	360	190
Arsenic (total)	50	NA	NA	NA
Benzene	5	710	NA	NA
Benzo(a)anthracene	NA	0.3	NA	NA
Benzo(a)pyrene	NA	0.3	NA	NA
3,4-Benzofluoranthene	NA	0.3	NA	NA
Benzo(k)fluoranthene	NA	0.3	NA	NA
Beryllium	NA	1.3	NA	NA
<i>g</i> -BHC (Lindane)	4	0.63	2	0.08
Bis(2-chloroethyl)ether	NA	14	NA	NA
Bis(2-ethylhexyl)phthalate	NA	59	NA	NA
Boron	NA	NA	NA	NA
Bromoform - (Tribromomethane)	NA	4700	NA	NA
Cadmium	10	NA	4 ^e	1 ^e
Carbon tetrachloride	5	44	NA	NA
Chlordane	NA	0.006	2.4	0.0043
Chloroform - (Trichloromethane)	NA	4700	NA	NA
Chromium (III)	NA	670,000	NA	NA
Chromium (hexavalent)	NA	NA	16	11
Chromium (total)	50	NA	NA	100
Chrysene	NA	0.03	NA	NA
Cobalt	NA	NA	NA	NA
Copper	NA	NA	18 ^e	12 ^e
Cyanide	NA	NA	22	5.2
4,4'-DDT	NA	0.006	1.1	0.001
4,4'-DDE	NA	0.006	NA	NA
4,4'-DDD	NA	0.008	NA	NA
1,2-Dichlorobenzene	NA	17,000	NA	NA
1,3-Dichlorobenzene	NA	2600	NA	NA
1,4-Dichlorobenzene- (<i>para</i> -Dichlorobenzene)	75	2,600	NA	NA
Dichlorobromomethane	NA	4700	NA	NA

Table 6.4 (continued)

Chemical	Domestic Water Supply	Recreation ^b	Fish and Aquatic Life	
			CMC ^c	CCC ^d
1,2-Dichloroethane	5	990	NA	NA
1,1-Dichloroethylene	7	32	NA	NA
1,3-Dichloropropylene	NA	1700	NA	NA
Dieldrin	NA	0.0014	2.5	0.0019
Diethyl phthalate	NA	120,000	NA	NA
Dimethyl phthalate	NA	2,900,000	NA	NA
Di-n-butyl phthalate	NA	12,000	NA	NA
2,4-Dinitrophenol	NA	14,000	NA	NA
2,4-Dinitrotoluene	NA	42	NA	NA
Dioxin	NA	0.000001	NA	NA
<i>a</i> -Endosulfan	NA	2.0	0.22	0.056
<i>b</i> -Endosulfan	NA	2.0	0.22	0.056
Endrin	0.2	NA	0.18	0.0023
Ethylbenzene	NA	29,000	NA	NA
Fluoranthene	NA	54	NA	NA
Fluorene	NA	0.03	NA	NA
Heptachlor	NA	0.002	0.52	0.0038
Heptachlor epoxide	NA	0.001	0.52	0.0038
Hexachlorobenzene	NA	0.007	NA	NA
Hexachlorobutadiene	NA	500	NA	NA
Hexachlorocyclo- pentadiene	NA	NA	NA	NA
Hexachloroethane	NA	89	NA	NA
Lead	50	NA	82 ^e	3 ^e
Lindane (<i>g</i> -BHC)	4	0.63	2	0.08
Lithium	NA	NA	NA	NA
Manganese	50 ^f	NA	NA	NA
Mercury	2	0.15	2.4	0.012
Methyl chloride - (Chloromethane)	NA	4700	NA	NA
2-Methyl-4,6-dinitro- phenol (4,6-Dinitro- <i>o</i> -cresol)	NA	765	NA	NA
Methylene chloride - (Dichloromethane)	NA	16,000	NA	NA
<i>n</i> -Butylbenzyl phthalate	NA	NA	NA	NA
Nickel	NA	4600	1400	160
Nitrobenzene	NA	1900	NA	NA
Pentachlorophenol	NA	NA	20 ^g	13 ^g
Phenanthrene	NA	0.03	NA	NA

Table 6.4 (continued)

Chemical	Domestic Water Supply	Recreation ^b	Fish and Aquatic Life	
			CMC ^c	CCC ^d
Polychlorinated biphenyls				
PCB-1242	NA	0.0005	NA	NA
PCB-1254	NA	0.0005	NA	NA
PCB-1221	NA	0.0005	NA	NA
PCB-1232	NA	0.0005	NA	NA
PCB-1248	NA	0.0005	NA	NA
PCB-1260	NA	0.0005	NA	NA
PCB-1016	NA	0.0005	NA	NA
PCBs (total)	NA	0.001	NA	0.001
Pyrene	NA	0.03	NA	NA
Selenium	10	NA	20	5
Silver	50	NA	4 ^e	NA
1,1,2,2-Tetrachloroethane	NA	110	NA	NA
Tetrachloroethylene	NA	88	NA	NA
Toluene	NA	300,000	NA	NA
Toxaphene	5	0.008	0.73	0.0002
1,1,1-Trichloroethane	200	170,000	NA	NA
1,1,2-Trichloroethane	NA	420	NA	NA
Trichloroethylene	5	807	NA	NA
2,4,6-Trichlorophenol	NA	6.5	NA	NA
Vanadium	NA	NA	NA	NA
Vinyl chloride	2	5250	NA	NA
Zinc	5000 ^f	NA	117 ^e	106 ^e

^aRules of the TDEC, Chap. 1200-4-3.

^bBased on a 10⁻⁵ risk level for carcinogens.

^cCMC = criterion maximum concentration.

^dCCC = criterion continuous concentration.

^eCalculated for a water hardness of 100 mg/L, the approximate average hardness of the Clinch River.

^fSecondary MCL; Rules of the TDEC, Chap. 1200-5-1.12.

^gAt pH = 7.8.

^hNA = not available.

Table 6.5. Federal ambient water quality criteria for the protection of freshwater organisms

Chemical	Maximum ^a (µg/L)	24-h (µg/L) ^b
Aldrin	3	NA ⁱ
Aluminum	750 ^c	87 ^c
Ammonia	Concentrations are temperature and pH dependent	
Arsenic (III)	360	190
Cadmium	1.8 ^d	0.66 ^d
Chlordane	2.4	4.3E-03 ^{e, f}
Chloride	860,000	230,000
Chlorine	19	11
Chlorpyrifos	0.083	0.041
Chromium (VI)	16	11
(III)	984 ^d	117 ^d
Copper	9.22 ^d	6.54 ^d
Cyanide	22	5.2
Dichlorodiphenyl-trichloroethane (DDT)	1.1	1.0E-03 ^g
Demeton	NA	0.1
Dieldrin	2.5	1.9E-03 ^f
Endosulfan	0.22	0.056
Endrin	0.18	2.3E-03 ^f
Guthion	NA	0.01
Heptachlor	0.52	3.8E-03 ^f
Heptachlor epoxide	0.52	3.8E-03 ^f
Hexachlorocyclohexanes (HCCH) gamma-HCCH (Lindane)	2	0.08
Hydrogen sulfide	NA	2
Iron	NA	1,000
Lead	33.8 ^d	1.32 ^d
Malathion	NA	0.1
Mercury	2.4	0.012 ^f
Methoxychlor	NA	0.03
Mirex	NA	1.0E-03
Nickel	789 ^d	88 ^d
Parathion	0.065	0.013
Pentachlorophenol	3.32 ^h	2.1 ^h
pH	NA	6.5-9
Polychlorinated biphenyls	NA	0.014 ^g
Selenium (inorganic selenite)	20	5
Silver	1.23 ^d	NA
Sulfides	NA	2
Zinc	65 ^d	59 ^d

^aOne-hour average concentration not to be exceeded more than once every 3 years.

^bFour-day average concentration not to be exceeded more than once every 3 years.

^cpH 6.5-9.0.

^dWater hardness dependent criteria (50 mg/L as CaCO₃).

^eRead as 4.3 × 10⁻³.

^fBased on marketability of fish.

^gFinal residue value based on wildlife feeding study.

^hpH dependent criteria.

ⁱNA = not available.

Source: U.S. Environmental Protection Agency, Region IV Criteria Chart, October 1991.

sources, or major modifications to existing sources, must ensure regional attainment of National Ambient Air Quality Standards. Although ORR is in a Tennessee state "attainment" area, it is unlikely that any emissions from RA cleanup will be considered a "major" source under present federal law. EPA has, however, listed "site remediation" as a major source category under Section 112(c) of the CAA (57 FR 31576, July 16, 1992). A regulatory schedule was issued in September 1992 for promulgating emission standards under Section 112(e) of the CAA for these newly-listed major source categories.

National Ambient Air Quality Standards are established as the criteria state and local governments must plan to achieve and, thus, are not directly enforceable. Under §110 of the CAA, states are required to implement regulations to achieve the National Ambient Air Quality Standards. The ambient air quality standards established by the TDEC Division of Air Pollution Control appear in Chap. 1200-3-3 of the Rules of the TDEC and are identical to the federal primary National Ambient Air Quality Standards (see Table 6.1). The ambient standards of 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 legally applicable if they apply to any of the remedial activities selected. Tennessee state air emission standards are considered "hybrid" regulations and will be summarized as action-specific regulations in Sect. 6.5.3; they would have to be analyzed on a site-specific basis depending on the type of RA planned for a site.

National Emission Standards for Hazardous Air Pollutants for various industrial sources that emit one of several pollutants are established in 40 CFR 61. Most of the National Emission Standards for Hazardous Air Pollutants are generally not legally applicable to cleanup at CERCLA sites because they regulate particular types of sources that would not be expected to be found at these sites. However, the National Emission Standards for Hazardous Air Pollutants for asbestos and radionuclides should be considered as potential "hybrid" regulations on a site-specific basis depending on the RAs planned at a site. The National Emission Standards for Hazardous Air Pollutants for radionuclides is discussed in Sect. 6.4.2.

The CAA Amendments of 1990 establish a list of 189 additional hazardous air pollutants for which technology-based standards must be promulgated. These will be applicable to categories of emission sources rather than to the substances emitted. A draft schedule has been published for promulgation of these technology-based standards (57 FR 44147).

6.3.3 Soil Regulations

Very little legislation or guidance is available governing cleanup criteria for contaminated soils. RCRA has addressed land disposal of treated hazardous wastes in its LDRs (40 CFR 268), and these are addressed as action-specific regulations in Sect. 6.5.2. If a site is identified as a RCRA Sect. 3004(u) solid waste management unit, or if RCRA-characteristic or RCRA-listed hazardous waste as defined in 40 CFR 261 is present at the site, it is subject to RCRA corrective action regulations. The proposed RCRA corrective action regulations address risk-based cleanup standards for soils (55 FR 30798); these are briefly discussed in Sect. 6.5.2. Treatment standards for contaminated soil and debris at CERCLA sites are discussed in Sect. 6.5.2.

The regulations found in the TSCA contain storage, disposal, and cleanup requirements for materials contaminated with PCBs. These regulations limit concentrations of PCBs disposed of in soil to 50 ppm and require that any soils containing concentrations of PCBs greater than 50 ppm (40 CFR 761.60) be incinerated (40 CFR 761.70) or stored in a chemical waste landfill (40 CFR 761.75). TSCA also specifies requirements that must be achieved for PCBs disposed of by incineration

(40 CFR 761.70), in a chemical waste landfill (40 CFR 761.75), or by other disposal methods [40 CFR 761.60(a)(5)(iii)]. A further discussion of the TSCA requirements appears in Sect. 6.5.6.

6.3.4 Nonregulatory Guidance

EPA has suggested cleanup values for lead in soils based on studies of blood-lead levels in exposed children. The EPA Office of Solid Waste and Emergency Response Directive 9355.4-02 (dated Sept. 7, 1989) recommends a cleanup level for soils of 500–1000 ppm lead.

Although not a legal standard, EPA has published a TSCA PCB spill cleanup policy (52 FR 10688) that recommends cleanup standards for PCBs of 25–50 ppm for sites with restricted access; a 10-ppm cleanup level is recommended for residential and unrestricted access rural areas. In this latter case, a 10-inch cap of clean soil must cover the site. In the EPA guidance report for RAs at Superfund sites containing PCBs, preliminary remediation goals are set at 1 ppm for residential land use (a risk of 10^{-5}) and between 10 and 25 ppm for industrial and/or remote areas (a risk of 10^{-4}).⁷ Alternatives should reduce concentrations to these levels or limit exposures. EPA also presents an approach to deriving cleanup levels of PCBs in sediments.⁷ This approach results in "sediment quality criteria" as a function of organic carbon concentrations and is meant to protect wildlife consumers of freshwater benthic species.

In the absence of federally or state-promulgated standards, or in the case where standards are not adequately protective, EPA states a preference for RfDs or reference concentrations (RfCs) for systemic toxicants, and CSFs for carcinogens or Office of Drinking Water Health Advisories for drinking water contaminants.⁸ The RfDs, RfCs, and CSFs are available through the *Integrated Risk Information System* and the *EPA Health Effects Assessment Summary Tables*.^{5, 9}

The EPA Office of Drinking Water has developed nonregulatory health advisories for concentrations of noncarcinogenic contaminants in drinking water at which no adverse health effects would be expected to occur. EPA uses the lifetime HA (for noncarcinogens only) to develop MCLs and MCLGs; health advisories will most likely represent future MCL proposals.

6.4 RADIATION PROTECTION STANDARDS

Very few standards are available that are legally applicable to the cleanup of radioactively contaminated media at ORNL RA sites. The AEA and its amendments delegated authority for control of nuclear energy to DOE, NRC, and EPA. In addition, certain states have regulatory authority and programs for radioactive waste. The EPA's regulations are derived from several other statutes as well, and cover many types of activities and all types of radioactive materials, including naturally occurring and accelerator-produced radioactive material (NARM). NRC licenses the possession and use of various types of radioactive materials at certain types of facilities. Tennessee is an NRC-agreement state and, as such, has its own authority and licensing regulations. In addition, Tennessee enforces NARM standards.

DOE is authorized to control all types of nuclear materials at sites under its jurisdiction and is exempt from NRC licensing and regulatory requirements; therefore, NRC regulations are not considered to be legally applicable to RA activities at DOE facilities. DOE regulations for handling and cleanup of radioactive materials are outlined in a series of internal DOE orders that are binding to DOE contractors.

Because a complete characterization of the identity and quantity of radioactive waste at ORNL RA sites has not been completed, all of the available EPA regulations will be presented here, as well as the numerical NRC values. The proper definition of "mixed low-level waste and hazardous waste" has caused considerable debate with regard to dual jurisdiction by EPA and NRC. However, EPA has published a clarification of the problem (53 FR 37045, Sept. 23, 1988), as did DOE previously [52 FR 15937, May 1, 1987 and DOE Order 5400.3 (*Hazardous and Radioactive Mixed Waste Program*, dated Feb. 22, 1989)]. In effect, mixed wastes are those containing a RCRA hazardous waste as defined in 40 CFR 261 and a radioactive waste subject to the AEA. RCRA regulations apply to the hazardous component of the waste, and AEA regulations apply to the radioactive component. When the application of both standards is conflicting or inconsistent, RCRA yields to the AEA. Tennessee received final authorization to regulate radioactive mixed waste on July 3, 1986 (53 FR 37045, Sept. 23, 1988); however, the state has not implemented any regulations or guidance related to the handling of mixed waste.¹⁰

6.4.1 Generic Below Regulatory Concern 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 below regulatory concern (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. The BRC concept is based on the premise that risk from doses to individuals for practices that are under consideration for exemption are comparable to the voluntary and involuntary risks commonly accepted by the general public from radiation exposures in their daily lives (i.e., natural background radiation, which results in risks corresponding to doses on the order of 5–10 mrem/year or an annual risk of about 10^{-6}). This level of risk is within the risk-based guidelines of 10^{-4} to 10^{-7} established by the EPA.

Based on these considerations, the NRC policy states 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 recommends 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.

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).

EPA utilizes 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 RfDs 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).

As of September 1992, the NRC has been unable to reach consensus on a BRC policy acceptable to the general public and has no plans to pursue further action on this initiative, nor does it plan to enforce the BRC policy issued in July 1990. Instead, it will focus on developing waste-stream- and media-specific risk-based BRC levels, similar to EPA's *de minimis* levels, through a series of individual rule makings. Until these individual rules are promulgated, the lack of a generic BRC policy for radioactive wastes that would guide cleanup and release of radioactive components at RA sites has hampered RA activities at DOE facilities. At present, internal DOE orders (see Sect. 6.4.5) provide the only guidance for such cleanup activities.

6.4.2 Federal Agreements and Legislation

DOE has entered into a number of signed agreements with state and federal parties that define committed milestones and impact the handling of radioactive wastes at ORNL RA sites. In addition, recent Congressional legislation, and DOE action in response to it, will also have an impact.

In June 1992, EPA and DOE signed the LDR-FFCA/ORR to bring mixed waste generation and storage facilities on the reservation into compliance with environmental law. Under the agreement, effective immediately, DOE-OR will submit plans that will include treatment and storage options for LDR mixed wastes to meet the requirements of RCRA. The plans, to be prepared by DOE, will include proposals for waste minimization, treatment studies, technology development, facility construction, and schedules for future treatment. The LDR-FFCA/ORR allows DOE ORR facilities to continue to generate and store mixed wastes while addressing LDR mixed waste compliance issues. The mixed wastes covered under the LDR-FFCA/ORR include flammable and corrosive liquids, solvents, paint waste, waste oils and organics, and solid mixed wastes.

On May 26, 1992, EPA published (57 FR 22024) a notice, proposing to find that DOE has made all but one of the demonstrations required in its application, under RCRA rules in 40 CFR 268.5, for a one-year, case-by-case extension of the May 8, 1992, effective date

of the LDRs applicable to certain mixed wastes generated or stored at 31 DOE facilities. Comments were due back to EPA by July 27, 1992, and no official final action has been taken on this proposal as yet.

The FFCA of 1992 (Public Law 102-386, October 6, 1992) amends §6001 of the SWDA to waive immunity of the United States with respect to substantive and procedural requirements regarding control, abatement, or management of solid or hazardous waste. This waiver of immunity includes injunctive relief, administrative order, or civil or administrative penalties or fines, and subjects the federal government to the full range of available enforcement tools to penalize isolated, intermittent, or continuing violations. A delayed effective date of three years from enactment of the FFCA of 1992 is applied to the waiver of sovereign immunity for mixed waste regulated under SWDA §3004(j) so long as that waste is managed in accordance with other applicable requirements. Further, DOE is expressly exempt from the three year effective date for mixed waste in violation of SWDA of §3004(j) so long as DOE has in effect a plan that has been submitted and approved pursuant to SWDA §3021(b), and an order requiring compliance with such plan has been issued pursuant to SWDA §3021(b).

Even though the waiver is not delayed for DOE facilities that are subject to an existing agreement, permit, administrative or judicial order addressing compliance with the LDR storage prohibition for mixed wastes, the waiver will not apply to DOE as long as DOE meets certain conditions specified in the Act [FFCA of 1992, Sect. 102(c)(3)]. Specifically, the waiver shall not apply to DOE for mixed waste violations of §3004(j) of SWDA for as long as DOE has submitted, has in effect, and is in compliance with, a plan pursuant to §3021(b) of SWDA, and is in compliance with an order issued pursuant to SWDA §3021(b) requiring compliance with such plan.

Further sections of the Act regulate mixed waste inventory reports and plans required to be submitted by DOE within 180 days of the enactment of the FFCA of 1992. DOE has published its strategy for development of a national compliance plan for DOE mixed waste (57 FR 57170, December 3, 1992). DOE's National Compliance Plan will integrate ER and D&D activities with the development of appropriate mixed-waste treatment, storage and disposal capacity.

6.4.3 EPA Regulations

EPA has promulgated MCLs for radionuclides in community water systems (see Table 6.6). These MCLs appear in two forms—concentration limits for certain alpha-emitting radionuclides (40 CFR 141.15) and an annual dose limit for the ingestion of certain beta- and gamma-emitting radionuclides (40 CFR 141.16). MCLs and MCLGs were proposed for radon and uranium and repropose for ²²⁶Ra and ²²⁸Ra, beta emitters, and photon emitters on July 18, 1991, and are included in Table 6.6. Final promulgation of the concentration limits was scheduled for April 1993, but Congress voted to delay promulgation until the end of 1993. EPA plans to propose a schedule extension and issue a final rule in 1994.³ As with the chemical-specific MCLs, these concentration limits may be relevant and appropriate for cleanup of contaminated ground water at ORR.

Table 6.7 lists EPA and DOE radiation protection standards that are described below. Subpart H of 40 CFR 61 addresses atmospheric radionuclide emissions from DOE facilities and may be applicable to airborne emissions during RA activities at ORNL. EPA has issued a final National Emission Standards for Hazardous Air Pollutants rule (54 FR 51654, Dec. 15, 1989) that limits emissions of radionuclides to the ambient air from DOE facilities to amounts that would not cause any member of the public to receive an effective dose equivalent of 10 mrem/year (40 CFR 61.92).

Table 6.6. Radionuclide-specific standards under the SDWA for ground water and surface water contamination at the Oak Ridge Reservation

Radionuclide	Current SDWA MCLs ^a	Proposed SDWA MCLs ^b
Radium ^c	5 pCi/L	20 pCi/L
Gross alpha ^d	15 pCi/L	15 pCi/L
Gross beta	4 mrem/year	4 mrem/year
Natural uranium		20 µg/L ^e
Radon-222		300 pCi/L
Strontium-90 ^f	8 pCi/L	52 pCi/L
Tritium ^f	20,000 pCi/L	60,900 pCi/L
All other manmade radionuclides	4 mrem/year ^f	4 mrem/year ^g

^a SDWA MCL = Safe Drinking Water Act maximum contaminant level.

^b Proposed rule, July 18, 1991 (56 FR 33050); final rule expected 1994.

^c The present MCL applies to combined ²²⁶Ra and ²²⁸Ra; the proposed MCL applies to each separately.

^d The present MCL excludes radon and uranium but includes ²²⁶Ra; the proposed MCL excludes all three radionuclides.

^e Approximately equal to 30 pCi/L.

^f These values are not MCLs; rather they are concentrations that result in the effective dose equivalent (EDE) of 4 mrem/year, the MCL for gross beta emissions.

^g If two or more radionuclides are present, the sum of their annual dose equivalent to the total body or to any organ shall not exceed 4 mrem/year.

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.

Environmental protection standards for the management, storage, and disposal of spent nuclear fuel, high-level wastes, and TRU wastes are found in 40 CFR 191. Management and storage must be conducted so as to provide a reasonable assurance that no member of the public in the general environment will receive a combined annual dose equivalent or greater than 25 mrem to the whole body and 75 mrem to any organ (40 CFR 191.03). The standards for disposal systems, originally listed in Subpart B of 40 CFR 191, were vacated by a federal appeals court decision in 1987. These standards stated that disposal systems for the wastes defined above must be designed "to provide a reasonable expectation that, for 1000 years after disposal, undisturbed performance of the disposal system shall not cause the annual dose equivalent from the disposal system to any member of the public in the accessible environment to exceed 25 mrem to the whole body and 75 mrem to any critical organ." All potential pathways must be considered (40 CFR 191.15). These vacated disposal standards thus could not be considered legally applicable to RA activities, but could provide some guidance. In 40 CFR 191.04, alternative standards are established for DOE facilities if EPA determines that such standards prevent any member of the public from receiving a continuous exposure of more than 100 mrem/year effective dose equivalent or an infrequent

Table 6.7. Radiation protection standards that may be applicable to Oak Ridge Reservation D&D activities

Regulation	Applicability	Exposure conditions	Standard
40 CFR 61	National Emission Standards for Hazardous Air Pollutants for DOE facilities	Public exposure, airborne emissions	10 mrem/year
40 CFR 141	Drinking water maximum contaminant levels	Community water systems, gross beta	4 mrem/year
40 CFR 191	Spent nuclear fuel, high-level and transuranic wastes	Public exposure, all sources	25 mrem/year (total body) 75 mrem/year (thyroid)
DOE Order 5400.5 ^a	Radiation Protection of the Public and the Environment	Public exposure, all sources	100 mrem/year
		Temporary exemption, maximum limit	500 mrem/year 1 rad/d
		Aquatic organism exposure, absorbed dose	
DOE Order 5820.2A	Radioactive Waste Management	Public exposure, all sources, excluding air	25 mrem/year
		Public exposure, atmospheric releases	10 mrem/year
DOE Order 5480.11 ^b	Radiation Protection for Occupational Workers	Worker exposure limits, continuous exposure	5 rem/year, cancer effects 50 rem/year, noncancer effects, any organ or tissue
		Public exposures, controlled areas, effective dose equivalent	100 mrem/year

^a Proposed as 10 CFR 834 (58 FR 16268, March 25, 1993); final rule expected March 1994.

^b Proposed as 10 CFR 835 (56 FR 64334, Dec. 9, 1991); final rule expected July 1993.

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.

exposure of more than 500 mrem/year effective dose equivalent from all sources, excluding natural background, and medical exposures. EPA has proposed to revise its standards to create a new Subpart B and promulgate generally applicable environmental standards to establish limits for the release of radioactive materials to the environment (58 FR 7924, February 10, 1993); a final rule is expected by February 1994. When promulgated, these standards will supersede those mentioned above as legally applicable standards.

EPA intends to develop environmental radiation protection standards for the disposal of low-level waste (possibly including NARM) under 40 CFR 193 and 764. The intent of

these standards will be to protect the public health and general environment from potential adverse effects from low-level waste disposal. These proposed regulations may provide guidance for cleanup of the RA sites when promulgated. The proposed rule is scheduled for September 1993, final rule September 1994.³

In addition, EPA intends to develop public health and environmental radiation protection criteria for cleanup of residual radioactive materials at decommissioned DOE, Department of Defense and NRC-licensed sites, as well as others. These criteria may provide useful guidance for RA activities at ORR. However, there is no schedule for action for these criteria.³

6.4.4 Department of Transportation Regulations

The Department of Transportation Regulations for Hazardous Materials list general requirements for shipping and packaging at 49 CFR 172 and 173, and for requirements for carriage by public highway at 49 CFR 177. General requirements for shipping of hazardous materials are defined in 49 CFR 172, with specific marking, labeling, and placarding regulations for radioactive materials in 49 CFR 172.310, 172.403, and 172.556, respectively. These regulations would be applicable to any off-site shipments of hazardous or radioactive materials from RA activities.

49 CFR 173, Subpart I, lists requirements for packaging and shipping radioactive materials. General package design requirements are given in 49 CFR 173.411, with specific design requirements for Type A and B packaging found in 49 CFR 173.412 and 173.413, respectively. Activity limits for normal form radioactive material (termed A_2 limits) are listed in 49 CFR 173.435 for various radionuclides. Type A packaging is authorized for shipment if each package does not exceed the A_2 value (49 CFR 173.431). If package quantities exceed the A_2 value, Type B packaging is required (49 CFR 173.431). In addition, each package of radioactive materials must be designed and prepared for shipment such that under normal conditions, the radiation level does not exceed 200 mrem/h at any external point on the package (49 CFR 173.441). Small quantities of solid radioactive materials are exempt from the packaging and shipping requirements of this part if the materials package limit is less than $10^{-3} A_2$ (49 CFR 173.4 and 173.423).

Standards for the packaging and shipment of NRC-licensed material are found in 10 CFR 71. These are not legally applicable to DOE activities. However, DOE Order 5480.3 (*Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substances, and Hazardous Wastes*) specifies the Type A packaging requirements, which are given in 49 CFR 173.411 and 412. Type B packages shall be in compliance with requirements found in 10 CFR 71. Reference is made to 10 CFR 71.41 *et seq.* for general standards for all packages and special requirements for Type B packages [DOE Order 5480.3(8)].

Regulations governing transportation of hazardous materials by public highway are found in 49 CFR 177, and specific loading and unloading requirements for radioactive materials are in 49 CFR 177.842. The number of packages in any one motor vehicle must be limited so that the total transport index number does not exceed 50. The total transport index is described as the sum of the numbers expressing the maximum radiation level in mrem/h at 1 meter (3.3 ft) from the external surface of each package (49 CFR 173.403bb).

6.4.5 DOE Orders

DOE orders are not promulgated regulations and thus are not considered to be legally binding by EPA. They are, however, binding between DOE and Martin Marietta Energy Systems, Inc., because of contractual agreements. The radiation exposure limits for members of the public from management and storage of TRU waste defined in DOE Order 5400.5 (*Radiation Protection of the Public and the Environment*, February 8, 1990) are: (1) an effective dose equivalent of 25 mrem/year to the whole body, or (2) 75 mrem/year to a single organ [5400.5(II.1c)]. The basic dose limit for routine DOE activities, including RA monitoring, cleanup, and control of residual radioactive material is 100 mrem/year. In addition, guidelines are given for levels of residual surface contamination that shall not be exceeded if a RA 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. In all instances, the overriding principle of the DOE order is that all releases of radioactive material shall be ALARA. 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. Information on application of the 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)]. Table 6.8 summarizes the contents of DOE Order 5400.5 with respect to RAs. 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 FR 16268, March 25, 1993).

DOE Order 5820.2A (*Radioactive Waste Management*, Sept. 9, 1988) states that the management of low-level waste must ensure that external exposure to the waste and concentrations of radioactive material that may be released into surface water and soil does not exceed 25 mrem/year to any member of the public. Releases to the atmosphere shall not exceed 10 mrem/year (Table 6.7). Reasonable effort should be made to maintain releases to the environment to ALARA levels. The order pertains to the management of radioactive waste and contains closure and post-closure care requirements. Table 6.9 summarizes the substantive requirements of this DOE order.

DOE Order 5480.11 (*Radiation Protection for Occupational Workers*) contains guidelines for worker protection, which are similar to those of 10 CFR 20 [i.e., 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 (Table 6.7). 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 shall 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 then be legally applicable for RA activities at ORNL.

Table 6.8. DOE Order 5400.5, "Radiation Protection of the Public and the Environment"

Action	Requirement	Chapter
Planning and performance of all DOE activities	DOE will carry out all DOE activities to ensure that radiation doses to individuals will be as low as reasonably achievable (ALARA).	I.4
Routine DOE activities including remedial action	DOE must comply with all legally applicable requirements of 40 CFR 61 (NESHAPS ^a for DOE Facilities) and 40 CFR 191 (spent nuclear fuel, high-level, and transuranic wastes).	I
	Exposures to members of the public from all radiation sources shall not cause an effective dose equivalent to be greater than 100 mrem (1 mSv) per year.	II.1a
	Exposures to members of the public from all radiation sources released into the atmosphere shall not cause an effective dose equivalent to be greater than 10 mrem (0.1 mSv) per year.	II.1b
Management and storage of spent nuclear fuel, high-level or transuranic waste at a disposal facility that is not regulated by the NRC ^b	Members of the public shall not receive an effective dose equivalent greater than 25 mrem (0.25 mSv) to the whole body or 75 mrem (0.75 mSv) to a single organ per year.	II.1c
	Radioactive materials released into public drinking water supplies shall not cause an effective dose equivalent to be greater than 4 mrem (0.4 mSv) to an individual per year. Gross alpha activity shall not exceed 1.5×10^{-8} μ Ci/ml.	II.1d
	Liquid effluents shall not cause private or public drinking water systems downstream of the facility to exceed the MCL(s) of 40 CFR 141.	II.1d(3)
Discharge of liquid waste containing radionuclides to surface water	Implementation of best available technology (BAT) treatment required if discharge is at an annual average concentration greater than the derived concentration guide (DCG) level.	II.3a(1)

Table 6.8 (continued)

Action	Requirement	Chapter
Discharge of liquid waste containing radionuclides to surface water (continued)	Discharge of liquid waste containing radionuclides to surface water at an annual average concentration less than the DCG level does not require the implementation of BAT treatment.	II.3a(2)
	The absorbed dose to native aquatic animal organisms shall not exceed 1 rad/day from exposure to liquid wastes discharged to natural waterways.	II.3a(5)
	Liquid wastes containing concentrations of radioactive materials greater than 5 times the DCG(s) may be discharged to a federal sanitary sewerage system that provides liquid waste treatment prior to discharge to surface water according to II.3a(1). ALARA process considerations are required.	II.3d(3)
	If a waste stream contains multiple radionuclides, then the DCG shall be the sum of the fractional DCG values.	II.3a(3)
Management of low-level radioactive solid waste containing no RCRA ^c constituents	Design, operational, and monitoring requirements are found in DOE Order 5820.2A (Radioactive Waste Management).	II.4
Demonstration of compliance with the dose limits	DOE shall make appropriate documentation containing information about compliance with dose limits for members of the public in the immediate vicinity and within 80 km of the site.	II.6
Conduct of radiological environmental protection programs	DCGs for water ingestion, air inhalation, and immersion in a gaseous cloud are provided as reference values. These DCGs are based on a committed effective dose equivalent of 100 mrem for the radionuclide taken into the body by ingestion or inhalation during one year.	III.2
	The DCG values apply to only one mode of exposure (i.e., either ingestion or inhalation).	III.2a

Table 6.8 (continued)

Action	Requirement	Chapter
Conduct of radiological environmental protection program (continued)	For known mixtures of radionuclides the sum of the ratios of the observed concentration of each radionuclides to its corresponding DCG must not exceed 1.0.	III.2c
Cleanup of residual radioactive material and management of resulting wastes or residues	DOE facilities shall develop plans and protocols for the implementation of this guidance.	IV.1 & 2
	These guidelines are for levels of residual radioactive material that is acceptable for public use of property without restrictions because of residual radioactive material.	IV.2c
	Generic guidelines are taken from existing radiation protection standards.	IV.2c(1)
	Authorized limits are levels of residual radioactive material that shall not be exceeded if the remedial action is to be considered completed and the property is to be released without restrictions on use.	IV.2d
	Monitoring, cleanup, and control of residual radioactive material are subject to the ALARA policy.	IV.2e
	The basic dose limits for exposure to residual radioactive material is 100 mrem (1 mSv) annually.	IV.3a
	Under unusual circumstances, the dose limit for exposure to residual radioactive material is increased from 100 mrem (1 mSv) to 500 mrem (5 mSv) annually.	IV.3b
	Residual radioactive material in soil are those concentrations in excess of background concentrations averaged over an area of 100 m ² . These derivations are obtained by means of environmental pathway analysis and basic dose limits.	IV.4a

Table 6.8 (continued)

Action	Requirement	Chapter
Cleanup of residual radioactive material and management of resulting wastes or residues (continued)	Residual concentrations of radionuclides in the air and water shall not exceed 100 mrem (1 mSv) per year.	IV.4e
	Limits for hot spots shall be developed in cases where the average concentration in any surface or below surface area equal to or less than 25 m ² exceeds the limit or guidelines by a factor of $(100/A)^{0.5}$. Reasonable effort must be made to remove any radionuclide source that exceeds 30 times the limit.	IV.4a(1)
	The generic guidelines for ²²⁶ Ra, ²²⁸ Ra, ²³⁰ Th, and ²³² Th are 5 pCi/g averaged over the first 15 cm of soil or 15 pCi/g averaged over 15-cm-thick layers of soil below the first 15 cm.	IV.4a(2)
Management of residual radioactivity above the guidelines specified in IV.1-4	Interim storage control and stabilization features shall be planned to have a minimum life of 25 years and, if reasonably achievable, an effective life of 50 years.	IV.6b(1)
	Control features must be designed so that radionuclide concentration in the ground water shall not exceed applicable federal and state standards.	IV.6b(3)
	If residual radioactive material is in inaccessible locations and would be unreasonably costly to remove and when residual radioactive material exceeds guideline values, an interim management plan may be arranged to maintain the property.	IV.6c(1)
	Administrative controls shall include (but are not limited to): <ul style="list-style-type: none"> • periodic monitoring as appropriate, • appropriate shielding, • physical barriers to prevent access, and • appropriate radiological safety measures. 	IV.6c(2)

Table 6.8 (continued)

Action	Requirement	Chapter
Management of residual radioactivity above the guidelines specified in IV.1-4 (continued)	Control and stabilization for uranium, thorium, and their decay products must be designed to last at a minimum of 200 years and if reasonably achievable have an effective life of 1000 years.	IV.6d(1)(a)
	In accordance with legally applicable federal and state standards, DOE facilities shall protect ground water.	IV.6d(1)(d)
	Use of and access to residual radioactive material shall be controlled through appropriate administrative and physical controls.	IV.6d(1)(e)
	Long-term management of other radionuclides shall be controlled by applicable requirements in Chapters II, III, and IV of DOE 5820.2A.	IV.6d(2)

^aNESHAPS = National Emission Standards for Hazardous Air Polluting Substances.

^bNRC = Nuclear Regulatory Commission.

^cRCRA = 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.

Table 6.9. DOE Order 5820.2A, "Radioactive Waste Management"

Action	Requirement	Chapter
Management of low-level radioactive waste	Development of site-specific comprehensive closure plans shall address: • Disposal sites' closure after the site has been filled for 5 years and • National Environmental Policy Act (NEPA) requirements.	III.3j(1)
	Residual radioactivity levels for surface soil will comply with DOE decommissioning guidelines (DOE Order 5400.5).	III.3j(2)
	The Oak Ridge Reservation must correct problems that could jeopardize the attainment of this order's performance objectives.	III.3j(3)
	All disposal sites and units shall be maintained to conform with RCRA ^a , CERCLA ^b , and SARA ^c standards.	III.3j(4)
	An appropriate field organization shall review and approve any closure plans for new and existing low-level waste disposal sites.	III.3j(5)
	An analysis of site performance will be the basis for terminating the monitoring and maintenance activity at closed facilities or sites at the end of the institutional control period.	III.3j(6)
Management of buried transuranic waste	All disposal sites and units shall be maintained to conform with CERCLA and SARA standards.	II.1
	Transuranic waste shall be managed to protect the health and safety of the public and the workers at the site.	II.2
	Each DOE facility will develop a site closure plan which will include: • NEPA requirements; • Applicable federal, state, and local regulations; • Permits required; • Selected closure strategy and justification; and • Postclosure monitoring and control.	II.3i(4)

^aRCRA = Resource Conservation and Recovery Act.

^bCERCLA = Comprehensive Environmental Response, Compensation, and Liability Act.

^cSARA = Superfund Amendments and Reauthorization 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.

6.5 ACTION-SPECIFIC REGULATIONS

Performance, design, or other action-specific requirements set controls or restrictions on particular kinds of activities related to the management of hazardous waste. Certain RAs at a site may invoke the appropriate action-specific regulations that specify particular performance standards or technologies, as well as specific environmental levels for discharged or residual chemicals. Action-specific regulations are established under RCRA, CERCLA, CAA, CWA, SDWA, TSCA, Federal Insecticide, Fungicide, and Rodenticide Act, and OSHA.

6.5.1 Comprehensive Environmental Response, Compensation, and Liability Act

The intent of CERCLA as amended by SARA is to provide for the cleanup of inactive hazardous waste disposal sites and to provide for response to, and cleanup of, environmental problems that are not covered adequately by the permit programs of other environmental laws. RA activities that have been incorporated into the FFA would be subject to CERCLA regulations.

The administrative requirements of RCRA (e.g., permitting, reporting, and record keeping) or any other federal or state regulations are not required for on-site RA if a facility is being cleaned up under CERCLA [CERCLA §121(e) and FFA §XXII(A)]. However, under CERCLA §121(d)(3) and FFA §XXII(B), any removal or RA involving the off-site transfer of hazardous substances, pollutants, or contaminants must involve a facility in compliance with all RCRA substantive and administrative requirements. CERCLA response actions will be coordinated with, and supplement, the corrective measures required and conducted by DOE under its current RCRA permit [FFA §IV(A)].

6.5.2 Resource Conservation and Recovery Act

RCRA has nine distinct sections (subtitles) that regulate various aspects of hazardous waste. Three of these, Subtitle C "Hazardous Waste Management," Subtitle D "Solid Waste Management," and Subtitle I "Regulation of Underground Storage Tanks," provide the regulatory guidance for CERCLA actions and will be considered for regulations for on-site RA activities and cleanup at ORNL.

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 before HSWA.

Tennessee's promulgated RCRA requirements supersede federal regulations as legally applicable. However, Tennessee's substantive RCRA regulations are identical for the most part to the federal RCRA regulations.¹¹ New regulations imposed in 1984 by HSWA are to be considered applicable under federal law in all states until each authorized state promulgates its own HSWA-related standards. Although the Tennessee Solid Waste Disposal Control Board has promulgated many of the HSWA regulations, EPA has not yet authorized the program.¹²

6.5.2.1 RCRA Subtitle C regulations

RCRA Subtitle C 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 as 40 CFR 264. Standards for interim treatment, storage, and disposal facilities are found in 40 CFR 265.

In general, this text will address the Part 264 rather than the Part 265 standards as they are the more stringent. Table 6.10 lists the pertinent subparts of the permitted and interim standards and the equivalent section of the TDEC hazardous WM regulations.

As discussed in Sect. 6.2, D&D activities that generate RCRA hazardous wastes but are not incorporated as CERCLA Sites into the FFA would be subject to regulation under RCRA. In contrast to CERCLA, D&D activities subject to RCRA would be subject to the administrative as well as the substantive requirements of the law, including all the applicable permitting requirements.

The RCRA Subtitle C Part 264 regulations apply to particular WM processes (e.g., capping or incineration) or to general procedures (e.g., treatment, disposal, or closure), and it may be necessary to combine the two types of categories to adequately address the action-specific regulations for a particular remedial activity.

6.5.2.2 Land Disposal Restrictions

If RCRA-listed or -characteristic waste is generated/identified during the RA process, these wastes would be subject to the RCRA LDRs. For each hazardous waste, EPA has established treatment standards that are protective of human health and the environment when the wastes are land disposed. Land disposal includes, but is not limited to placement in a landfill, surface impoundment, waste pile, and land treatment facility. In the final National Contingency Plan, EPA reaffirms that movement of waste within a unit does not constitute "land disposal" for purposes of application of the RCRA LDRs; however, waste consolidation from different units at a CERCLA site are subject to the restrictions (55 *FR* 8759).

These LDRs apply only to RCRA hazardous waste placed after the effective prohibition date. Wastes may be land disposed if they have been treated with the best demonstrated available technology (BDAT) set by EPA and meet the treatment standards. A final rule listing provisions for specific treatment standards and prohibiting land disposal of the following wastes has appeared. Table 6.11 lists the waste categories for which LDRs have been promulgated, the *Federal Register* citation, and the corresponding section in 40 CFR 268. Tennessee Rule 1200-1-11-.10 contains the state LDRs, which are similar to the RCRA LDRs. A final rule for corrective action at RCRA sites and CERCLA sites contaminated with RCRA hazardous waste regulates wastes generated for the purpose of implementing RAs, and exempts designated sites from the LDRs and minimum technology requirements (MTRs) under 40 CFR 268 (see "Correction Action Requirements" below).

EPA has determined that the RCRA treatment standards are generally inappropriate or infeasible when applied to contaminated soil or debris (55 *FR* 8760). Therefore, EPA is proposing separate rule makings to establish treatment standards for disposal of such contaminated soil and debris. The advance notice of proposed rule making (ANPRM) for debris appeared in 56 *FR* 24444, May 30, 1991, the notice of proposed rule making (NPRM) on Jan. 9, 1992 (57 *FR* 958) and the final rule on August 18, 1992 (57 *FR* 37194). The rule requires contaminated debris to be treated before land disposal using extraction, destruction, or immobilization technologies. Six different categories of debris and ten different categories of contaminants are specified in the rule. As with mixed waste, debris contaminated with both hazardous and radioactive waste must

Table 6.10. RCRA^a Subtitle C—standards for the treatment, storage, and disposal of hazardous waste

Federal	Tennessee	Category
<i>40 CFR Part 264</i>	<i>1200-1-11-06^b</i>	
Subpart I	Section 9	Containers
Subpart J	Section 10	Tanks
Subpart K	Section 11	Surface impoundments
Subpart L	Section 12	Waste piles
Subpart M	Section 13	Land treatment
Subpart N	Section 14	Landfills
Subpart O	Section 15	Incinerators
Subpart X	Section 19	Miscellaneous treatment units
<i>40 CFR Part 265</i>	<i>1200-1-11-05</i>	
Subparts I-O	Sections 9-15	As listed above
Subpart P	Section 16	Thermal treatment
Subpart Q	Section 17	Chemical, physical, and biological treatment

^aRCRA = Resource Conservation and Recovery Act.

^bRule 1200 of the Tennessee Department of Environment and Conservation Hazardous Waste Management Regulations.

Table 6.11. Federal RCRA^a land disposal regulations

Waste category	Citation	40 CFR Part
Spent-solvent and dioxin-containing wastes	51 FR 40572 (Nov. 7, 1986)	268.30 268.31
"California List" wastes	52 FR 25760 (July 8, 1987)	268.32
First Third wastes ^b	54 FR 31138 (Aug. 17, 1988)	268.33
Second Third wastes ^b	54 FR 26594 (June 23, 1989)	268.34
Final Third wastes ^b	55 FR 22520 (June 1, 1990)	268.35

^aRCRA = Resource Conservation and Recovery Act.

^bAll listed hazardous wastes identified under 40 CFR 261.

comply with the treatability standards for contaminated debris as well as those under the AEA. Disposal of treated debris and resultant wastes are discussed in the rule.

In the debris rule, EPA established a new treatment unit for treating contaminated debris; a "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 for a new Subpart DD to 40 CFR 264 and 265 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 be legally applicable to any RA activities involving dismantlement of structures and subsequent decontamination in a building. Physical extraction technologies such as abrasive blasting or spalling used to treat debris in place, but that is intended for discard (e.g., treatment of a contaminated building prior to demolition), 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 debris rule).

The ANPRM for soil appeared Oct. 24, 1991 (56 *FR* 55160); NPRM expected August, 1993, final rule August 1994.³ 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 (BMPs) for debris. These should be considered as guidance when RA activities are scheduled that may contaminate or deal with contaminated soil. In addition, EPA has granted an extension of the generic national capacity variance from the LDRs for certain soils and debris and radioactive mixed wastes until May 8, 1993 (57 *FR* 20766, May 15, 1992).

6.5.2.3 Corrective action requirements

Several sections of RCRA require promulgation of corrective action regulations; when finalized, these requirements will most likely be legally applicable to RA sites where there is RCRA hazardous waste contamination. Currently, only the 40 CFR 264 Subpart F regulations on ground-water protection at RCRA-regulated units are potentially applicable to RA activities within facility boundaries and these include ground-water protection standards (40 CFR 264.92 and 40 CFR 264.94) and ground-water monitoring requirements (40 CFR 264.97). The corrective action standards developed under RCRA §3004(u) will be applicable to any D&D or RA cleanup site that is also an active or a formerly active RCRA facility with an active solid waste management unit; thus, the standards will also be applicable to a D&D or RA site where disposal is currently occurring. In addition, RCRA §3004(v) authorizes cleanup beyond facility boundaries.

Requirements for corrective action for RCRA solid waste management units have been proposed (55 *FR* 30798, July 27, 1990). A final rule is expected to appear in December 1993. EPA proposes a risk-based approach to establish media cleanup standards for surface water, ground water, soil, and air. These standards are to be established at concentrations that ensure protection of human health and the environment and are to be set for each media of concern during the remedy selection process. RCRA corrective action levels are not intended to be used as cleanup levels; they are intended only to "trigger" the corrective action process when exceeded. Target cleanup levels may initially

be set at these RCRA action levels but must be modified as appropriate to reflect site-specific exposure assumptions (55 FR 30826). Appendix A of the proposed rule lists proposed action levels for 165 compounds (55 FR 30865), and Appendix E gives governing equations for calculating action levels (55 FR 30870).

A portion of the proposed Subpart S rule was promulgated as a final rule for corrective action at Corrective Action Management Units (CAMUs) and Temporary Units (TUs). This rule establishes two sections in Subpart S (*Corrective Action for Solid Waste Management Units*): 40 CFR 264.552 (CAMUs) and 40 CFR 264.553 (TUs) (58 FR 8658, February 16, 1993). Both of these units function solely to manage wastes that are generated at a RCRA facility for the purpose of implementing RA (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 the LDRs and MTRs. The CAMU or TU designations must be made by EPA or the 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 into 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.

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. CAMUs would also not be subject to MTRs, 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 LDRs or MTRs, 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 LDRs or MTRs.

The EPA Regional Administrator may designate tanks and container storage units used for treatment or storage of remediation wastes as TUs. Permit specifications for TUs must include design, operating, and closure requirements. These may be less stringent than the 40 CFR 264 requirements as long as they are protective of human health and the environment and comply with statutory requirements.

The substantive requirements of this rule are expected to be legally applicable to RAs at CERCLA RA sites that involve the management of RCRA hazardous waste. In this context, CAMU designations would be incorporated into CERCLA decision documents.

6.5.2.4 RCRA Subtitle I Regulations

RCRA §9003 requires promulgation of regulations pertaining to detection, prevention, and correction of releases from underground storage tanks; implementing regulations appear in 40 CFR 280.50 ("Release Reporting, Investigation, and Confirmation"), 280.60 ("Release Response and Corrective Action for Underground Storage Tank Systems Containing Petroleum or Hazardous Substances"), and 280.70 ("Out-of-Service Underground Storage Tank Systems and Closure") and should be considered as regulations for cleanup of any Underground Storage Tanks located at RA sites. 40 CFR 280.66 specifies that corrective action plans designed to protect human health and the environment must be submitted to the "implementing agency" (TDEC Underground Storage Tank Division) for approval. The state must be notified of permanent closure plans not taken in response to corrective action (40 CFR 280.71); suggested cleaning and closure procedures are recommended in 40 CFR 280.71 and may be considered guidance for closure of any tanks at RA sites.

Tennessee Code Annotated (TCA) §68-53-101 *et seq.* authorized the Underground Storage Tank Board to promulgate regulations on July 1, 1988. The implementing regulations for release response and corrective action were promulgated April 15, 1990, and are found in TDEC Rules Chaps. 1200-1-15-.05 to 1200-1-15-.07. These regulations closely parallel the 40 CFR 280 regulations, although the state regulations only apply to Underground Storage Tanks containing petroleum products.

6.5.2.5 RCRA Subtitle D Regulations

EPA has promulgated a final rule establishing a new 40 CFR Part 258, which sets forth revised minimum federal criteria for municipal solid waste landfills (56 FR 50978, Oct. 9, 1991). These criteria include closure and postclosure care requirements (40 CFR 258.60 and 258.61).

In addition, the Tennessee (Rules of the TDEC Chap. 1200-1-7) and federal RCRA regulations governing solid WM facilities may regulate RA activities. Specifically, 40 CFR 257.3-3 prohibits nonpoint source contamination of surface waters from solid WM facilities. 40 CFR 257.3-3 also prohibits point source discharges of pollutants into surface waters that are in violation of the requirements of the National Pollutant Discharge Elimination System. 40 CFR 257.3-4 prohibits contamination of an underground drinking water source above SDWA MCLs.

6.5.3 Clean Air Act

Chapter 25, "Air Pollution Control," of the 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 and are identical to the federal primary National Ambient Air Quality Standards (see Sect. 6.3.2 and Table 6.1). 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 legally applicable if they apply to any of the RA sites. Table 6.12 lists sections of the Tennessee air emission standards that should be analyzed on a site-specific basis for each remedial alternative.

The CAA (§111) requires EPA to promulgate standards for new sources of air emissions. This requirement has been implemented in 40 CFR 60 through the New Source Performance Standards that are based on the BDAT and set minimum federal emission limitations on classes of facilities. The National Emission Standards for Hazardous Air Pollutants have been discussed as potential "hybrid" regulations (see Sects. 6.2 and 6.4.1), which should be considered as remedial alternatives are selected.

Certain on-site construction and/or excavation activities may be necessary to prepare a site for remediation. Airborne pollutants may result from these construction activities. The primary concern is elevation of particulate concentrations resulting from earth-moving and site-grading activities. 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/h or 20 min/day.

**Table 6.12. 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.

6.5.4 Clean Water Act

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 National Pollutant Discharge Elimination System 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. Various National Pollutant Discharge Elimination System permits regulate discharges from ORR to the Clinch River and its tributaries. The effluent limitations and monitoring requirements found in the National Pollutant Discharge Elimination System permits should be analyzed on a site-specific basis for any cleanup at RA sites that would include discharge of pollutants to surface waters.

Direct discharge of dredge-and-fill material into navigable waters is regulated under CWA §404 and implemented through 33 CFR 320-330 and 40 CFR 230. Actions that may be considered dredge-and-fill activities include dredging of sediments from contaminated water bodies, disposal of contaminated soil or materials in surface water, capping of a site, building berms and levees to contain wastes, excavation for the containment of effluent, and dewatering of a site to obtain adequate flow.⁸

The U. S. Army Corps of Engineers issues dredge-and-fill permits for activities regulated under §10 of the Rivers and Harbors Act and §404 of the CWA; in addition, the Tennessee Valley Authority Act §26A approval application for streambed sediment removal may be necessary. Permits may be required by the Corps of Engineers for RA activities at ORNL because the Clinch River and portions of Poplar Creek are designated as "navigable waters" by the Corps of Engineers. All of the CWA §404 requirements for protection of wetlands from fill operations are potentially applicable to remedial activities at ORNL that would impact wetland communities (see Sect. 6.6.3 and Table 6.13 for a further discussion of these issues). CERCLA §121(e) stipulates that permits are not

Table 6.13. Action-specific regulations applicable to remedial action activities at the Oak Ridge Reservation^a

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Air emissions	Standards for control of emissions of volatile organics. These are based on CAA ^{f,g} , emission standards found in 40 CFR 60.480-60.489.	Emissions from process vents and equipment leaks at treatment, storage, and disposal (TSD) facilities handling or recycling hazardous waste containing 10% or more volatile organics	55 FR 25454 (June 21, 1990)	
	EPA is <i>proposing</i> to require organic emission controls be installed and operated on tanks, surface impoundments, containers, and certain miscellaneous treatment units if any hazardous waste having a volatile organic concentration equal to or greater than 500 ppm by weight is placed in the unit.	<i>Proposed</i> rule, not yet an ARAR ^u	<i>Proposed</i> rule, 56 FR 33490, July 22, 1991; Final rule expected October 1993	

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Capping	Placement of a cap over waste (e.g., closing a landfill, or closing a surface impoundment or waste pile as a landfill, or similar action) requires a cover designed and constructed to:	RCRA ^{h, i} hazardous waste placed at site after Nov. 19, 1980, or placement of hazardous waste into another unit will make requirements applicable when the waste is being covered with a cap for the purpose of leaving it behind after the remedy is completed.	40 CFR 264.228(a) (Surface impoundments) 40 CFR 264.258(b) (Waste piles) 40 CFR 264.310(a) (Landfills)	1200-1-11-.06(11)(l) 1200-1-11-.06(12)(l) 1200-1-11-.06(14)(k)
	<ul style="list-style-type: none"> • Provide long-term minimization of migration of liquids through the capped area; • Function with minimum maintenance; • Promote drainage and minimize erosion or abrasion of the cover; • Accommodate settling and subsidence so that the cover's integrity is maintained; and • Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present. 	Capping without such placement will not make requirements applicable, but technical requirements are likely to be relevant and appropriate		
	Restrict postclosure use of property as necessary to prevent damage to the cover.	Final closure of a RCRA hazardous waste facility with some hazardous materials or residues left in place	40 CFR 264.117(c)	1200-1-11-.06(7)(h)
	Prevent run-on and run-off from damaging the final cover.	Postclosure care	40 CFR 264.228 (b) 40 CFR 264.310(b)	1200-1-11-.06(11)(l) 1200-1-11-.06(14)(k)
	Protect and maintain surveyed benchmarks used to locate waste cells (landfills, waste piles).	Postclosure care	40 CFR 264.310 (b)	1200-1-11-.06(14)(k)

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Clean closure (e.g., closure with no post-closure care)	<i>Closure and postclosure standards</i>	Applicable to land-based unit containing hazardous waste ^d . Applicable to RCRA hazardous waste (listed or characteristic) placed at site after Nov. 19, 1980, or placement of hazardous waste into another unit	40 CFR 264.110-120 (Subpart G)	1200-1-11-.06(7)(a)-(k)
	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 environment.	Not applicable to material undisturbed since Nov. 19, 1980, or if treated in situ or consolidated within area of contamination	40 CFR 264.111	1200-1-11-.06(7)(b)
		Designed for cleanup that will not require long-term management; designed for cleanup to health-based standards.		
	Removal or decontamination of waste residues, contaminated containment system components (e.g., liners and dikes), contaminated subsoils, and structures and equipment contaminated with waste and leachate, and management of them as hazardous waste.		40 CFR 264.114 40 CFR 264.178 40 CFR 264.197 40 CFR 264.228 40 CFR 264.258	1200-1-11-.06(9)(c) 1200-1-11-.06(11)(i) 1200-1-11-.06(12)(c) 1200-1-11-.06(13)(i) 1200-1-11-.06(14)(i)
	Must protect human health and the environment.		40 CFR 264.111(b)	1200-1-11-.06(7)(b)

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Closure with waste in place (capping)	Eliminate free liquids by removal or solidification.	Applicable to land-based unit containing RCRA hazardous waste ^d	40 CFR 264.228(a)(2) (Surface impoundments)	1200-1-11-.06(11)(i)
	Stabilization of remaining waste and waste residues to support cover.		40 CFR 264.258(b) (Waste piles)	1200-1-11-.06(12)(i)
			40 CFR 264.310(a) (Landfills)	1200-1-11-.06(16)(k)
			40 CFR 264.310	1200-1-11-.06(14)(k)
	Installation of final cover to provide long-term minimization of infiltration (see "capping" for further restrictions).		40 CFR 264.310	1200-1-11-.06(14)(k)
	Postclosure care and ground-water monitoring. ^j			
Consolidation between units	Placement on or in land outside unit boundary or area of contamination will trigger land disposal requirements and restrictions.	Placement of RCRA hazardous wastes subject to land disposal restrictions	40 CFR 268 (Subpart D)	1200-1-11-.10(3)
		Movement of hazardous waste (listed or characteristic) from one unit or area of contamination into another		
		Consolidation within a unit or area of contamination does not trigger applicability ^{d, k}		

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Container storage (on site)	Containers of hazardous waste must be:	Storage of RCRA hazardous waste (listed or characteristic) not meeting	40 CFR 264 (Subpart I)	1200-1-11-.06(9)
	• Maintained in good condition;	small quantity generator	40 CFR 264.171	1200-1-11-.06(9)(b)
	• Compatible with hazardous waste to be stored; and	criteria held for a temporary period before treatment,	40 CFR 264.172	1200-1-11-.06(9)(c)
	• Closed during storage (except to add or remove waste).	disposal, or storage elsewhere, in a container	40 CFR 264.173	1200-1-11-.06(9)(d)
	Inspect container storage areas weekly for deterioration.	(i.e., any portable device in which a material is stored, transported, disposed of, or handled)	40 CFR 264.174	1200-1-11-.06(9)(e)
		A generator who accumulates or stores hazardous waste on site for 90 days or less in compliance with 40 CFR 262.34 (a)(1-4) is not subject to full RCRA storage requirements.	40 CFR 264.175	1200-1-11-.06(9)(f)
	Place containers on a sloped, crack-free base, and protect from contact with accumulated liquid. Provide containment system with a capacity of 10% of the volume of containers. Remove spilled or leaked waste in a timely manner to prevent overflow to the containment system.			

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Container storage (on site) (continued)	Keep containers of ignitable or reactive waste at least 50 ft from the facility's property line.		40 CFR 264.176	1200-1-11-.06(9)(g)
	Keep incompatible materials separate. Separate incompatible materials stored near each other by a dike or other barrier.		40 CFR 264.177	1200-1-11-.06(9)(h)
	At closure, remove all hazardous waste and residues from the containment system, and decontaminate or remove all containers, liners.		40 CFR 264.178	1200-1-11-.06(9)(i)
	Storage of banned wastes must be in accordance with 40 CFR 268. When such storage occurs beyond one year, the owner/operator bears the burden of proving that such storage is solely for the purpose of accumulating sufficient quantities to allow for proper recovery, treatment, and disposal.		40 CFR 268.50	1200-1-11-.10(1)(e)
Dike construction	Design and operate facility to prevent overtopping from overfilling; wind and wave action; rainfall; run-on; malfunctions of level controllers, alarms, and other equipment; and human error.	Existing surface impoundment containing hazardous waste, or creation of new surface impoundment	40 CFR 264.221	1200-1-11-.06(11)(b)
	Construct dikes with sufficient structural integrity to prevent massive failure.		40 CFR 264.221	1200-1-11-.06(11)(b)

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Dike construction (continued)	Ensure that the dike, including that portion which provides freeboard, has structural integrity that will withstand stress of pressures from added wastes and will not fail due to scouring or piping.	Following a period of six months or greater when an impoundment has been out of service	40 CFR 264.226(c)	1200-1-11-.06(13)(g)3
	Inspect weekly for proper operation and integrity of the containment devices.		40 CFR 264.226	1200-1-11-.06(11)(g)
	Remove surface impoundment from operation if the dike leaks or there is a sudden drop in liquid level.		40 CFR 264.227	1200-1-11-.06(11)(h)
	U.S. Army Corps of Engineer permit approval may be required.	Structures or work in, or affecting, navigable waters of the U.S.	§§9 and 10, Rivers and Harbors Act.	
Direct discharge of treatment system effluent	<i>National Pollutant Discharge Elimination System (NPDES) Permitting Program</i>		40 CFR 122 (Clean Water Act) ^o	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.	Point source discharge to waters of the United States ^{m, n}	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) ^p .		40 CFR 122.44(d) and state regulations approved under 40 CFR 131	1200-4-3-.03

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Direct discharge of treatment system effluent (continued)	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	
	<i>Criteria and standards for NPDES</i>		40 CFR 125	1200-4-5
	The BMP program must:	Discharge to waters of the United States ⁿ	40 CFR 125.104	
	<ul style="list-style-type: none"> • Establish specific procedures for the control of toxic and hazardous pollutant spills; • Include a prediction of direction, rate of flow, and total quantity of toxic pollutants where experience indicates a reasonable potential for equipment failure; • Ensure proper management of solid and hazardous waste in accordance with regulations promulgated under RCRA. 			

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Direct discharge of treatment system effluent (continued)	<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; • 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>	Off-site discharges	40 CFR 122.44(i)	
	Comply with additional permit conditions such as:		40 CFR 136.1-136.3(e)	
	<ul style="list-style-type: none"> • Duty to mitigate any adverse effects of any discharge; and • Proper operation and maintenance of treatment systems. 		40 CFR 122.41(d,e)	
Discharge of dredge and fill material to navigable waters	<p>The four conditions that must be satisfied before dredge and fill is an allowable alternative are:</p> <ul style="list-style-type: none"> • There must be no practicable alternative. • Discharge of dredge or fill material must not cause a violation of state water quality standards, violate any applicable toxic effluent standards, jeopardize an endangered species, or injure a marine sanctuary. 		40 CFR 230.10 (Marine Protection, Research, and Sanctuaries Act)	

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Discharge of dredge and fill material to navigable waters (continued)	<ul style="list-style-type: none"> No discharge shall be permitted that will cause or contribute to significant degradation of the water. Appropriate steps to minimize adverse effects must be taken. 		33 CFR 320-330 (Clean Water Act)	
	Determine long- and short-term effects on physical, chemical, and biological components of the aquatic ecosystems.		40 CFR 122.41(i)	
	Comply with additional substantive conditions such as:			
	<ul style="list-style-type: none"> Duty to mitigate any adverse effects of any discharge; and Proper operation and maintenance of treatment systems. 			
	Monitor and report results as required by permit (minimum of at least annually).	Off-site discharges	40 CFR 122.44(i)	
Dredging	Removal of all contaminated soil.	RCRA hazardous waste placed at site after Nov. 19, 1980, or movement of hazardous waste from one unit, area of contamination or location into another unit or area of concentration	40 CFR 264.228 (surface impoundments)	1200-1-11-.06(11)(i)
			40 CFR 264.258 (waste piles)	1200-1-11-.06(11)(i)
	Prohibits construction of any structures, or work in or affecting navigable waters, without approval of the U.S. Corps of Engineers.	Work performed in navigable waters of U.S.	§§ 9 and 10, Rivers and Harbors Act.	

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Excavation	Site excavations must be shored or sloped to prevent accidental collapse in accordance with Subpart P of 29 CFR 1926.	Occupational Safety and Health Act (OSHA) regulations for workers at hazardous waste sites	29 CFR 1926, 54 FR 45894 (Nov. 31, 1989)	
	Movement of excavated materials to new location and placement in or on land will trigger land disposal restrictions for the excavated waste or closure requirements for the unit in which the waste is placed.	Materials containing RCRA hazardous wastes subject to land disposal restrictions are placed in another unit	40 CFR 268 (Subpart D)	1200-1-11-.10(3)
	Total suspended particulates (TSP) must be maintained below National Ambient Air Quality Standards	Nonpoint source contribution to fugitive dust emissions	40 CFR 50.6	1200-3-3-.03
	Control of fugitive dust emissions may be required under state air quality regulations.			
Gas collection	Standards for control of emissions of volatile organics. These are based on CAA emission standards found in 40 CFR 60.480-60.489.	Emissions from process vents and equipment leaks at TSD facilities handling or recycling hazardous waste containing 10% or more volatile organics	55 FR 25454 (June 21, 1990)	
Ground-water diversion	Excavation of soil for construction of slurry wall may trigger closure or land disposal restrictions.	Materials containing RCRA hazardous waste subject to land disposal restrictions if moved to another unit	40 CFR 268 (Subpart D)	1200-1-11-.10(3)
	Site excavations must be shored or sloped to prevent accidental collapse in accordance with Subpart P of 29 CFR 1926.	OSHA regulations for workers at waste sites	54 FR 9294 (March 3, 1989)	
Incineration (on site)	Analyze the waste feed.	RCRA hazardous waste	40 CFR 264.341	1200-1-11-.06(15)(b)

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Incineration (on site) (continued)	Dispose of all hazardous waste and residues, including ash, scrubber water, and scrubber sludge.			
	No further requirements apply to incinerators that only burn wastes listed as hazardous solely by virtue of combination, and if the waste analysis shows that no Appendix VIII constituent is present that might reasonably be expected to be present.			
	Performance standards for incinerators:			
	<ul style="list-style-type: none"> • Achieve a destruction and removal efficiency of 99.99% for each principal organic hazardous constituent in the waste feed and 99.999% for dioxins; 		40 CFR 264.343(a)	1200-1-11-.06(15)(d)
	<ul style="list-style-type: none"> • Reduce hydrogen chloride emissions to 1.8 kg/h or 1% of the HCl in the stack gases before entering any pollution control devices; and 		40 CFR 264.343(b)	1200-1-11-.06(15)(d)
	<ul style="list-style-type: none"> • Limit emissions of particulate matter. 		40 CFR 264.343(c)	1200-1-11-.06(15)(d)
	EPA is <i>proposing</i> to amend the hazardous waste incinerator regulations to improve control of toxic metals, hydrogen chloride, and organic emissions.	<i>Proposed rule, not yet ARAR</i>	55 FR 17862 (April 27, 1990)	

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Incineration (on site) (continued)	Monitoring of various parameters during operation of the incinerator is required. These parameters include:		40 CFR 264.347	1200-1-11-.06(15)(g)
	<ul style="list-style-type: none"> • Combustion temperature; • Waste feed rate; • An indicator of combustion gas velocity; and • Carbon monoxide 			
	Control fugitive emissions either by:		40 CFR 264.345(d)	1200-1-11-.06(15)(f)
	<ul style="list-style-type: none"> • Keeping combustion zone sealed; or • Maintaining combustion zone pressure lower than atmospheric pressure. 			
	Utilize automatic cutoff system to stop waste feed when operating conditions deviate.		40 CFR 264.345(e)	1200-1-11-.06(15)(f)
	Special performance standards for incineration of polychlorinated biphenyls		40 CFR 761.70(b) (Total Substances Control Act) ^f	
	New source performance standards for incinerators.	Incinerators with a charge rate greater than 45 metric tons/day	40 CFR 60.50-60.54 (Clean Air Act)	
Land treatment	Ensure hazardous constituents are degraded, transformed, or immobilized within the treatment zone.	RCRA hazardous waste being treated or placed into another unit	40 CFR 264.271(a)	1200-1-11-.06(13)(b)

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Land treatment (continued)	Maximum depth of treatment zone must be no more than 1.5 meters (5 ft) from the initial soil surface; and more than 1 meter (3 ft) above the seasonal high-water table.		40 CFR 264.271(c)	1200-1-11-.06(13)(b)
	Minimize run-off of hazardous constituents.		40 CFR 264.273(b)	1200-1-11-.06(13)(d)
	Maintain run-on/run-off control and management system.		40 CFR 264.273(c)	1200-1-11-.06(13)(d)
	Special application conditions if food-chain crops grown in or on treatment zone.		40 CFR 264.276	1200-1-11-.06(13)(g)
	Unsaturated zone monitoring program required.		40 CFR 264.278	1200-1-11-.06(13)(l)
	Special requirements for ignitable or reactive waste.		40 CFR 264.281	1200-1-11-.06(13)(l)
	Special requirements for incompatible waste.		40 CFR 264.282	1200-1-11-.06(13)(m)
	Special requirements for RCRA hazardous wastes.	RCRA waste FO20, FO21, FO22, FO23, FO26, FO27, (dioxin-containing wastes)	40 CFR 264.283	1200-1-11-.06(13)(n)
		May be superseded by new land ban regulations.		
	Prior to land disposal, waste must be treated to BDAT levels or meet a "no migration" standard.	RCRA hazardous waste being disposed of in another unit	40 CFR 268 (Part D)	1200-1-11-.10(3)
	Treatment standards and land disposal restrictions apply to: spent solvent wastes, dioxin-containing wastes, California-list wastes, and all RCRA hazardous waste (see Treatment).		52 FR 25760 (July 8, 1987) RCRA 3004(d)	

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Operation and maintenance	30-year postclosure care to ensure that site is maintained and monitored.	Closure of hazardous waste management units	40 CFR 264.117	1200-1-11-.06(7)(h)
Placement of liquid waste in landfill	No bulk or noncontainerized liquid hazardous waste or hazardous waste containing free liquids may be disposed of in landfills. Containers holding free liquid may not be placed in a landfill unless the liquid is mixed with an absorbent or solidified.	Placement of a bulk or noncontainerized RCRA waste in a landfill	40 CFR 264.314(b)	1200-1-11-.06(14)(o)
Placement of waste in land disposal unit	Attain land disposal treatment standards to comply with "land ban" restrictions (see Treatment)	Placement of RCRA hazardous waste in a landfill, surface impoundment, waste pile, injection well, land treatment facility, salt dome formation, salt bed formation, or underground cave or mine	40 CFR 268 (Subpart D)	1200-1-11-.10(3)
Slurry wall	Excavation of soil for construction of slurry wall may trigger cleanup or land disposal restrictions.	RCRA hazardous waste placed at site after Nov. 19, 1980, or movement of hazardous waste from one unit into another unit or area of contamination	40 CFR 268 (Part D) See also Consolidation, Excavation, and Treatment regulations	1200-1-11-.10(3)
Surface-water control	Prevent run-on and control and collect run-off from at least the amount of water volume resulting from a 24-h, 25-year storm (waste piles, land treatment facilities, landfills).	RCRA hazardous waste treated, stored, or disposed at a site after Nov. 19, 1980	40 CFR 264.251(c,d); 40 CFR 264.273(c,d); 40 CFR 264.301(c,d)	1200-1-11-.06(12)(b) 1200-1-11-.06(13)(d) 1200-1-11-.06(14)(b)
	Prevent over-topping of surface impoundment.		40 CFR 264.221(c)	1200-1-11-.06(11)(b)

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Surface-water control (continued)	Monitor surface water to ensure compliance with state water quality standards.	Discharge of wastes to adjacent streams or other surface water bodies	40 CFR 122	1200-4-3
Tank storage (on site)	Existing and new tanks must have sufficient structural strength, compatible with the waste, and corrosion protection to ensure that they do not collapse or rupture.	Storage of RCRA hazardous waste (listed or characteristic) not meeting small quantity generator criteria held for a temporary period greater than 90 days before treatment, disposal, or storage elsewhere, in a tank (i.e., any portable device in which a material is stored, transported, disposed of, or handled) A generator who accumulates or stores hazardous waste on site for 90 days or less in compliance with 40 CFR 262.34 (a)(1-4) is not subject to full RCRA storage requirements	40 CFR 264.191-192	1200-1-11-.06(10)(b)-(c)
	Waste must not be incompatible with the tank material unless the tank is protected by a liner or by other means.		40 CFR 264.191	1200-1-11-.06(10)(b)
	Tanks must be provided with secondary containment and controls to prevent overfilling, and sufficient freeboard maintained in open tanks to prevent overtopping by wave action or precipitation.		40 CFR 264.193-194	1200-1-11-.06(10)(d)-(e)

Table 6.13 (continued)

Actions^b	Requirements	Prerequisites^{c,d}	Federal citation	TDEC^e Rules, Chapter
Tank storage (on site) (continued)	Prevent the migration of spills or leaks to soils or surface water. Remove and dispose of any visible containment of soils or surface water.	Leaks or spills from tanks or secondary containment systems containing RCRA hazardous waste	40 CFR 264.196(c)	1200-1-11-.06(12)(d)3
	Remove tank from service; remove waste from tank or secondary containment system.		40 CFR 264.196(a,b)	1200-1-11-.06(12)(d)3
	Repair any corrosion, crack, or leak.		40 CFR 264.196(c)	1200-1-11-.06(12)(d)3
	Notify pursuant to 40 CFR 302 if spill or leak is above a reportable quantity		40 CFR 264.196(d)	1200-1-11-.06(12)(d)3
	Inspect the following: overfilling control; control equipment, monitoring data, waste level (for uncovered tanks), tank condition, aboveground portions of tanks (to assess their structural integrity), and the area surrounding the tank (to identify signs of leakage).		40 CFR 264.195	1200-1-11-.06(10)(f)
	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)

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Tank storage (on site) (continued)	Store ignitable and reactive waste so as to prevent the waste from igniting or reacting. Ignitable or reactive wastes in covered tanks must comply with buffer zone requirements in "Flammable and Combustible Liquids Code," Tables 2-1 through 2-6 (National Fire Protection Association 1976, 1981).		40 CFR 264.198	1200-1-11-.06(10)(i)
	Storage of banned wastes must be in accordance with 40 CFR 268. When such storage exceeds one year, the owner/operator bears the burden of proving that the storage is solely for the purpose of accumulating sufficient quantities to allow for proper recovery, treatment, and disposal.		40 CFR 268.50	1200-1-11-.10(4)(a)
Transportation	Compliance with the RCRA manifest and pretransportation regulations must be achieved.	Transportation of RCRA waste to an off-site treatment, storage, or disposal facility	40 CFR 262	1200-1-11-.03
	Compliance with Department of Transportation (DOT) packaging, labeling, marking, and placarding requirements must be achieved (49 CFR 172-179)		40 CFR 262	1200-1-11-.03
Treatment (in a unit)	Design and operating standards for units in which hazardous waste is treated must ensure protection of human health and the environment.	Treatment of RCRA hazardous waste in a unit	40 CFR 264.601 (Miscellaneous treatment units)	1200-1-11-.06(19)(b)

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Treatment (in a unit) (continued)	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: <ul style="list-style-type: none"> • the ground water or subsurface environment. • surface water, or wetlands, or the soil surface. • or the air. 		40 CFR 264.601(a)	1200-1-11-.06(19)(b)
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)
	Special requirements for ignitive, reactive, or incompatible wastes.		40 CFR 265.17	1200-1-11-.05(2)

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e 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 268.1101(c)(1)	
	Take measures to prevent the tracking of hazardous waste outside of the unit by the personnel or equipment.			
	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)	

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Treatment in a containment building (continued)	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)	
	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 postclosure requirements of 40 CFR 264.310.		40 CFR 264.1101(b)	

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Treatment	Treatment of wastes subject to ban on land disposal must attain levels achievable by BDAT for each hazardous constituent in each listed waste if residual is to be land disposed. If residual is to be further treated, initial treatment and any subsequent treatment that produces residual to be treated need not be BDAT if it does not exceed the value in the Constituent Concentration in Waste Extract Table for each applicable wastewater	The following wastes have been prohibited from land disposal without treatment:	40 CFR 268 (Part D)	1200-1-11-.10(3)
		<ul style="list-style-type: none"> Spent solvent wastes and dioxin-containing wastes. "California List" wastes 	51 FR 40572 (Nov. 7, 1986) 52 FR 25760 (July 8, 1987)	
		All ranked and listed hazardous wastes identified under 40 CFR Part 261:		
		<ul style="list-style-type: none"> First third Second third Final third, and mixed radioactive hazardous waste Newly listed wastes and contaminated debris 	40 CFR 268.33 40 CFR 268.34 40 CFR 268.35 40 CFR 268.36; 40 CFR 268.45	
	No-migration variance for restricted hazardous waste land disposal	Proposed ARAR. Land disposal of untreated hazardous waste that has been restricted from land disposal	40 CFR 268 (Part D) Notice of Proposed Rule Making (NPRM) Aug. 1992; Final rule expected August 1994	1200-1-11-.10(3)
	Treatment and disposal of hazardous soil	EPA will propose treatment standards for contaminated soil	40 CFR 268 (Part D) NPRM (soil) August 1993; Final rule expected August 1994	1200-1-11-.10(3)

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Treatment (continued)		<p>Effective Nov. 8, 1990, disposal of contaminated soil or debris resulting from CERCLA^s response actions or RCRA corrective actions is subject to land disposal prohibitions and/or treatment standards established for spent solvent wastes, dioxin-containing wastes, and "California List" wastes</p> <p>Disposal of soil and debris contaminated with RCRA hazardous waste for which the treatment standard is incineration is not subject to the land disposal restrictions until Aug. 1990, July 1991, and Nov. 1991, for the three thirds, respectively</p> <p>Mixed radioactive waste is included in the final third capacity national capacity variance schedule</p>		
Underground injection of wastes and treated ground water	<p>Underground Injection Control (UIC) program prohibits:</p> <ul style="list-style-type: none"> Injection activities that allow movement of contaminants into underground sources of drinking water (USDW) and results in violation of MCLs or adversely affects health^u. 		<p>40 CFR 144 (Safe Drinking Water Act)^t</p> <p>40 CFR 144.12</p>	<p>1200-4-6</p> <p>1200-4-6-.04</p>

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Underground injection of wastes and treated ground water (continued)	<ul style="list-style-type: none"> Construction of new Class IV wells, and operation and maintenance of existing wells. 	Excludes Class IV wells used to reinject contaminated ground water that has been treated if part of a CERCLA or RCRA remedial action	40 CFR 144.13	1200-4-6-.13
	Subsurface emplacement of waste fluids into ground water in area of regional rock deformation of the magnitude that occurs in east Tennessee	Class I wells		1200-4-6-.10(1)(c)
	All hazardous waste injection wells must also comply with the RCRA Part 264 permitting requirements.		40 CFR 144.14	
	Use or operation of unpermitted injection wells			1200-4-6-.03
	<i>General standards and methods</i>			
	Owners and operators must:		40 CFR 144.26	1200-4-6-.09
	<ul style="list-style-type: none"> Submit inventory information to the director of the UIC program for the state; including hydrogeologic data for wells, construction record, nature or composition of injected fluids, injection rate and pressure, and ground-water monitoring data. 		40 CFR 144.27	1200-4-6-.08(13)(j)

Table 6.13 (continued)

Actions^b	Requirements	Prerequisites^{c,d}	Federal citation	TDEC^e Rules, Chapter
Underground injection of wastes and treated ground water (continued)	<ul style="list-style-type: none"> Report noncompliance orally within 24 hours. Prepare, maintain, and comply with plugging and abandonment plan. 	Class I wells	40 CFR 144.28(b)	1200-4-6-.08(13)(l)
			40 CFR 144.28(c)	1200-4-6-.09(6)
	Monitor Class I wells by:	Class I wells are used to inject hazardous waste beneath the lowermost formation containing, within one quarter mile, a USDW	40 CFR 144.28(g)(1)	1200-4-6-.10(4)(f)
	<ul style="list-style-type: none"> Frequent analysis of injection fluid; Continuous monitoring of injection pressure, flow rate and volume; and Installation and monitoring of ground-water monitoring wells. 			
	Applicants for Class I permits must:			
	<ul style="list-style-type: none"> Identify all injection wells within the area of review; 		40 CFR 144.55	1200-4-6-.10(3)(b)
	<ul style="list-style-type: none"> Take action as necessary to ensure that such wells are properly sealed, completed, or abandoned to prevent contamination of USDW. 		40 CFR 146.4	1200-4-6-.10(5)
	Case and cement all Class I wells to prevent movement of fluids into USDW, taking into consideration well depth, injection pressure, hole size, composition of injected waste, and other factors.		40 CFR 146.12(a)(b)	1200-4-6-.10(3)(d)(2) 1200-4-6-.10(3)(f)
	Appropriate logs shall be recorded and other tests conducted during construction and a descriptive report prepared and submitted to the UIC program director.		40 CFR 146.12(d)	1200-4-6-.10(i)

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Underground injection of wastes and treated ground water (continued)	Injection pressure may not exceed a maximum level designed to ensure that injection does not initiate new fractures or propagate existing ones and cause the movement of fluids into a USDW.		40 CFR 146.13(b)	1200-4-6-.10(4)(b)(1) 1200-4-6-.10(4)(b)(2)
	Continuous monitoring of injection pressure, flow rate and volume, and annual pressure, if required.		40 CFR 146.13(a)	1200-4-6-.10(4)(e) 1200-4-6-.10(4)(f) 1200-4-6-.10(4)(g)
	Demonstration of mechanical integrity is required every 3 years.		40 CFR 146.12(a)(b)	1200-4-6-.10(4)(e)(6)
	Criteria for determining whether an aquifer may be an exempted aquifer include current and future use, yield, and water quality characteristics.			
	Ground-water monitoring may also be required.		40 CFR 146.13(b)	1200-4-6-.10(4)(e) 1200-4-6-.10(4)(f)
	Prohibits underground injection of hazardous wastes (solvents and dioxins) in Class I wells; amendments to existing UIC regulations.	Class I injection wells	53 FR 28118 (July 26, 1988)	1200-4-6-.10(1)
Underground storage tanks (UST) temporary closure	Continuous monitoring for leaks; leave vent lines open and functioning; cap and secure all other lines, pumps, man ways and ancillary equipment; notify implementing agency of return to service or permanent closure.	Pertains to releases of CERCLA hazardous substances from any one or a combination of tanks the volume of which is 10% or more beneath the surface of the ground (including pipes). Tanks that have been out of service for 3-24 months	53 FR 37082 (Sept. 23, 1988) 40 CFR Part 280.80(-a)(b)	

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
Underground storage tanks permanent closure	Removal requires removing all flammable liquids from the UST, removing all pipes from the UST, and purging the UST of all hazardous vapors before removal and disposal.	Pertains to releases of CERCLA hazardous substances from any one or a combination of tanks the volume of which is 10% or more beneath the surface of the ground (including pipes). Tanks that have been out of service for 3-24 months	53 FR 37082 (Sept. 23, 1988) 40 CFR Part 280.80(c-f)	
	Closure requires removal of all flammable liquids from the UST, disconnect or cap all pipes, fill tank system with an inert solid material		52 FR 12662 (April 17, 1987)	
Waste pile	Use liner and leachate collection and removal system.	RCRA hazardous waste, noncontainerized accumulation of solid, nonflammable hazardous waste that is used for treatment or storage in piles	40 CFR 264.25(a)	
	Operate and maintain run-on and run-off control systems for at least the amount of water resulting from a 14-h, 25-year storm.		40 CFR 264.251 (c)(d)	1200-1-11-.06(12)(b)
	Pile must be managed to control wind erosion.		40 CFR 264.251(f)	1200-1-11-.06(12)(b)
	Pile must be monitored and inspected.		40 CFR 264.254	1200-1-11-.06(12)(e)
Waste pile	Closure and postclosure care required.		40 CFR 264.258	1200-1-11-.06(12)(i)

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
<p>^aAdapted from EPA (1989). Currently only RCRA, CWA, and Safe Drinking Water Act requirements are included. Additional action-specific requirements will be added as additional statutes are analyzed.</p> <p>^bAction alternatives from the Record of Decision keyword index, <i>FY 1986 Record of Decision Annual Report</i>. January 1987, Hazardous Site Control Division, EPA.</p> <p>^cRequirements have been proposed but not promulgated for various remedial actions. When these regulations are promulgated, they will be included in the matrix.</p> <p>^dSome action-specific requirements listed may be relevant and appropriate even if RCRA definitions of storage, disposal, or hazardous waste are not met (40 CFR 260.10), or if the waste at the site is similar to but not identifiable as a RCRA hazardous waste.</p> <p>^eTDEC = Tennessee Department of Environment and Conservation.</p> <p>^fCAA = Clean Air Act.</p> <p>^gTitle I of the CAA covers Air Pollution Prevention and Control, and implementing regulations are found in 40 CFR Parts 50-99.</p> <p>^hRCRA = Resource Conservation and Recovery Act.</p> <p>ⁱSubtitle C of RCRA governs hazardous waste management (§3001-3020). Implementing regulations appear in 40 CFR Parts 260-268, 270, 271, 280, and 124.</p> <p>^jRegional administrator may revise length of postclosure care period (40 CFR 264.117).</p> <p>^kIn many cases there are no defined "units" at a CERCLA site. Instead, there are areas of contamination with differing concentration levels (including hot spots) of hazardous substances, pollutants, or contaminants. When RCRA hazardous wastes are moved into or out of an area of contamination, RCRA disposal requirements are applicable to the waste being managed and certain treatment, storage, or disposal requirements (such as for closure) are applicable to the area where the waste is received.</p> <p>^lLandfill units meeting the requirements of 40 CFR 264.301(f) are not subject to RCRA minimum technology requirements.</p> <p>^mThe term "Waters of the U.S." is defined broadly in 40 CFR 122.2 and includes essentially any water body and wetland.</p> <p>ⁿSection 121 of the Superfund Amendments and Reauthorization Act of 1986 (SARA) exempts on-site CERCLA activities from obtaining permits. However, the substantive requirements of a law or regulation must be met. In particular, on-site discharges to surface waters are exempt from procedural NPDES permit requirements. Off-site dischargers would be required to apply for and obtain an NPDES permit.</p> <p>^oTitles III and IV of the CWA cover Standards and Enforcement, and Permits and Licenses, respectively. Implementing regulations appear in 40 CFR Parts 110, 112, 116, 117, 122, 124, 125, 131, and 136. 40 CFR Subchapter N sets forth effluent guidelines for various point source categories.</p> <p>^pFederal Water Quality Criteria (WQC) may be relevant and appropriate depending on the designated or potential use of the water, the media affected, the purposes of the criteria, and current information [SARA §121(d)(2)(B)(i)]. Federal WQC for the protection of aquatic life will be relevant and appropriate when environmental factors (e.g., protection of aquatic organisms) are being considered (55 FR 8755, March 8, 1990).</p> <p>^qDischarge to publicly owned treatment works (POTWs) is considered an off-site activity. Off-site actions must comply with all legally applicable requirements, both substantive and administrative. The concept of "relevant and appropriate" is not available for off-site actions.</p> <p>^rImplementing regulations for the Toxic Substance Control Act of importance to cleanup at CERCLA sites are 40 CFR Parts 717 and 761.</p> <p>^sCERCLA = Comprehensive Environmental Response, Compensation, and Liability Act</p> <p>^tTitle IV of the Safe Drinking Water Act covers Safety of Public Water Systems. Implementing regulations are found in 40 CFR Parts 124 and 141-147.</p>				

Table 6.13 (continued)

Actions ^b	Requirements	Prerequisites ^{c,d}	Federal citation	TDEC ^e Rules, Chapter
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^aUnderground sources of drinking water (USDW) is a nonexempted aquifer or its portion which: (1) supplies any public water system, or (2) contains sufficient quantity of ground water to supply a public water system and currently supplies drinking water for human consumption or contains fewer than 10,000 mg/L total dissolved solids (40 CFR 144.3).

^bARAR = applicable or relevant and appropriate requirements

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.

required for on-site CERCLA cleanup; however, the applicability of these regulations for on- or off-site RA activities should be addressed on a site-specific basis.

Storm water discharges from activities at industrial sites involving construction operations that result in the disturbance of five acres total land have been included in the final rule for National Pollutant Discharge Elimination System permits for storm water discharges (40 CFR 122). Consultation with TDEC is required to ensure compliance with the substantive requirements of the National Pollutant Discharge Elimination System permitting process for storm water discharges during construction activities for CERCLA sites (Chap. 1200-4-10-.05 of the Rules of the TDEC). For RA activities not operating under CERCLA, compliance with the full storm water permitting process is required. In either case, implementation of good site planning and BMPs to control storm water discharges is required.

6.5.5 Safe Drinking Water Act

Part C of Title XIV of the SDWA authorizes the establishment of an underground injection control permit program designed to prevent contamination of underground sources of drinking water. Any RA activities involving discharge by way of underground injection wells would be subject to these regulations. An underground drinking water source is defined in the underground injection control regulations (40 CFR 146.3) as an aquifer or its portion that supplies drinking water for human consumption, contains a sufficient supply of ground water to supply a public water system, and contains fewer than 10,000 mg total dissolved solids per liter of water. Tennessee has a underground injection control program (Chap. 1200-4-6 of the Rules of the Water Control Board) that classifies all ground water as useful for domestic water supply unless certain exemption criteria apply. Aquifers are exempted for various reasons, including economic or technical impracticality (1) in recovery because of depth or location or (2) in successful treatment of contaminated water for drinking water purposes.

6.5.6 Toxic Substances Control Act

Specific TSCA standards exist for incineration or alternate disposal of liquid and nonliquid waste and for articles and soils containing PCBs. TSCA storage requirements for PCBs (40 CFR 761.65) specify that PCBs and PCB-containing items at concentrations of greater than 50 ppm must be disposed of within one year after being placed in storage for disposal. A federal facilities agreement is pending which would allow the continued storage of PCBs at ORNL. There are also structural requirements for facilities and containers used for storage of PCBs. These requirements, too detailed to be listed here, are delineated in 40 CFR 761.65(b) for facilities and 40 CFR 761.65(c) for containers. PCB WM is discussed further in Vol. 1, Pt. C, Chap. 7, which deals with WM regulations.

6.5.7 Federal Insecticide, Fungicide, and Rodenticide Act

The Federal Insecticide, Fungicide, and Rodenticide Act delegates authority to EPA to regulate the disposal and storage of excess pesticides and pesticide containers. To that end, EPA has published nonregulatory procedures for disposal of pesticides in 40 CFR 165, Subpart C. These recommendations might provide guidance for cleanup of pesticides and pesticide containers at RA sites and should be analyzed on a site-specific basis. EPA is currently updating these guidelines to make them consistent with current

regulations and technologies. Regulatory initiatives for 40 CFR 165 will be published in three phases. An NPRM for Phase I, concerning suspended and canceled pesticides, was published May 5, 1993 (58 FR 26856). The NPRM for Phase II, concerning container design, residue removal storage, containment, and excess, is due in July 1993, and the Phase III NPRM is due in 1994.³

6.5.8 Occupational Safety and Health Administration

Title I, §126(b) of CERCLA mandated that Occupational Safety and Health Administration (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; effective date, March 1990). 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*.

Standards for the protection of workers involved in construction, demolition, alteration, or repair activities involving asbestos-containing materials are listed in 29 CFR 1926.58 and would be applicable to RA activities involving asbestos-containing materials.

CERCLA provides in §126(b) that the OSHA regulations address certain worker protection provisions; however, employers would have to continue to comply with other pertinent OSHA standards found in 29 CFR 1910 (*General Industry*) as well. Air contaminant Permissible Exposure Limits for general industry for 212 substances were revised and updated on Jan. 19, 1989 (54 FR 2332), effective March 1, 1989, 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. In the case of conflict or overlap of worker protection standards and general industry standards, the more restrictive provisions apply. DOE orders related to occupational safety, as well as the regulations promulgated by OSHA, are usually addressed in the site-specific Health and Safety Plan for each RA site.

6.5.9 Federal and State Regulations

Table 6.13 gives a preliminary list of federal and state action-specific regulations established under RCRA and various other statutes discussed above. Action alternatives are listed alphabetically, followed by a summary of the requirements found in the particular statute cited. The prerequisites for applicability are also given; however, the regulations must be related to site-specific conditions to determine whether the regulation cited is legally applicable. This table does not represent a complete listing of action-specific regulations; analysis of the regulations on a site-specific basis would be necessary to ensure a comprehensive summary.

6.6 LOCATION-SPECIFIC REGULATIONS

Location-specific requirements set restrictions upon the concentration of hazardous substances or the conduct of activities solely because they are in special locations. In determining the use of location-specific regulations for actions at RA sites, one must investigate the jurisdictional prerequisites of each of the regulations. Basic definitions and exemptions should be analyzed on a site-specific basis to confirm the correct application of the requirements. Table 6.14 lists the major federal and state location-specific regulations that might be pertinent to RA actions at ORNL.

6.6.1 Caves, Salt-Dome Formations, Salt-Bed Formations, and Underground Mines

ORR, located in the Valley and Ridge Physiographic Province of eastern Tennessee, is characterized by gently to moderately sloping ridges and valleys.¹³ A variety of geologic formations of sedimentary origin underlie ORR. The most important formations are the Rome Formation and the Conasauga, Knox, and Chicamauga Groups. There are no indications of salt-dome formations, salt-bed formations, or underground mines on or near the ORNL sites.¹⁴ If any caves are located in areas where remedial activities might occur, the regulations found in RCRA [40 CFR 264.18(c)], which prohibit the placement of noncontainerized or bulk liquid hazardous waste in caves, might be applicable (Table 6.14).

6.6.2 Faults

The White Oak Mountain and Copper Creek thrust faults transect ORR; the faults on ORR are ancient (pre-Holocene) and are stable.¹⁵ The possibility of fault movement is considered extremely unlikely.¹⁶

ORNL is exempted from compliance with the RCRA seismic requirements of 40 CFR 264.18 because 40 CFR 264.18(a) stipulates that all facilities located within political jurisdictions other than those listed in Appendix VI of 40 CFR 264.18 are assumed to be in compliance for location of new treatment, storage, and disposal facilities. Tennessee is not listed in the appendix.

6.6.3 Wetlands and Floodplains

ORNL is located within the Clinch River drainage basin and is bound on the south and west by the Clinch River; ORNL is located in a sub-basin of the Clinch River. Portions of ORNL are located within 100- and 500-year floodplain of the Clinch River.¹⁷

There are a number of wetlands located in and around ORNL. A draft report of a recent wetlands survey was released in March 1991.¹⁸ Before any RA is taken, this report should be consulted and a survey conducted of the particular site to determine whether there are wetlands present that could be impacted by RA activities. If any RA activities are selected that would impact floodplains, the requirements found in Executive Order (EO 11988, 40 CFR 264.18(b), 40 CFR 6.302(b), 40 CFR 6 (Appendix A), and 10 CFR 1022 would provide applicable requirements for ORNL. If wetlands are affected, consideration should be given to EO 11990, 40 CFR 6.302(a), 40 CFR 6 (Appendix A), 10 CFR 1022, CWA §404, 40 CFR 230, and 33 CFR 320-330 for applicable requirements.

Table 6.14. Location-specific regulations applicable to remedial action activities at the Oak Ridge Reservation

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Faults			
With displacement in Holocene time	New treatment, storage or disposal facility RCRA ^a -defined listed or characteristic hazardous waste (40 CFR 261) -or- RCRA-permitted facility	Portions of new facilities must not be within 61 meters (200 ft) of such fault	40 CFR 264.18(a)
Salt-dome formations, salt-bed formations, underground mines or caves			
	RCRA-defined listed or characteristic hazardous waste (40 CFR 261) -or- RCRA-permitted facility	Placement of noncontainerized or bulk liquid hazardous waste in these locations is prohibited	40 CFR 264.18(c)
Wetlands			
Presence of wetlands as defined in Executive Order 11990 §7(c) and 40 CFR 6, Appendix A §4(j)	Agency action which involves: – acquiring, managing, and disposing of lands and facilities – providing federally undertaken, financed, or assisted construction and improvements – conducting federal activities and programs affecting land use	Whenever possible, actions must avoid or minimize adverse impacts on wetlands and act to preserve and enhance their natural and beneficial values. New construction in wetlands areas should be particularly avoided unless there are no practicable alternatives. Wetlands protection considerations shall be incorporated into planning, regulating, and decision-making processes.	Executive Order 11990 40 CFR 6.302(a) 40 CFR 6, Appendix A 10 CFR 1022

Table 6.14 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Presence of wetlands as defined in 40 CFR 230.3(t) and 33 CFR 328.3(b)	Action involving discharge of dredge or fill material into wetlands	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 which 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 100-year floodplain	Treatment, storage, or disposal facility RCRA-defined listed or characteristic hazardous waste (40 CFR 261) -or- RCRA- permitted facility	Facility must be designed, constructed, operated, and maintained to prevent washout of any hazardous waste by 100-year flood	40 CFR 264.18(b)

Table 6.14 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Within "lowland and relatively flat areas adjoining inland and coastal waters and other flood-prone 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." [Executive Order 11988 §6(c) and 40 CFR 6, Appendix A §4(d)]	Action which involves: - acquiring, managing, and disposing of lands and facilities - providing federally undertaken, financed, or assisted construction and improvements - conducting federal activities and programs affecting land use	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	Executive Order (EO) 11988 40 CFR 6.302(b) 40 CFR 6 (Appendix A) 10 CFR 1022
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	Action involving the discharge of any pollutants into the waters of the state [see TCA 69-3-103(18) and (21) for noninclusive list]	Discharge of "substances" which "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 Rules - Chap. 1200-4-4)

Table 6.14 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Within area affecting stream or river -and- presence of fish or wildlife resources	Action which results in the control or structural modification of a natural stream or body of water	The effects of water-related projects on fish and wildlife resources must be considered Action must be taken to prevent, mitigate, or compensate for project-related damages or losses to fish and wildlife resources Off-site actions that alter a resource require consultation with the FWS ^d , NMFS ^f , and/or appropriate state agency Consultation is also strongly recommended for on-site actions	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	Action involving the discharge of dredge or fill material into aquatic ecosystem	Degradation or destruction of aquatic ecosystems must be avoided to the extent possible. Discharges which 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
Location encompassing a state-designated natural area		The scientific, scenic, recreational, and educational values of these areas must be preserved and steps taken to prevent impairment thereof	TCA 11-14-101 <i>et seq</i>

Table 6.14 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
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	Action which is likely to jeopardize species or destroy or adversely modify critical habitat	Actions that jeopardize species/habitat must be avoided or appropriate mitigation measures taken Off-site actions that affect species/habitat require consultation with DOI ^f , FWS, NMFS, 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 Consultation is also strongly recommended for on-site actions	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>)
Presence of endangered or threatened species or critical habitat (see above citation) of same within an aquatic ecosystem as defined in 40 CFR 230.3(c)	Action involving discharge of dredge or fill material into aquatic ecosystem	Dredge or fill material shall not be discharged into an aquatic ecosystem if it would jeopardize such species or would likely result in the destruction or adverse modification of a critical habitat of the species	Clean Water Act §404 40 CFR 230.10(b)

Table 6.14 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Presence of Tennessee state-listed endangered or threatened animal species as created and amended pursuant to TCA 70-8-105		Protected species may not be taken, possessed, transported, exported, processed, sold, offered for sale, or shipped. Certain exceptions may be allowed such as for educational, scientific, etc., reasons or where necessary to alleviate property damage or protect human health or safety. These exceptions require a permit if the remedial action or its attendant effects are off site	Tennessee Nongame and Endangered or Threatened Wildlife Species Conservation Act of 1974 (TCA 70-8-101 <i>et seq.</i>)
Archaeologic and Historic Resources			
Presence of archaeological resources on public land	Action which would impact resource	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 archaeologic or historic resources	Action involving dam construction or other alteration of terrain which might cause irreparable loss or destruction of significant scientific, prehistoric, historic, or archaeologic data	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

Table 6.14 (continued)

Location characteristic(s)	Operating condition(s)	Requirement(s)	Citation(s)
Presence of federally owned, administered, or controlled prehistoric or historic resources -or- the likelihood of undiscovered resources		<p>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</p> <p>Action(s) that will affect such resources must be identified and alternatives to the action(s) examined and considered</p> <p>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</p> <p>When all or part of a remedial action is off site, the consultation requirements of 16 USC 470f must be completed</p> <p>Consultation is also strongly recommended for on-site actions</p>	<p>National Historic Preservation Act (16 USC 470a-w)</p> <p>Executive Order 11593</p> <p>40 CFR 6.301</p> <p>36 CFR 800</p>
Cemetery located on property within Tennessee		Destruction or degradation of property in a graveyard or cemetery is prohibited	Tennessee General Cemetery Act of 1968 (TCA 46-1-101 <i>et seq.</i>)

^aRCRA = Resource Conservation and Recovery Act; definitions appear at 40 CFR 260.10.

^bTCA = Tennessee Code Annotated.

^cTDEC = Tennessee Department of Environment and Conservation.

^dFWS = Fish and Wildlife Service.

^eNMFS = National Marine Fisheries Service.

^fDOI = 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.

6.6.4 Wilderness Areas, Wildlife Refuges, Wildlife Resources, and Scenic Rivers

There are no known designated wilderness areas, wildlife refuges, or scenic rivers on the ORNL site or within range of the reservation, such that RAs would likely impact these resources. However, if any RAs result in the control or structural modification of a natural stream or water body, the provisions found in the Fish and Wildlife Coordination Act (16 USC 661 *et seq.*) and 40 CFR 6.302(g) may be applicable. If any action involves the discharge of dredge or fill material into an aquatic system, the CWA §404, 40 CFR 230, and 33 CFR 320-330 may also be applicable.

The Clinch River, Poplar Creek with its various tributaries and forks, and White Oak Creek have all been classified by TDEC for a variety of uses, including fish and aquatic life and wildlife. It is therefore possible that the provisions of the Tennessee Water Quality Control Act (TCA 69-3-101 *et seq.*) would be legally applicable should any RAs at ORNL cause, or be likely to cause, harm to wildlife or aquatic life in these waters.

Slightly over 5000 acres of ORR have been designated as a DOE National Environmental Research Park (NERP), which also includes research areas located both within and without the NERP itself.¹⁹ Portions of the NERP come to within at least 2-3 km of the K-25 Site, ORNL, and Y-12. Several research areas are within 0.5 km of ORNL, including research area No. 25, carbon monoxide monitoring, and research area No. 37, biomass demonstration plots.¹⁹

In addition to the NERP and its associated research areas DOE has also designated areas on ORR as DOE-NERP reference areas and DOE-NERP natural areas. The reference areas and natural areas are located in various sites on ORR, with several in close proximity to the reservation facilities. Eight of the reference areas and natural areas have also been registered by Tennessee as State Natural Areas.

Because of the unique purposes and goals in establishing the NERP, the uses and restrictions that apply to these resources should be considered nonregulatory guidance if remedial activities appear likely to impact the designated areas. Guidance regarding the permitted uses and restrictions of the various locations can be obtained from the NERP Project Manager at ORNL. For a general overview, please refer to Vol. 23 of *The Resource Management Plan for the Oak Ridge Reservation*.¹⁹ Such impacts should be avoided. In addition, should areas which are also designated State Natural Areas by the state of Tennessee be affected, the provisions of the Tennessee Natural Areas Preservation Act of 1971 (TCA 11-14-101 *et seq.*) may be applicable.

6.6.5 Rare, Threatened, or Endangered Species

In addition to the 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 inhabit east Tennessee (50 CFR 17).²⁰ An in-depth discussion of these species appears in Vol. No. 24 of *The Resource Management Plan of the Oak Ridge Reservation*.²⁰ The list of rare and endangered species for ORR, provided by the state of Tennessee, also includes two state-listed and federally listed endangered clams.²¹

Should any RAs at ORNL impact any federally listed endangered or threatened species, the provisions found in the Endangered Species Act (16 USC 1531 *et seq.*), 50 CFR 492, 40 CFR 6.302(h), and the Fish and Wildlife Coordination Act (16 USC 661 *et seq.*) may be legally applicable. Additionally, if the RAs involve the discharge of dredge or fill

material, CWA §404 and 40 CFR 230.10(b) may be 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. The prohibitions of the Tennessee Rare Plant Protection and Conservation Act of 1985 (TCA 11-26-201 *et seq.*) do not apply to a landowner, lessee, or other person entitled to possession of the land on which the species is located (TCA 11-26-209). This also includes managers in the case of publicly owned land and those with written permission of the landowner or manager (TCA 11-26-209). These exclusions would apparently apply to ORNL. However, the purpose of the statute to protect and preserve rare plants should be considered guidance for any RAs on the reservation.

6.6.6 Historic Sites and Archaeological Findings

ORR, as well as the surrounding region, is rich in both archaeological and historic resources.²² 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*²² which also includes a list and descriptions of most of the documented sites. Eight archaeological sites were identified at ORNL; of the eight, it was recommended that three (40RE27, 40RE101, and 40RE1-32) be extensively tested and possibly excavated if threatened by construction or remedial activities.²² None of the surveys done is recent, however, nor have they covered all of the specific sites where RAs 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 RA is undertaken which 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 EO 11593, 40 CFR 6.301 and 36 CFR 800 *et seq.*

Lastly, there are a number of cemeteries located on ORR which predate the acquisition of the property by the government. Any RAs that affect these cemeteries would be subject to the provisions of the Tennessee Cemetery Protection Act (TCA 46-1-101 *et seq.*), which prohibits their destruction or degradation.

6.6 REFERENCES

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APPENDIX

PARTIAL 1992 AND 1993 TECHNICAL TASK PLAN SEARCH DATA BASE LISTING

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

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	ALTPMSA	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					