OAK

IDGE NATIONAL LABORATORY
ECHNOLOGY LOGIC DIAGRAM

VOLUME 2

TECHNOLOGY LOGIC DIAGRAM

PART B Remedial Action

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Prepared for the
Office of Technology Development
U.S. Department of Energy

**1993
Edition**

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**Oak Ridge National
Technology Laboratory**

**Volume 1
Technology Laboratory**

**Part 1
Remedial**

Prepared for the Office of Technology Assessment
U.S. Department of Energy

September 1980

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The *Oak Ridge National Laboratory Technology Logic Diagram* that relates environmental restoration (ER) and waste management potential technologies that can remediate these problems. The *Ridge Reservation* and a previous Hanford TLD.

The TLD identifies the research, development, demonstration technologies to a state that allows technology transfer and application (RA), and WM activities. It is essential that follow-on engineering. These studies will begin by selecting the most promising technologies that will provide a socially acceptable balance between

The TLD consists of three fundamentally separate volumes: *Diagram*, and Vol. 3 (*Technology Evaluation Data Sheets*). Part A focuses on the RA of contaminated facilities. Part C of Vols. 1 and 2, the TLD, an explanation of the program-specific responsibilities, technologies. Volume 2 (Pts. A, B, and C) contains the logic linking technologies that have the potential to solve these problems. Volume

Remedial action is the focus of Vol. 2, Pt. B, which highlights characterization, RA, and robotics and automation. Each of the is broken down by problem area/constituents and linked to potential information about a technology's status, its science and technology. is explained in detail in the Explanation and Understanding Key to the

The TLD *Index*, a stand-alone volume, facilitates information. comprises three separate indexes, one for each of the corresponding searched by specific ORNL problem, problem area/constituents, or

The technology evaluations contained in these volumes are the TLD. New or more accurate information is solicited to improve the Editor, *Oak Ridge National Laboratory Technology Logic Diagram*, Oak Ridge, TN 37831-7274. FAX (615-576-8558).

rogram (TLD) was developed to provide a decision support tool for environmental management (WM) problems at Oak Ridge National Laboratory (ORNL) to help decision makers. The TLD uses information from the *Strategic Roadmap for the Oak*

illustration, testing, and evaluation needed to develop these technologies for application to decontamination and decommissioning (D&D), remedial action, and other studies to be conducted to build on the output of this project. The TLD identifies technologies identified in the TLD and finding an optimum mix of technologies based on cost and risk.

Contents: Vol. 1 (*Technology Evaluation*), Vol. 2 (*Technology Logic*). Part A of Vols. 1 and 2 focuses on D&D. Part B of Vols. 1 and 2 focuses on WM. Each part of Vol. 1 contains an overview of the review of identified technologies, and the rankings of remedial technologies among EM goals, environmental problems, and the various environmental goals. Part 3 (Pts. A, B, and C) contains the TLD data sheets.

The TLD has been divided into the three necessary subelements of RA: the sections address general ORNL problems, which are then ranked by remedial technologies. The diagrams also contain summary information on technology needs, and its implementation needs. The diagram structure is as follows.

The TLD contains searches on specific technologies. The *Index* actually lists the parts (A, B, and C) of Vols. 1 and 2. Information can be searched by technology name.

The TLD is based on the best information available during compilation of the TLD data base. Please send comments to R. L. Fellows, ORNL, Martin Marietta Energy Systems, Inc., P.O. Box 2003, Oak Ridge, TN 37831-6003.

Explanation and Understanding Key

The logic elements described in the "Technical Approach" section of Chap.

for the Technology Logic Diagram

of the Executive Summary serve as column headings in this diagram.

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
<p>ides the general or generic technology approaches to lem remediation.</p>	<p>Provides a specific technology that may reasonably be applied to remediate the problem.</p> <p>Technology Evaluation Data Sheet (TEDS) Codes, located after the technology names in this column, refer to TEDSs in Vol. 3. The TEDS address each technology in more detail. Each TEDS contains a single, unique logic path from the Diagrams.</p> <p>Rankings appear after the TEDS code for each technology. The technologies are ranked according to the following criteria:</p> <ul style="list-style-type: none"> • Overall assessment of usefulness (E—essential, H—high, M—medium, L—low) • Ranking of the site problem (1–5 from lowest significance to highest) • Time required to bring the technology to commercial or mature state at the site—expressed in years. • Cost for bringing the technology from its present state to large-scale commercial use (millions [\$M] or thousands [\$K] of dollars). • Projected unit processing cost for mature technology (\$ per ft³ or other unit or N for no estimate). <p>An example of a ranking follows: H-5-5 (\$3.5M;N). 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.</p>	<p>Provides information on the status of the preceding technology.</p> <ul style="list-style-type: none"> • In Use—problem is in the process of being remediated with this technology. • Accepted—accepted by industry and/or the problem owner. The demonstrated technology exists for use at ORNL. • 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. <p>— Conceptual—a scientific or knowledge basis for the technology exists.</p> <p>— Preconceptual—only a partial scientific or knowledge basis of the technology exists.</p> <p>The following areas further define the applicability of a technology to the problem:</p> <ul style="list-style-type: none"> • Efficacy—the effectiveness of the technology in remediating the problem. Normally, quantitative measures are given for the technology's performance in standard practice, such as decontamination, estimating the final dpm/cm² of surface contamination; dismantlement; the time to cut a 24-in. pipe; and characterization; the analysis time and lower-detection limit. • Waste—the potential output from the technology. This describes the nature and volume of both the waste and the potentially useful materials (recyclable) suitable for materials disposition evaluation. 	<p>Lists needs in Science and Technology where support should be applied to develop an "immature" technology to a field-deployable state.</p> <p>Science needs are related to the fundamental understanding of the scientific phenomena that form the basis for the technology. These needs are typically for laboratory or bench-scale experiments, and, when possible, experiments addressing specific areas of uncertainty are suggested.</p> <p>Technology development (TD) conversion of a scientifically understood phenomenon into an operating system (technology) that can be applied to, and can remediate an EM problem.</p> <p>Technology improvement needs relate to improvements that 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.</p> <p>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 TD opportunity implies that technology improvements are also likely to be needed.</p> <p>Past and currently funded Technical Task Plans (TTP) were correlated with the technologies. If a match was found, "TTP Match" appears in this column. The TTP number and technology number matches can be found in the TTP tables of Vol. 1, Pt. A, Pt. B, and Pt. C.</p>	<p>Covers many of the areas of concern for technology transfer activities. Specialized needs for both development of a technology and deployment of a mature technology are identified.</p> <p>These needs were evaluated in the areas of (1) resources (financial or personnel); (2) hardware (process equipment, development equipment, and computers); (3) software (models, procedures, computer programs); (4) facilities (labs, shops, and buildings); and (5) education (training classes or degreed personnel). Only extraordinary needs are highlighted (i.e., those needs that would require long lead time or unusual procurements such as line items for facility construction).</p> <p>Technology integration identifies the technologies which can be integrated to produce a safer, better or cheaper remediation system.</p> <p>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.</p>

Characterization fo

The Characterization section is grouped into a large section which most of the characterization technologies are applied to specific problems, where a more select group of technologies are applied to a specific section. The former section is divided into several subsections which are sampling design, sample collection, sample analysis, detection/measurements—laboratory, and data analysis. The latter are listings under the specific subsections of radioactive materials, chemical, and biological pathogens. Each of these is divided into field methods and laboratory deployment.

Remedial Action

, generally inclusive section of ORNL Problems to
applicable and smaller sections for specific ORNL
called for in addition to those offered in the general
sections under the Alternatives column. These
sample preparation, detection/measurements—field,
s/management. Following these general subsections
e elements, inorganics, organics, physical, and
and laboratory methods according to their primary

Characterization for

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements	
<ul style="list-style-type: none"> Clean Up Legacy Waste Prevent Future Insult Develop Environmental Stewardship 	All Problems Buried Waste WAG 1, WAG 3, WAG 4, WAG 5, WAG 6, WAG 7 Ground Water/Surface Water WAG 2, WAG 3, WAG 4, WAG 5, WAG 6, WAG 8, WAG 9, WAG 10; WAG 11 Hydrofracture WAG 10 Impoundments WAG 1, WAG 5, WAG 8, WAG 9 Pipelines WAG 1, WAG 4, WAG 5, WAG 7, WAG 8 Pits and Trenches WAG 7 Soils/Sediments WAG 1, WAG 2, WAG 3, WAG 4, WAG 5, WAG 6, WAG 7, WAG 11, WAG 13 Tanks WAG 1, WAG 5, WAG 8, WAG 9	General	Refer to the Vol. 1, Pt.C, Chap. 6, for potentially applicable, proposed, and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization	Sa
EM Problems <ul style="list-style-type: none"> Facility Decontamination and Decommissioning (D&D) Remedial Action (RA)—Soils, Groundwater and Surface Water Waste Management (WM) 					Sa

Remedial Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Sampling Design	M Sequential Sampling Plans CHAR-252-OL <i>Ranking:*</i> M-3-5 (\$.1M; \$0.5Kam)	Accepted TTP Match	Experimental Site Data Available at X-10.	Initial Planning Time
	E Sampling Program Configuration Management System CHAR-228-OL <i>Ranking:*</i> E-5-1 (\$0.5M;\$50Kam)	Accepted. A range of application software to assist with configuration management is available both commercially and in the public domain. TTP Match	Enhancements to existing products may be required to provide the level of support needed for a large sampling program. Available at X-10.	Separate configuration management systems should be considered for each of (a) Characterization Sampling Program, (b) Remedial Action, (c) Waste Management, and (d) Decontamination and Decommissioning instead of setting up one large all- encompassing system.
	H Optimization of Sampling Designs CHAR-71-OL <i>Ranking:*</i> H-5-5 (\$.1M;N)	Demonstration	Literary searches for finding useful sampling designs from investigations in other fields. New statistical methods for sampling design. Available at all sites.	Development Cost: at \$100K.
Sample Collection	H In-situ Solid Phase Microextraction of Organics CHAR-210-OL <i>Ranking:*</i> H-5-1 (\$.25M;\$200/sample)	Predemonstration, technology has been demonstrated on the laboratory bench.	Develop protective sheath and apparatus for field sampling. Available at X-10.	Development Cost: \$250K.
	E Sampling and Mixing Methods CHAR-81-OL <i>Ranking:*</i> E-5-1 (\$.25M;N)	Accepted TTP Match	Need to optimize methods for collection of representative samples and to mix samples into a homogeneous state.	Requires statistical sampling design and proper laboratory blenders, mixers, and other equipment. Development Cost: at \$250K.
	H Soil/Sediment Sampling for Volatile Organics Analysis CHAR-256-OL <i>Ranking:*</i> H-4-1 (\$.1M;\$50/sample)	Demonstration, previous work has shown that soils can be sampled for volatile organics analysis but further work is needed to adapt to the specific needs of the ORNL site. TTP Match	Adaptation of the procedure to the specific applications required at ORNL. Available at X-10.	Development Cost: \$100K.
	H Sampling Underground Storage Tanks for Volatile Organics CHAR-257-OL <i>Ranking:*</i> H-5-1 (\$.26M;\$500/sample)	Demonstration, the technology has been applied at the Hanford underground storage tanks. Technology is based on reasonably well- proven air sampling methods, but specific applications must be validated.	Adapt laboratory purge-and- trap techniques to field sampling within or immediately outside tanks, particularly USTs for nuclear process waste. Available at X-10.	Hardware costs, \$10K; Development Cost: \$250K.
	H Solid Sorbent Sampling for Airborne Organics CHAR-254-OL <i>Ranking:*</i> H-5-1 ((\$.2M;\$50/sample)	Demonstration, technology is available, but validation is required for particular conditions and target species. TTP Match	Adaptation of the procedure to the specific applications required at ORNL.	Depends upon contaminants. Development costs-\$100- 200K.

* See the Explanation and Understanding
Key in the front of this document for a
description of the ranking code/scheme.

or Remedial Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Sample Collection	M Membranes for Sample Collection and Concentration CHAR-55-OL <i>Ranking:*</i> M-5-1 (\$.25M;\$50/sample)	Accepted TTP Match	Membranes are permeable predominantly to selected components in mixtures, allowing separation for accumulation or to facilitate analysis/detection.	System development or adaptation for specific applications; validation. Sample collection systems for site-specific applications.
	H Sampling of Heterogeneous Wastes CHAR-270-OL <i>Ranking:*</i> H-5-3 ((\$2.8M;N))	Conceptual TTP Match	Development of statistical approaches, strategies, and methods for removing a representative sample must be developed.	Cost: \$2.8M over 3 years.
	M Sediment Sampling from Restricted Access Locations CHAR-276-OL <i>Ranking:*</i> M-5-2 (\$.45M;N)	Predemonstration The technology is based upon refinements of current methods. TTP Match	Develop articulated sampling arm with coring device.	Hardware Cost: \$50K, Development Cost: \$400K
	M Multiangle Drilling for Depth Profiling of Contaminants CHAR-64-OL <i>Ranking:*</i> M-4-1 (\$.2M;N)	Demonstration	Model studies need to be performed. Available at K-25.	Development Cost: \$200K
Sample Preparation	H Radioactive Sample Preparation CHAR-205-OL <i>Ranking:*</i> H-4-1 (\$.1M;N)	Demonstration, current work shows that methods can be adapted to meet these needs. TTP Match	Adaptation of EPA and other methods, and development of new technologies for the safe and efficient preparation of radioactive samples for analysis. Available at X-10.	Development Cost: \$500K each of two years; personnel and facilities are available.
	M Supercritical Fluid Extraction of Organics CHAR-208-OL <i>Ranking:*</i> M-5-1 (\$.33M;\$100/sample)	Predemonstration, technology requires final development. TTP Match	Extraction conditions need to be optimized for the specific target analytes and matrices at ORNL. Available at X-10.	Hardware Cost: \$30K; Development Cost: \$300K.
	E Adaptation of the EPA Toxicity Characteristic Leaching Process for Use with Radioactive Samples CHAR-209-OL <i>Ranking:*</i> E-5-1 (\$.45M;N)	Predemonstration, some work has been conducted, but full adaptation and testing remain to be done. TTP Match	The leaching equipment and protocol must be adapted to glove box and hot cell operations. Available at X-10.	Development Cost: \$450K. Equipment must be modified and tested under containment and shielding.
	M Metallographic Sectioning and Preparation CHAR-67-OL <i>Ranking:*</i> M-4-0 (\$0M;<\$500/sample)	Accepted	Procedure development for specific applications and protocols for standardized preparation. Available at X-10, K-25.	None. Facilities available.
	H Microwave Digestion CHAR-19-OL <i>Ranking:*</i> H-5-1 (\$.2M;\$100/sample)	Accepted Demonstrated TTP Match	This technology shows much promise in reducing the amount of waste produced in analyzing samples as well as increasing the quality of the data obtained. Available at X-10.	Protocols are needed to optimize the digestion of environmental samples in preparation for subsequent analytical techniques.

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EM Problems <ul style="list-style-type: none"> • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Groundwater and Surface Water • Waste Management (WM) 					De Fi

Remedial Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Sample Preparation	H High Pressure Ashing for Sample Preparation CHAR-203-OL <i>Ranking:*</i> H-4-1 (\$1M;N)	Demonstration: Commercially available, but not mature.	High pressure ashing (HPA) is useful for the dissolution of organics and other difficult-to-dissolve materials, but it lacks sufficient validation to meet quality assurance (QA) requirements. Some sample types require method development. Available at X-10.	Commercially available but lacks sufficient validation to meet QA requirements. Some special sample types may be at the development stage. Some equipment/personnel currently available at ORNL to develop new procedures but needs to be expanded to meet the increased work load. Estimated Cost: \$60-120K/year for two years.
	M Supercritical Fluid Extraction of Inorganics CHAR-201-OL <i>Ranking:*</i> M-3-2 (\$.2M;N)	Predemonstration: Supercritical fluid extraction of inorganics, extraction of metal ions from liquid and solid material by supercritical carbon dioxide and chelators. TTP Match	Need to determine optimum extraction conditions, including chelators. Available at X-10.	Hardware Cost: \$30K; Development Cost: \$400K over 2 years.
Detection/Measurement— Field Methods	H Fiber-Optic Chemical Sensors CHAR-25-OL <i>Ranking:*</i> H-4-1 (\$1M;\$10/sample)	Accepted; demonstration Remote detection using a variety of spectral methods, including optical absorption, Raman scattering, and luminescence spectroscopy. The fiber optic is used to deliver or return light to or from the sample. This technology allows remote sensing in hazardous environments. TTP Match	A combination of waveguides and spectroscopic techniques are needed that have been matched not only for each other but also for specific monitoring scenarios.	Waveguides are needed that can withstand the harsh chemical environment that may be present in some of the sampling locations.
	M Ion Mobility Mass Spectrometry CHAR-264-OL <i>Ranking:*</i> M-5-2 (\$1M;\$50/sample)	Predemonstration Provides a means for the rapid separation and identification of complex mixtures based on the mobility of ions in an electric field at atmospheric pressure.	Software control of high-speed data acquisition, interpretation and instrument control. Available at X-10.	Hardware Cost: \$30K; software development additional.
	H Immunoassay Detection CHAR-23-OL <i>Ranking:*</i> H-5-3 (\$1M;\$50/sample)	Accepted Immunoassay detectors are used to determine environmentally important analytes. The technique is very selective, sensitive, and extremely easy to use.	This is a mature and emerging technology. Kits are designed to perform in specialized waste streams. DOE has a calibrated PCB kit in the Analytical Field Screening Program.	Automated sampling and reading systems for quick, on-line testing of groundwater and waste stream contamination.
	M Portable Raman Spectrometer CHAR-84-OL <i>Ranking:*</i> M-5-2 (\$1M;\$10/sample)	Demonstration of field capabilities at ORNL Raman spectra provide fingerprint identification of chemical species. No direct contact with the sample is necessary. Often interfaced with fiber optics for remote sensing in inaccessible areas. TTP Match	Develop methods that exploit surface enhancement are resonance excitation for vastly improved sensitivity.	Equipment is available at ORNL but has not been assembled for a specific application.
	H Optical Absorption Spectroscopy (OAS) CHAR-27-OL <i>Ranking:*</i> H-5-1 (\$.6M;\$50/sample)	Accepted Measures the transmission of UV, visible, and near IR to determine the concentration of chemical species in gases, liquids, or solids. OAS can be applied to the analysis of any species that absorbs electromagnetic radiation in the region of excitation, UV through IR. TTP Match	Mature, field-portable technology available in IR, UV. Available at all sites.	It can be implemented for site-specific needs.

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r Remedial Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Detection/Measurement— Field Methods	E Air Monitoring CHAR-59-OL <i>Ranking:*</i> <i>E-5-0 (\$.25M;\$500/sample)</i>	Accepted Encompasses several methods of monitoring particulate loading and characteristics during remedial action. Collected samples can be analyzed for many species. TTP Match	This is a mature sampling technology with EPA protocols. Available at all sites.	This is a mature technology.
	M Infrared Spectroscopy (wavelength dispersion) CHAR-18-OL <i>Ranking:*</i> <i>M-5-1 (\$.5M;\$100/sample)</i>	Accepted This method includes: Long-path (LP-FTIR); diffuse reflectance, and attenuated total reflectance for determination of compounds found in the air and water and on surfaces. TTP Match	No units currently exist on site. Several vendors are marketing equipment. Software development would enhance site-specific applications. Available at all sites.	Centralized mounting areas with robotically controlled units would allow multiple-site areas to be monitored with one unit.
	H Personnel Monitoring CHAR-52-OL <i>Ranking:*</i> <i>H-5-1 (\$.2M;N)</i>	Demonstration	Model studies are needed to correlate exposure and quantitative analysis from various human factors. Available at all sites.	We need a detailed monitoring program for personnel protection.
	M Tomographic Seismic Monitoring CHAR-60-OL <i>Ranking:*</i> <i>M-5-N (N;N)</i>	Accepted TTP Match		
	H Ultrasonic Ranging and Data System CHAR-123-OL <i>Ranking:*</i> <i>H-5-0 (\$0;N)</i>	Accepted and being used commercially.	Adaptation to various data generation systems is needed. Available at X-10.	None. Currently in use.
	H Ground-penetrating Radar CHAR-124-OL <i>Ranking:*</i> <i>H-5-0 (\$.03M;N)</i>	Accepted. Commercially available. TTP Match	Improvements are needed in the depth of penetration and signal-to-noise and signal processing, particularly antenna design. Available at X-10, K-25.	System Cost: ~\$30K.
	H Electrical and Electromagnetic Detection of Ground and Geologic Features CHAR-125-OL <i>Ranking:*</i> <i>H-5-1 (\$.2M;N)</i>	Developed through accepted. TTP Match	Development of site-specific techniques and data handling and imaging methods are needed. Available at X-10.	Development Cost: ~\$200K; System Cost: \$100K.
	M Seismic Methods (Refraction, Profiling, Reflection) CHAR-126-OL <i>Ranking:*</i> <i>M-5-1 (\$.2M;N)</i>	Developed through accepted. TTP Match	Developed, shallow sources should be tested. Techniques should be adapted and used for both vertical and horizontal boreholes. Available at X-10.	Development Cost: ~\$200K; System Cost: \$50K.
	M Microgravity Methods CHAR-127-OL <i>Ranking:*</i> <i>M-5-1 (\$.2M;N)</i>	Development	Development of increased sensitivity for rapid, cost-effective subsurface detection and mapping is needed. Also, site-specific development is needed for detecting karst cavities and conduits.	Development Cost: ~\$200K; System Cost: ~\$60K.
	M Magnetics CHAR-128-OL <i>Ranking:*</i> <i>M-5-1 (\$.2M;N)</i>	Accepted. An aerial survey has been completed in Oak Ridge. TTP Match	Development of methods to minimize interference is needed. Available at X-10.	Development Cost: ~\$200K; Deployment Cost: \$15K.

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Characterization for

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Remedial Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Detection/Measurement— Methods	M Luminescence Detection CHAR-92-OL <i>Ranking:*</i> M-5-1 (\$.5M;\$10/sample)	Predemonstration; demonstration The detection of organic and inorganic chemicals using fluorescence, phosphorescence, and chemiluminescence. Samples are illuminated by a laser or a conventional light source. Subsequent luminescence emission is detected yielding spectral information about the sample. This may be used to identify or quantitate analytes in a variety of sample background matrices. TTP Match	The technology is mature, but may not provide absolute identification of compounds in complex mixtures. Available at X-10.	Hardware is available at ORNL. Specific techniques need development and procedures written.
	M Electrochemical Methods CHAR-10-OL <i>Ranking:*</i> M-4-2 (\$.5M;\$100/sample)	Accepted Oxidizable or reducible species, excited by a voltage of current function in an electrical circuit, yield quantitative and qualitative information about species of interest. Selective and sensitive sampling is possible in many situations. TTP Match	Adaptation and protocols for model studies to be performed on complex systems are needed.	Hardware Cost: \$50K-\$250K; Development Cost: \$250K.
Detection/Measurement— Laboratory Methods	H Contamination Control— Analytical Equipment CHAR-204-OL <i>Ranking:*</i> H-5-2 (\$.5M;N)	Accepted Commercially available for some systems, but usually must be done on a case-by-case basis due to facility limitations and different containment requirements. TTP Match	Contamination control for analytical equipment/instrumentation frequently requires extensive instrument modification to contain the equipment in radiochemical hoods, glove boxes, or hot cells. Requires special expertise, but must be done for higher levels of radioactivity. Available at X-10.	Some equipment/personnel currently available at ORNL but needs to be expanded to meet the expected increase in work load. Implementation includes engineering design, fabrication of containment/shielding, and modification of facility. Typical cost for containment of an ICP in a glove box was approximately \$150K several years ago; this did not include the cost of the instrument.
	M Fourier Transform Infrared Spectroscopy CHAR-8-OL <i>Ranking:*</i> M-5-1 (\$.2M;\$50-500/sample)	Accepted TTP Match	Database for rapid materials identification and model suites of materials interaction is needed. Available at all sites.	Hardware Cost: \$25-\$500K; Development Cost: <\$200K.
	M Isotopic Dilution Mass Spectroscopy CHAR-48-OL <i>Ranking:*</i> M-5-0 (\$0M;\$100-1000/sample)	Accepted	Model studies are needed to enable quick analysis. Available at X-10.	Equipment, as well as the model studies mentioned above, is needed.
	M Nuclear Magnetic Resonance CHAR-11-OL <i>Ranking:*</i> M-5-1 (\$.2M;\$200-500/sample)	Accepted, available on site TTP Match	None, available on site Available at X-10.	Hardware Cost: \$200K-\$2M; Development Cost: \$200K-\$500K.
	H Secondary Ion Mass Spectroscopy CHAR-3-OL <i>Ranking:*</i> H-5-0 (\$0M;\$400/sample)	Accepted	This is a mature technology. Model studies are needed to calibrate for depth-profiling studies. Available at all sites.	Instrumentation and personnel exist at the three plants.

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or Remedial Action

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Detection/Measurement— Laboratory Methods	H Ultraviolet/Visible Spectroscopy CHAR-9-OL <i>Ranking:*</i> H-5-0 (<\$1M;\$50–200/sample)	Accepted, available on site TTP Match	Model studies and application design. Available at all sites.	Hardware Cost: <\$200K; Development Cost: <\$100K.
	M Laser Ionization Mass Spectrometry CHAR-4-OL <i>Ranking:*</i> M-5 -0 (\$0M;\$300–500/sample)	Accepted TTP Match	This is a mature technology. Model studies are needed to optimize results interpretation.	Prototype instrumentation and research instrumentation exists. More equipment would be required. The necessary personnel are available.
Data Analysis/Management	Project Information Access Services (Needed Enabling Technologies) DISM-151-OL <i>Ranking:*</i> No Ranking.	Demonstration The technology needs to be demonstrated because of the degree of integration of different host computers required to support effective information access across wide area networks.	Technology to implement such a system is commercially available and is found typically in financial services companies and some large corporations.	Computer networks, especially Ethernet (cable, fiber), need to be extended throughout the X-10 Site to provide a basic foundation for information access and file transfers.
	Network Architecture with Integrated Workstations CHAR-221-OL <i>Ranking:*</i> No Ranking.	Demonstration Commercial engineering workstations provide the capabilities to support this technology.	The greatest obstacle to use of this technology is the current legacy of older operating systems (DOS, MacOS) not designed to support integration of desktop applications with each other and with network services.	This technology is best introduced in the context of a commitment to use open system standards for all new computer acquisitions.
	E Client/Server Access to Standards and Regulatory Guidelines (Needed Enabling Technologies) DISM-153-OL <i>Ranking:*</i> E-5-0.5 (\$1.25M;\$25Kam)	Demonstration Component technologies are well-established, commercially available, and affordable. They have not yet been integrated for use in a client/server environment.	A product is needed that provides network access to the databases on CD-ROM using the TCP/IP communications protocols between client and server.	Automated, on-line access to basic reference documents is essential to reducing costs and increasing reliability of operations in a highly regulated work environment.
	E Data Access Services (Needed Enabling Technologies) DISM-154-OL <i>Ranking:*</i> E-5-.5 (\$1.5M;\$200Kam)	Demonstration. The particular network and communications configurations needed to support restoration activities may not exist, so would have to set up and their successful operation demonstrated.	Some software will be available commercially; some will have to be developed locally.	Requirements and specifications for such services must be identified and documented to serve as a common reference so that data can be accessed using a single set of services regardless of the type of computer at each node on the network.
	E Geographic Information System for DOE Sites (Needed Enabling Technologies) DISM-181-OL <i>Ranking:*</i> E-5-1 (\$1M;\$200Kam)	Accepted Most information, data, and computer system components for a basic geographic information system (GIS) for each DOE site already exists but must be integrated to meet the needs of the environmental restoration program.	Existing technology must be enhanced by adding a tagging mechanism to permit the system to be used for tracking activities and to link information in databases associated with a physical location to appropriate map and drawing displays on desktop computers.	A large initial effort may be required to scan and digitize diagrams and drawings for electronic storage and quick retrieval or transfer across networks.

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Remedial Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Analysis/Management	E Automated Scanning and Conversion of Engineering Drawings (Needed Enabling Technologies) DISM-155-OL <i>Ranking:*</i> E-5-2 (\$2M;\$300Kam)	Demonstration The basic technology is well established. Whether the current state of the art can adequately process the large number of drawings needed for reference and how effectively this technology can be integrated with other aspects of automated support needs to be demonstrated.	Improvements are needed in the speed and accuracy of converting scanned images to graphical representations that will meet the needs (e.g., ability to change scale to show more detail) of the environmental restoration program.	Considerable human intervention may be required to handle large drawings or drawings that cannot easily be laid flat on a scanning bed.
	E Hazard Analysis Expert System CHAR-233-OL <i>Ranking:*</i> E-5-2 (\$.5m;\$150Kam)	Demonstration Expert systems have been very effective tools for some applications; success or failure depends critically on how well the problem domain has been analyzed and how thoroughly the knowledge base has been specified.	Availability of and access to specification and design tools for developing the knowledge base and structure of the rules are the biggest needs.	Implementation strategy and problem analysis process used are the most important elements of developing a successful hazard analysis expert system.
	E Application of Approximate Reasoning to Data Analysis/Evaluation CHAR-234-OL <i>Ranking:*</i> E-5-2 (\$.5M;\$150Kam)	Demonstration Effective and successful use of this technology depends on availability of experienced and qualified technical people.	Development is needed of tools (e.g., a range of graphical models designed to assist in visualizing relationships) to assist with conceptual analysis or to examine consequences of choosing a logical strategy (e.g., automated theorem provers) in the analysis of problems.	Powerful computing capabilities exist for applying approximate reasoning techniques but are not widely used. Education and training in the use of this technology will be needed.
	E Simulated Walk-through Facility for Robotics Task Sequence Analysis (Needed Enabling Technologies) DISM-171-OL <i>Ranking:*</i> E-5-1 (\$.3M;\$60Kam)	Demonstration The IGRIP applications software running on a Silicon Graphics workstation is capable of identifying situations in which collisions will occur. It can also use human factors and ergonomics data to indicate which tasks requiring human assistance are or are not possible or safe for a human operator to perform.	Development of support reference databases (e.g., human factors, ergonomics) to increase the effectiveness of this technology is an area of need.	The greatest need is to acquire the site-specific data, organize, assemble, and store it for rapid retrieval across computer networks. Integration of this technology with other networked resources will also be required at each site.
	E Computer-based Training Systems (Needed Enabling Technologies) DISM-191-OL <i>Ranking:*</i> E-5-1 (\$.3M;\$100Kam)	Demonstration Application software is available that permits rapid development of courses using many media (visual, audio), including support for a variety of testing strategies.	Further development is needed in the area of authoring support.	A well-defined course development life cycle does not yet exist. Currently used software engineering development life cycle methods should work well.
	E Computer-aided Task Analysis and Procedure Preparation (Needed Enabling Technologies) DISM-172-OL <i>Ranking:*</i> E-5-1 (\$.5M;\$150Kam)	Demonstration This technology is used extensively in planning by various federal agencies, most notably the Department of Defense in military operations planning.	More natural language analysis tools are needed to assist with analysis of information used for planning, much of which is provided in text form.	Knowledge base development will require the largest effort, followed by development of expert systems and decision aids needed to make effective use of the information in the knowledge bases.
	E Client/Server Architecture for Database Access (Needed Enabling Technologies) DISM-157-OL <i>Ranking:*</i> E-5-1 (\$.5M;\$200Kam)	Demonstration The effectiveness and appropriateness of a particular architecture design to meet the requirements of the restoration activities needs to be demonstrated.	This technology will benefit most from improvements in network technology (higher transmission speeds, improved transmission protocols and data access services) needed to support it.	Effectiveness depends strongly on the definition, design and implementation of the data dictionaries, data directories and data models that are the essential foundation for use of this technology.

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Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Data Analysis/ Management				
E	Hypertext Information Systems (Needed Enabling Technologies) DISM-158-OL <i>Ranking:*</i> E-5-1 (\$3M;\$150Kam)	Demonstration A range of products exists to support development of hypertext information systems having many capabilities such as mechanisms for linking related items, for starting execution and controlling other applications, and for navigating documents for faster access to information.	Authoring and design tools are needed.	Hypertext information systems must be designed with great care to avoid problems with maintenance (e.g., modifying or replacing blocks of text from which or to which many links have been made to selected text strings within the block).
H	Spatial Sample and Data Analysis Plans CHAR-253-OL <i>Ranking:*</i> H-3-.5 (\$1M;\$5Kam)	Accepted TTP Match	Personnel and computer time, access to survey data Available at X-10.	Time and data
M	Statistical Methods for the Analysis of Large Data Sets CHAR-251-OL <i>Ranking:*</i> M-3-3 (\$5M;\$5Kam)	Conceptual	To allow for the survey of many areas, statistical methods to take advantage of new parallel processors may need to be developed. Available at X-10.	Possible large-scale computer needs and software development time.
E	Quality Control for Measurement Processes CHAR-250-OL <i>Ranking:*</i> E-4-.25 (\$5M;\$5Kam)	Accepted TTP Match	Data from standards evaluations Available at X-10.	Access to quality standard measurements
H	Analysis of Censored Data CHAR-249-OL <i>Ranking:*</i> H-4-.25 (\$5M;\$5Kam)	Demonstration , some work is available in the literature. The application likely will have to be expanded to meet current needs.	Computer work station with access to appropriate data bases. Available at X-10.	Access to appropriate data bases, computer time, mathematical development time, and programming time.
L	Criticality Indices (CI) CHAR-44-OL <i>Ranking:*</i> L-2-1 (\$25M;N)	Accepted	The program must be implemented to specifically address the D&D technologies to be implemented and suggest the modifications that are needed for low- versus how-enrichment materials.	Same as Science/Technology needs.
M	Modeling of Volatile Organic Compounds Migration in Porous Materials CHAR-53-OL <i>Ranking:*</i>	Demonstration TTP Match	Models need to be developed that are applicable to site-specific scenarios.	Software and hardware are needed to implement the modeling systems.
E	Task Scheduling Aids CHAR-241-OL <i>Ranking:*</i> E-5-1 (\$5M;\$80Kam)	Demonstration Several component technologies must be integrated to provide the level of support needed for the highly regulated environment in which restoration activities will be conducted.	A combination of automated analysis tools (e.g., automated reasoning, theorem provers) and a conceptual framework for representing regulatory requirements needs to be developed that can identify possible logical conflicts that arise in scheduling tasks on jobs for which many requirements must be met.	Validation of data used for generating schedules will require much more attention in cases in which many regulations and requirements must be met.

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Characterization for

Remedial Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Analysis/Management				
H	Multi-sensor Fusion Measurement Systems CHAR-222-OL <i>Ranking:*</i> H-3-1 (\$5M;\$25/measurement)	Pre-demonstration Technology development in this area has been pushed significantly in the aerospace industry, especially for combining measurement techniques based on electromagnetic scattering (radar) with other sensor measurements.	Fiber optic technology integrated with silicon technology is one route to combining multiple types of measurements in a single, compact package resulting in a "smart" sensor. Available at X-10.	Integration of digital processing technology into measurement systems is a more attractive option as result of commercial fabrication facilities that will manufacture silicon chips from custom designs.
M	Detection and Measurement Systems with Feature Extraction CHAR-223-OL <i>Ranking:*</i> M-4-2 (\$1M;\$1/image scanned)	Pre-demonstration With appropriate training of the measurement system and application of feature recognition methods, this technology can be very effective and reliable.	Sensor and measurement technology components are better developed than the application methods that use recently developed mathematical approaches for feature extraction. Available at X-10.	Most measurement systems with feature extraction must be trained in some way by first applying them to known cases.
M	Dynamic Modeling of Material Transport CHAR-225-OL <i>Ranking:*</i> M-2-2 (\$5M;\$20Kam)	Evolving One of the early application areas of the mathematical concepts of fractals and fractal geometry has been to flow in porous media.	Application of fractal concepts to problems of flows in porous media is useful in classifying existing models according to what is appropriate to use for a particular situation. Available at X-10.	Fractal concepts may be applied to analysis of data or to output from porous flow model calculations as criteria incorporated into existing software.
E	Configuration Management System CHAR-229-OL <i>Ranking:*</i> E-5-1 (\$5M;\$50Kam)	Accepted A range of application software to assist with configuration management is available both commercially and in the public domain. TTP Match	Enhancements to existing products may be required to provide the level of support needed for a large remediation program. Available at X-10.	Separate configuration management systems should be considered for each of (a) Characterization Sampling Program, (b) Remedial Action, (c) Waste Management, and (d) Decontamination and Decommissioning instead of setting up one large all-encompassing system.
E	Stored Material Neural Net Identification System CHAR-242-OL <i>Ranking:*</i> E-5-2 (\$1M;\$100/container analyzed)	Demonstration Neural net identification systems must always be trained first to determine whether a proposed use is going to work satisfactorily or to provide a demonstration of identification capabilities.	Speed of data acquisition and quality of the data are the areas where technology improvements would be most beneficial.	Most of the implementation effort will have to be given to setting up and calibrating the various measurement stations needed to gather the data for use by the neural net application software.
	Subsurface Complexation Model CHAR-45-OL <i>Ranking:*</i> No Ranking.	Demonstration TTP Match	Models need to be implemented that take into account the geological formations that exist within the Oak Ridge Reservation.	Same as Science/Technology needs.
H	Dynamic Modeling CHAR-255-OL <i>Ranking:*</i> H-5-2 (\$3M;\$10Kam)	Accepted , measurement, data collection, and data analysis programs are being established with (apparently) insufficient technology available to assure that adequate data will be taken and that the interpretation of the results will be valid.	Models and simulations of the soils and groundwater characteristic of the sites under study need to be developed, tested, and verified in time to be factored into the measurement, data collecting, and data analysis phases of the program. Available at X-10.	Resources needed to develop and verify the simulations should be deployed before extensive measurement R&D and actual data collection and analysis is done to characterize sites, plan remedial action, and assess the results of cleanup activities.

* See the Explanation and Understanding Key in the front of this document for a description of the ranking code/scheme.

EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements
<ul style="list-style-type: none"> • Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship 	All Problems Buried Waste WAG 1, WAG 3, WAG 4, WAG 5, WAG 6, WAG 7 Ground Water/Surface Water WAG 2, WAG 3, WAG 4, WAG 5, WAG 6, WAG 8, WAG 9, WAG 10, WAG 11 Hydrofracture WAG 10 Impoundments WAG 1, WAG 5, WAG 8, WAG 9. Pipelines WAG 1, WAG 4, WAG 5, WAG 7, WAG 8 Pits and Trenches WAG 7 Soils/Sediments WAG 1, WAG 2, WAG 3, WAG 4, WAG 5, WAG 6, WAG 7, WAG 11, WAG 13. Tanks WAG 1, WAG 5, WAG 8, WAG 9	Radioactive Elements	Refer to the Vol. 1, Pt.C, Chap. 6, for potentially applicable, proposed, and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization
EM Problems <ul style="list-style-type: none"> • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Groundwater and Surface Water • Waste Management (WM) 				

Remedial Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Field Methods				
H	Proportional Counter for Alpha and Beta Activity CHAR-108-OL <i>Ranking:*</i> H-5-0 (\$1M;\$100/sample)	Accepted	This is a well-established technology. Some minor development may be needed to distinguish Technetium activity from Uranium. Probes for measuring vertical or overhead items are needed.	Normal
M	Passive Monitors for Weak Beta Radionuclides CHAR-102-OL <i>Ranking:*</i> M-4-2 (\$.6M;\$20/sample)	Pre-demonstration The thermally stimulated exoelectron (TSEE) technique is the weakly penetrating radiation analog to thermoluminescence. The exposed TSEE dosimeter is heated to liberate low-energy electrons from a thin surface layer. The thin exoactive layer is especially sensitive to low-energy, beta radiations such as those from H-3, C-14, or Tc-99.	A thorough evaluation of this technology is needed for differentiating Tc-99 from other radionuclides in mixed-surface contaminations. Pairs of detectors, one with a beta absorber on its surface, will be needed to discriminate weak beta from more penetrating radiations.	A commercial TSEE reader is available at ORNL. Different types of ceramic exoelectron materials should be tested to select the most suitable type for H-3, Tc-99, and other applications. Approximately \$100K will be needed for development.
M	Thermoluminescence Dosimeter Array for Spatial Characterization of Alpha Contamination CHAR-103-OL <i>Ranking:*</i> M-4-3 (\$.6M;\$20/sample)	Demonstration A flexible sheet containing a fine grid of miniature thermoluminescence dosimeter elements that have a preferential sensitivity to alpha rays. Exposed sheets are scanned with a laser beam to heat the individual chips and produce a readable thermoluminescence that is converted into a two-dimensional map.	Technique is well-established but investigation of potentially confounding factors is needed. Such factors include moisture, oil, and radon.	It will need to be adapted to specific D&D needs. Size and shape of detector sheets need tailoring to specific geometries. Discriminating ability in mixed radiation fields needs further definition. Development Cost: ~\$200K.
M	Long-range Alpha Detector (LRAD) CHAR-65-OL <i>Ranking:*</i> M-4-1 (\$.4M;\$100/sample)	Demonstration It is a screening device for detecting alpha radioactivity on surfaces or personnel and in soil or waste. It measures ionized air drawn from a container holding a contaminated object, irrespective of shape. TTP Match	Adaptation for site-specific applications.	Overall Cost: \$10K/device; after commercialization price should decrease. Field testing is needed (~\$300K).
M	Bubble Dosimeters for Neutron Flux CHAR-216-OL <i>Ranking:*</i> M-4-1 (\$.2M;\$15/sample)	Accepted. These dosimeters are an integral part of a field neutron dosimetry system for use where neutron sources and shielding are not well known. They are capable of measuring neutron dose equivalent in low level fields and of providing simple spectral information.	The technique is will established for measuring neutron flux around personnel. It must be evaluated for potential confounding effects in less benign environments.	Development Cost: ~\$200K is needed to develop acoustic coupler for applications requiring real-time measurement of neutron dose rate and for development of a less expensive, automated bubble counter for reliable processing of passive detector results.
M	Advanced Radiation Monitors CHAR-269-OL <i>Ranking:*</i> M-4-2 (\$.4M;\$50/sample)	Predemonstration. TTP Match	Development of additional probes is needed. Available at X-10.	Development Cost: \$400K over 2 years.

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Remedial Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Methods	H Electret Passive Surface Alpha Monitor CHAR-95-OL <i>Ranking:*</i> H-4-1 (\$3M;\$15/sample)	Demonstration. It is a device that performs as a passive ion chamber when placed on a contaminated surface; positive ions produced by alpha particles are drawn to a negatively charged Teflon electret screwed into the roof of the chamber.	Sensitivity is sufficient to quantify alpha contamination after a few hours of exposure even at the most stringent DOE release limit of 100 dmp/100cm2. Demonstration	The limits of alpha monitoring in mixed radiation fields needs to be defined. Algorithms for multidevice deployment should be developed and tested to give a high confidence level of not missing contamination on large area surfaces. Development of needed protocols will require 1-2 years of effort.
	H Alpha Track Etch Detectors for Surface Alpha Contamination CHAR-96-OL <i>Ranking:*</i> H-4-1 (\$4M;\$10/sample)	Accepted. These are Alpha-sensitive plastics that can be cut to a size appropriate for specific applications, e.g., to fit inside pipes or in narrow crevices. After exposure, the plastic is developed chemically to visualize damage tracks produced by alpha-emitting contamination.	Technique is well-established (i.e., commercially available) for measuring alpha activity in indoor air. Potentially confounding factors in surface or soil applications include: inhomogeneously sized particles, moisture, oils, and radon in soil.	Plastic monitors of differing sizes and flexibilities need to be tailored and fabricated for specific tasks to be identified in pilot testing on-site. Deployment of detectors in large numbers will require establishment of on-site chemical etching and track reading capabilities.
	Portable Gamma-ray Scintillometers CHAR-263-OL <i>Ranking:*</i> No Ranking.	Accepted. In either single-channel or multichannel format, they are available commercially. The instrument consists of a NaI crystal, photomultiplier tube, portable battery-operated power supply, pulse height analyzer, and readout. TTP Match	Robotic technology needed for remote control applications.	The technology is commercially available. Specialized detector holders may need to be developed for particular applications.
Laboratory Methods	H Neutron Activation CHAR-107-OL <i>Ranking:*</i> H-4-1 (\$2M;\$300/sample)	Demonstration TTP Match	Development is needed for containers that are larger than 55-gal drums. Separate calibration standards are needed for each matrix.	Normal
	H Sodium Iodide-Germanium Gamma Spectroscopy CHAR-106-OL <i>Ranking:*</i> H-4-0 (\$0M;N)	Accepted TTP Match	Correction factor methodology needs to be published.	None
	H Radioanalytical Procedures CHAR-202-OL <i>Ranking:*</i> H-4-2 (\$1M;;N)	Development Upgrade of Radioanalytical Procedures, general upgrade and modernization of radiochemical separation technology. TTP Match	Considerable new technology is available but lacks sufficient validation to meet QA requirements. Other areas are at the basic development stage. Available at X-10.	Some instrumentation/personnel currently exist at ORNL to develop new procedures but needs to be expanded to meet the increased work load. Estimated cost \$600K/year for 5 years.
	H Proportional Counter for Alpha and Beta Activity CHAR-108-OL <i>Ranking:*</i> H-5-0 (\$1M;\$100/sample)	Accepted	This is a well-established technology. Some minor development may be needed to distinguish Technetium activity from uranium. Probes for measuring vertical or overhead items are needed.	Normal

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Characterization f

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Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Laboratory Methods	H Photon Electron Rejecting Alpha Liquid Scintillation CHAR-97-OL <i>Ranking:*</i> <i>No Ranking.</i>	A very sensitive (pCi/g) technique for measuring alpha-emitting isotopes in soil, water, and airborne dust. TTP Match	Cost effective, timely analysis of select alpha emitting radionuclides in large numbers of samples is needed to verify nonviolation of cleanup standards. Available at X-10, Y-12.	A PERALS laboratory is already set up at the ORNL DOR/SAR facility. It can be adapted for rapid "on-line" monitoring of both airborne and loose contamination.
	H Neutron Activation Analysis CHAR-266-OL <i>Ranking:*</i> <i>H-4-1 (\$1.2M;\$300/sample)</i>	Accepted, mature technology TTP Match	Mature technology, startup studies to be done to evaluate possible interferences. Available at X-10.	Instrumentation and personnel currently exist at ORNL but needs to be expanded to meet the expected work load. Estimated cost of upgrade and expansion \$250K.
	H Gamma-ray Spectrometry CHAR-268-OL <i>Ranking:*</i> <i>H-5-0 (\$1M;\$100/sample)</i>	Accepted, mature technology.	Commercially available and mature. Available at X-10.	Some equipment/personnel currently available at ORNL but needs to be expanded to meet the expected increase in work load. Detector costs range from \$10K to \$50K.
	H Liquid Scintillation Counting CHAR-267-OL <i>Ranking:*</i> <i>H-5-0 (\$1M;\$100/sample)</i>	Accepted, mature technology. TTP Match	Commercially available and mature. Available at X-10.	Some equipment/personnel currently available at ORNL but needs to be expanded to meet the expected increase in work load. Instrumentation costs range from \$30K - \$40K.
Field Methods	M Atomic Emission Spectroscopy CHAR-76-OL <i>Ranking:*</i> <i>M-5-1 (\$1.2M;\$N)</i>	Accepted TTP Match	The technology is well-developed and applicable as is.	Technology is available at the K-25 Site.
	H Portable X-Ray Fluorescence CHAR-219-OL and CHAR-6-OL <i>Ranking:*</i> <i>H-5-1 (\$1.2M;\$N)</i>	Accepted Can be use for in situ monitoring of toxic heavy metals in paints, on surfaces, and in soils. Portable XRF units are commercially available and have been widely used for screening painted surfaces for lead contamination. TTP Match	This is a mature technology.	Substrate effects need to be studied. The lower limit of detection for some metals on surfaces needs to be measured (~\$200K).
Laboratory Methods	H Inductively Coupled Plasma—Mass Spectroscopy (ICP-MS) CHAR-78-OL <i>Ranking:*</i> <i>H-4-2 (\$1M;\$200/sample)</i>	Demonstration - available, but not fully developed. TTP Match	It is applicable as is for multi-element analysis of aqueous solutions. Development is progress to use the technology for surface analysis using laser ablation techniques, and for low specific activity, long-lived radionuclides.	It is now available at the X-10 Site. \$400K development costs to extend to long-lived, low specific activity radionuclides.
	H Inductively Coupled Plasma Spectroscopy (ICP) CHAR-77-OL <i>Ranking:*</i> <i>H-4-0 (\$1M;\$200/sample)</i>	Accepted TTP Match	It is applicable as is. This is a well-developed technology.	It is available at ORNL.

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Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Laboratory Methods	Atomic Emission Spectroscopy (AE) CHAR-76-OL <i>Ranking:*</i> <i>No Ranking.</i>	TTP Match		
	H Ion Chromatography (IC) CHAR-50-OL <i>Ranking:*</i> <i>H-4-0 (\$1M;\$100/sample)</i>	Accepted TTP Match	A detector system that is optimized for the expected waste streams that will be generated needs to be determined. Available at all sites.	We have systems available for process control of D&D efforts.
	M Electron Diffraction (ED, SAED, LEED) CHAR-37-OL <i>Ranking:*</i> <i>M-4-0 (\$0M;\$100/sample)</i>	Accepted TTP Match	None Available at all sites.	None
	Wavelength Dispersive X-ray Spectroscopy (WDS, WDX) CHAR-36-OL <i>Ranking:*</i> <i>No Ranking.</i>	Accepted	None Available at all sites.	None
	M Energy Dispersive X-ray Spectroscopy (EDS, EDX, EDAX) CHAR-35-OL <i>Ranking:*</i> <i>M-4-0 (\$0M;\$100/sample)</i>	Accepted TTP Match	None Available at all sites.	None
	M Transmission Electron Microscopy (TEM) CHAR-34-OL <i>Ranking:*</i> <i>M-4-0 (\$0M;\$100/sample)</i>	Accepted TTP Match	This is a mature technology. Available at all sites.	This is a mature technology.
	M Scanning Electron Microscopy (SEM) CHAR-33-OL <i>Ranking:*</i> <i>M-4-0 (\$0M;\$100/sample)</i>	Accepted TTP Match	This is a mature technology. Available at all sites.	This is a mature technology.
	M Particle-induced X-ray Emission (PIXIE) CHAR-17-OL <i>Ranking:*</i> <i>M-4-0 (\$0M;\$100/sample)</i>	Accepted	This is not a mature technology; photon source is under development. Available at K-25.	The instrumentation is available on-site. Analysis is available at outside laboratories. Sampling scenarios could be designed to identify and use the strengths of the technique.
	H Cold Vapor (Mercury) Analysis CHAR-24-OL <i>Ranking:*</i> <i>H-4-0 (\$0M;\$100/sample)</i>	Accepted This technique is based on the atomic absorption spectroscopy of mercury and very sensitive and highly selective.	This is a mature technology.	This is a mature technology which needs to be part of a mobile laboratory.
	H Neutron Activation Analysis CHAR-266-OL <i>Ranking:*</i> <i>H-4-1 (\$2M;\$200/sample)</i>	Accepted, mature technology TTP Match	Mature technology, startup studies to be done to evaluate possible interferences. Available at X-10.	Instrumentation and personnel currently exist at ORNL but needs to be expanded to meet the expected work load. Estimated cost of upgrade and expansion \$250K.

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EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements
<ul style="list-style-type: none"> Clean Up Legacy Waste Prevent Future Insult Develop Environmental Stewardship 	All Problems Buried Waste WAG 1, WAG 3, WAG 4, WAG 5, WAG 6, WAG 7 Ground Water/Surface Water WAG 2, WAG 3, WAG 4, WAG 5, WAG 6, WAG 8, WAG 9, WAG 10, WAG 11 Hydrofracture WAG 10 Impoundments WAG 1, WAG 5, WAG 8, WAG 9 Pipelines WAG 1, WAG 4, WAG 5, WAG 7, WAG 8 Pits and Trenches WAG 7 Soils/Sediments WAG 1, WAG 2, WAG 3, WAG 4, WAG 5, WAG 6, WAG 7, WAG 11, WAG 13 Tanks WAG 1, WAG 5, WAG 8, WAG 9	Inorganics	Refer to the Vol. 1, Pt. C, Chap. 6, for potentially applicable, proposed, and promulgated environmental laws, signed and pending agreements for the Oak Ridge Reservation (ORR), radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization
EM Problems <ul style="list-style-type: none"> Facility Decontamination and Decommissioning (D&D) 		Organics	Refer to Vol. 1, Pt. C, Chap. 6, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Characterization
<ul style="list-style-type: none"> Remedial Action (RA)—Soils, Groundwater and Surface Water 				
<ul style="list-style-type: none"> Waste Management (WM) 				

or Remedial Action

Alternatives		Technologies	Status	Science/Technology Needs	Implementation Needs
Laboratory Methods	M	Powder X-ray Diffraction CHAR-31-OL <i>Ranking:*</i> <i>M-4-0 (\$0M;>\$100/sample)</i>	Accepted	This is a mature technology. Available at all sites.	None
	M	Electron Spectroscopy for Chemical Analysis (ESCA) CHAR-1-OL <i>Ranking:*</i> <i>M-4-0</i> <i>(\$0M;\$200-600/sample)</i>	Accepted	Model studies are needed to identify binding energies for standard compounds of Tc and U for suspected matrices. Available at all sites.	Instrumentation and personnel currently exist at K-25.
	M	Auger Electron Spectroscopy (AES) CHAR-2-OL <i>Ranking:*</i> <i>M-4-0</i> <i>(\$0M;\$300-800/sample)</i>	Accepted	Mature, model studies are needed to probe the host/contaminant effects for accurate depth profiling. Available at X-10, Y-12, K-25.	Instrumentation and personnel exist within the three plants.
	H	Glow Discharge Ionization Mass Spectroscopy CHAR-56-OL <i>Ranking:*</i> <i>H-4-1 (\$.5M;N)</i>	Accepted (laboratory) Predemonstration (field) TTP Match	Need to determine relative sensitivity factors, and use of DC and rf glow discharges. Available at X-10.	Hardware Cost: \$200K Development Cost: \$500K
Field Methods	H	Portable Gas Chromatograph/Electron Capture Detector for Analyzing PCBs in Soil/Dust CHAR-100-OL <i>Ranking:*</i> <i>H-4-0 (\$.25M;\$50/sample)</i>	Accepted TTP Match	Available at Y-12.	We need to order GC/ECD devices (~\$15K each).
	H	PCB Immunoassay Kit CHAR-99-OL <i>Ranking:*</i> <i>H-4-0 (\$.25M;\$80/sample)</i>	Accepted Has been demonstrated thoroughly at ORNL	Available at X-10, K-25.	The technology is ready to apply and should be used for routine analyses.
	H	Portable Volatile Organic Compounds (VOCs) Detectors CHAR-5-OL <i>Ranking:*</i> <i>H-5-0 (\$.25M;\$10/sample)</i>	Accepted TTP Match	This is a mature technology. Available at X-10, Y-12.	For quick screening and surveying, instruments are available commercially. Interfacing the instruments with an ion mobility mass spectrometer would allow detection of individual compounds (~\$30K).
	H	Direct Sampling Ion Trap Mass Spectrometry (DSITMS) CHAR-90-OL <i>Ranking:*</i> <i>H-5-2 (\$.2M;\$50/sample)</i>	Predemonstration, method development needed. TTP Match	Methods need to be developed for specific applications. Available at X-10.	Hardware Cost: \$100K; Implementation Cost: \$200K. Personnel are needed for development, training

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Key in the front of this document for a
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Remedial Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Methods				
M	Synchronous Fluorescence Screening for Polycyclic Aromatic Hydrocarbons CHAR-101-OL Ranking:* M-4-1 (\$2M;<\$50/sample)	Demonstration When light of a specific wavelength is directed onto a sample, certain organic compounds (such as PAHs) absorb and re-emit that light (fluoresce) at a higher wavelength. In this technique, exciting and fluorescing wavelengths are scanned synchronously. Analytes can be differentiated because they absorb and fluoresce at different wavelengths. Demonstration, technology available. TTP Match	Technology needs to be validated in the EPA program. Numerous situations at X-10 have involved used oils and lubricants which contain PAHs. Available at X-10.	Hardware Cost: \$25K; Development Cost: \$200K.
H	Gas Chromatography in the Field CHAR-262-OL Ranking:* H-5-0 (\$.25M;\$50/sample)	Accepted Using flame ionization, electron capture, thermal conductivity, photoionization, flame photometric, or thermionic detectors with gas chromatography can determine a variety of environmentally important analytes. TTP Match	Technology needs are minimal. While improvements can be made, in general, the technology is ready to use. Available at all sites.	A variety of gas chromatography equipment exists already at ORNL and may be useful for many needs. Various groups at ORNL have large sample handling capabilities.
Laboratory Methods				
H	Analytical Methods for Chelators and Decontamination Agents CHAR-206-OL Ranking:* H-5-1 (\$.25M;\$500-1000/sample)	Demonstration , an existing method shows the technology is promising, but further development is needed. TTP Match	Adapt current methods to the specific constituents and sample matrices at ORNL, conduct method performance validation, and prepare an analytical protocol.	Development Cost: \$250K.
M	Capillary Zone Electrophoresis CHAR-207-OL Ranking:* M-5-1 (\$.25M;\$300/sample)	Demonstration , the technology is gaining widespread acceptance in biomedical applications, and appears useful for RA/WM applications. TTP Match	Adaptation and validation for the specific target compounds and sample matrices at ORNL. Available at X-10.	Hardware Cost: \$30K-\$60K; Development Cost: \$250K.
H	On-line Supercritical Fluid Extraction—Multidetector Gas Chromatography (SPE-GC) CHAR-115-OL Ranking:* H-5-1 (\$.25M;\$300/sample)	Predemonstration ; technology requires final development and demonstration. TTP Match	The technology requires optimization for the most efficient extraction and chromatography of both total petroleum hydrocarbons and PCBs in a single operation.	Capital Cost: \$60K; Development Cost: \$250K.
H	Gas Chromatography-Fourier Transform Infrared Spectroscopy (GC-FT-IR) CHAR-66-OL Ranking:* H-5-2 (\$.5M;\$400/sample)	Demonstration , technology is available	Specific methods for targeted analytes and general methods for unknown identification need to be developed. Available at X-10.	Hardware Cost: \$200K; Development Cost: \$400K. One instrument is available at ORNL.
H	Liquid Chromatography—Mass Spectroscopy (LC-MS) CHAR-89-OL Ranking:* H-5-1 (\$.34M;\$500/sample)	Demonstration , not yet available on-site for service work. TTP Match	Case-by-case development and demonstration for specific applications is needed. Available at X-10, Y-12.	Hardware Cost: \$200K; Development Cost: \$300K.

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Characterization f

r Remedial Action

Alternatives		Technologies	Status	Science/Technology Needs	Implementation Needs
Laboratory Methods					
	E	Gas Chromatography—Mass Spectroscopy (GC-MS) CHAR-88-OL <i>Ranking:*</i> E-5-0 (\$0M;\$200–800/sample)	Accepted, available on-site TTP Match	Technology is applicable as is. Benefit would be derived from faster chromatography to shorten analysis time. Available at all sites.	Technology is available at ORNL
	M	Synchronous Fluorescence Screening for Polycyclic Aromatic Hydrocarbons (PAHs) CHAR-101-OL <i>Ranking:*</i> M-5-1 (\$.2M;\$10/sample)	Demonstration, technology available. TTP Match	Technology needs to be validated in the EPA program. Numerous situations at X-10 have involved used oils and lubricants. Available at X-10.	Hardware Cost: \$25K; Development Cost: \$200K.
	E	Gas Chromatography CHAR-94-OL <i>Ranking:*</i> E-5-0 M;\$0M;\$300/sample)	Accepted, technology available on-site. TTP Match	Technology needs are minimal. While improvements can be made, in general, the technology is ready to use.	A variety of gas chromatography equipment exists already at ORNL and may be useful for many needs.
	H	Solid Phase Microextraction Analytical Method CHAR-211-OL <i>Ranking:*</i> H-5-1 (\$.3M;\$500/sample)	Predemonstration, technology demonstrated but requires refinement for quantitative analysis.	Adapt a conventional automated sample injector and develop quantitative method. Influence of waste sample characteristics on partition coefficient and sampling efficiency must be determined.	Hardware Cost: \$20K; Development Cost: \$300K.
Field Methods					
	H	In Situ Ground Water Flow Meter CHAR-258-OL <i>Ranking:*</i> H-5-0 (\$.4M;\$1–3K/well)	Conceptual, permanent probe has been demonstrated at Sandia National Laboratory. TTP Match	Conceptual, permanent probe has been demonstrated at Sandia National Laboratory. Construct probe and demonstrate in laboratory and field. Available at X-10.	Development Cost: ~\$400K.
	E	Ground Water Discharge Location CHAR-259-OL <i>Ranking:*</i> E-5-0.5 (\$0;\$50K/survey)	Accepted, used at ORNL. TTP Match	Design of sampling and analyses required on this site. Available at X-10.	Setup Cost: ~\$50K.
Laboratory Methods					
	M	Particle Size Analysis CHAR-26-OL <i>Ranking:*</i> M-5-0 (\$0M;\$1000/sample)	Accepted	None, this is a mature technology. Available at all sites.	In situ devices need to be implemented to allow more aggressive IH-HP protection of personnel and to ensure the control (spread) of radioactive contamination.
	H	Optical Microscopy CHAR-32-OL <i>Ranking:*</i> H-5-0 (\$0M;\$100–800/sample)	Accepted	A particle atlas of site-specific materials is needed to allow rapid identification. Available at all sites.	A centralized image collection system is needed to establish a site-specific database.

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Characterization for

Remedial Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
atory Methods	<div><div>E</div><div>Pathogen Surveillance CHAR-215-OL</div><div>Ranking: * E-5-1 (\$.25M; \$50-250/sample)</div></div>	Accepted (pathogenic bacteriology) and demonstrated (pathogenic virology).	The pathogenicity of newly discovered bacteria associated with free-living amoeba needs delineation since such amoebae are ubiquitous and can harbor and amplify known pathogens. There is a need to develop pathogenic virology capabilities. We need equipment necessary for speciation by DNA fingerprinting and phospholipid fatty acid analysis which can further aid in identification of isolates not readily speciated by conventional methodology. Available at all sites.	Hardware Cost: \$80K-\$90K; Development Cost: \$250K.
ile Collection and Field ods	<div><div>H</div><div>SEAMIST Inverted Membrane CHAR-273-OL</div><div>Ranking: * H-5-1 (\$1.6M; \$15K/survey)</div></div>	Demonstration - successfully used at Lawrence Livermore for characterization of a tritium site, and at the Savannah River Integrated Demonstration Project. TTP Match	Cold test facility of buried waste in a trench.	Ca. \$600K for 6 months cold test demonstration.
Methods	<div><div>M</div><div>Electromagnetic Offset Log Survey CHAR-272-OL</div><div>Ranking: * M-5-1 (\$.25M; \$50K/survey)</div></div> <div><div>H</div><div>Fiber-optic Chemical Sensors CHAR-25-OL</div><div>Ranking: * H-5-1 (\$1M; \$3.3M/survey)</div></div> <div><div>H</div><div>Hydrofracture Ground Water Monitoring CHAR-274-OL</div><div>Ranking: * H-1-2 (\$.5M; \$3.3M/survey)</div></div>	Demonstration TTP Match Accepted; demonstration Remote detection using a variety of spectral methods, including optical absorption, Raman scattering, and luminescence spectroscopy. The fiber optic is used to deliver or return light to or from the sample. This technology allows remote sensing in hazardous environments. TTP Match Accepted - in-site logging tools have been in use by industry and multipoint Westbay samplers are in use at ORNL and Y-12, and are accepted by regulators. TTP Match	Laboratory measurements of various compounds to determine the resistivity versus chemical type and concentration. A combination of waveguides and spectroscopic techniques are needed that have been matched not only for each other but also for specific monitoring scenarios. Due to the high radiation levels inside the boreholes, improvements in the detection and sensitivity of the in-situ measurements instruments may be necessary. Also, the instrumentation must be resistant to the highly saline conditions of the wellbore fluids and groundwater.	Ca. \$200K to test on an established site. Waveguides are needed that can withstand the harsh chemical environment that may be present in some of the sampling locations. \$500K for development of corrosion resistant casing, probes, and cables; \$1.75M to install in-site groundwater monitoring equipment in 25 deep wells; \$200K per year monitoring costs using downhole samplers; \$1.25M for installation of probes for downhole monitoring of gamma activity, temperature, conductivity, and pressure; additional manpower costs of ca. \$150K per year.

* See the Explanation and Understanding Key in the front of this document for a description of the ranking code/scheme.

Remedi

The remedial action section is grouped according to areas: buried waste, tanks, pits and trenches, soils, hydrofracture, and ground water and surface water. treatment technologies are identified for each problem.

Action

to source and media into the following ORNL problem
d sediments, buried pipelines, impoundments,
containment, in situ treatment, retrieval, and ex situ
n area as appropriate.

Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Structural stabilization	H Dynamic Compaction (Compaction of Soil to increase structure strength.) REMA-1-OL <i>Ranking:*</i> H-5-1 (\$0.5M;\$1.50/ft2)	Demonstration Efficacy: This technology was successfully demonstrated on a 58-acre LLW site at Savannah River. Sixteen feet of miscellaneous LLW was compacted to six feet in thickness with minimal exposure to personnel. This resulted in a five-fold increase in waste stability.	Test results on WAG 6 at ORNL were inconclusive because of limitations on crane lift capacity and lift height. Tests with appropriate equipment are needed to verify the effectiveness of this process at ORNL.	Demonstration of the effectiveness of DC of soils at the ORNL site are needed. It is estimated that the cost to compact twenty WAG 6 trenches would be \$0.5 million. Capital Costs: low Operating Costs: ~\$1.50/ft2
	M Structural caps (Providing structural support to support caps over subsiding trenches.) REMA-96-OL <i>Ranking:*</i> M-5-1 (\$.5M;\$1M/acre)	Demonstrated Efficacy: This technology is a commercially available technology. This technology is the same as that used for road and bridge construction.	Technology Improvement: There is a need to develop coating materials for the support members to ensure a long life.	Need to demonstrate that support members will provide the required support for the required time periods. Development Costs: low Capital Costs: low Operating Costs: low
	L Thermal set Resin Impregnation (Fills the voids in buried wastes with a thermal-set resin.) REMA-97-OL <i>Ranking:*</i> L-5-10 (>\$1M;<\$50/ton)	Conceptual Efficacy: This technology has been accepted for encapsulation of some wastes, such as ion exchange resins (See REMA-113-OL), but has not been demonstrated for this use.	Technology Improvement: Steam heating or other methods for heating the soil and waste materials needs to be demonstrated.	Much effort will be needed to integrate and develop techniques for application of this technology. Development Costs: high (~\$20 million) Capital Costs: medium Operating Costs: low
	M Surcharge (Use of a mandrel to install disposable geotext.1c drains to increase the rate of drainage.) REMA-82-OL <i>Ranking:*</i> M-5-1 (\$0.25M;\$25/yd3)	Demonstrated Surcharge with geotextile drains have been used extensively to increase the strength and decrease the compressibility of soils. Efficacy: This technology may be useful for inundated wastes. Waste: This technology could result in some volume reduction of the waste.	Technology Improvement: The technology is widely used, and off-the-shelf equipment is available. Science development: Need to develop two different installation techniques to prevent contamination of the mandrill.	Need to demonstrate this technology on an inundated waste area. Costs to demonstrate the technology on 41 inundated trenches at WAG 6 would be \$0.4M. Capital Costs: medium Operating Costs: field demonstration and monitoring ~\$25/yd3
	H Horizontal Mixed in-Place (Use of directional drilling and jet cutting to mix wastes in place.) REMA-81-OL <i>Ranking:*</i> H-5-4 (\$1.5M;\$275/yd3)	Predemonstration Directional drilling and jet cutting are well-established techniques, but delivery and mixing of grout to the waste form have not been demonstrated. Efficiency: The usefulness of this technology must be demonstrated. Waste: This technology generates a moderate amount (40-60% of the injected grout volume) of waste.	Technology Improvement: Need to show that grouts can be mixed effectively with the waste. Science development: Need to develop grouts that will stabilize the waste and pass the leach test.	Need to develop a way to control cuttings ejected during directional drilling to minimize worker exposure. Development costs: \$1.5M Capital costs: medium Operating Costs: ~\$275/yd3
	M In situ Solidification (Use of additives to increase structural strength of soils.) REMA-05-OL <i>Ranking:*</i> M-5-3 (\$0.5M;\$150/yd)	Demonstration Efficacy: This technology was demonstrated as part of the SITE program at a General Electric site to immobilize PCB's up to 18 feet deep. Tests currently being conducted at DOE Portsmouth Gaseous Diffusion Plant. TTP Match	Technology Improvement: There is a need to develop techniques for depths greater than 35 feet.	Need to evaluate data from Portsmouth Gaseous Diffusion Plant before determining needs. Development costs: \$0.5M Capital costs: medium Operating costs: ~\$150/yd3

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EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements
<ul style="list-style-type: none"> • Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship 	Buried Waste WAG 1, WAG 3, WAG 4, WAG 5, WAG 6, WAG 7	Low Level Waste (LLW), metals, organics, mixed	Refer to Vol. 1, Pt. B, Chap. 6, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste- specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Containment/isolation
EM Problems <ul style="list-style-type: none"> • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM) 		Radionuclides, metals, organics	Refer to Vol. 1, Pt. B, Chap. 6.	Containment/isolation
		Low Level Waste (LLW), metals, organics, mixed	Refer to Vol. 1, Pt. B, Chap. 6.	Containment/isolation

Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Capping	H Intruder Barriers (Provides sufficient depth or cover over the waste to assure protection of an intruder.) REMA-94-OL <i>Ranking:*</i> H-5-1 ($\leq \$5M$; $< \$50/\text{ton}$)	Demonstrated Efficacy: This technology is in common use, and the NRC has regulations that specify conditions for its usage.	Technology Improvement: Need to continue to develop new materials to provide better caps and containment of buried wastes. The potential for subsidence and gas production needs to be assessed at each waste site.	Need to demonstrate effective use of cap materials as they are identified. Development costs: low Capital costs: low Operating costs: low
	H Capping (Use of barriers to limit direct and hydrologic contact.) REMA-46-OL <i>Ranking:*</i> H-5-1 ($\leq \$5M$; $\$0.5M$ - $\$7M/\text{acre}$)	Accepted Efficacy: However the issues of potential subsidence and long-term maintenance push the limits of the typical application of a cap. TTP Match	Science Needs: Long-term performance testing is needed. Available at Y-12, Portsmouth.	Exact determination of area of contamination, dewatering of impoundments. Development costs: low Capital costs: $\$0.5$ - $7M/\text{acre}$ Operating costs: low
Barriers	M Slurry Walls (Narrow vertical walls that are backfilled with slurry to direct ground water flow.) REMA-40-OL <i>Ranking:*</i> M-5-1 ($\leq 1M$; $\$15$ - $\$20/\text{ft}^2$)	Accepted Efficacy: Technology is commercially available and has been used at Portsmouth. However, the lack of a confining layer at ORNL makes typical application unacceptable. Waste: This technology would help to limit the amount of material to be treated, but the containment walls may have to be treated as waste. TTP Match	Science Needs: Development needed so slurry walls could be used in fractured system. Available at Portsmouth.	To apply, would need subsurface characterization. There are significant construction and monitoring requirements. Development costs: medium Capital costs: low Operating costs: low
	M Sheet Pile Walls (Interlocked sheets of steel installed in the ground to divert ground water flow.) REMA-41-OL <i>Ranking:*</i> M-5-2 ($\leq 1M$; $\$30$ - $\$40/\text{ft}^2$)	Accepted Efficacy: Commercially available for depths from 30 to 40 ft. Waste: This technology would help to limit the amount of material to be treated, but the containment walls may have to be treated as waste. TTP Match	Science Needs: Material compatibility testing. Available at all sites.	Sheet piling will leak. Another barrier or monitoring to evaluate the effects of leaking may be needed. Characterization of soil and subsurface needed. Development costs: medium Capital costs: low Operating costs: low
	M Grout Curtains (Narrow vertical walls installed in the ground to direct laterally flowing ground water.) REMA-42-OL <i>Ranking:*</i> M-5-1 ($\leq 1M$; $\$30$ - $\$40/\text{ft}^2$)	Accepted Efficacy: Commercially available to from 30 to 40 ft. Without a confining layer (not present at ORNL), this application will not be very effective. Waste: This technology would help to limit the amount of material to be treated, but the containment walls may have to be treated as waste.	Science Needs: Characterization of soil conditions and geology. May need studies to improve effectiveness without a confining layer.	Significant monitoring requirements to assess effectiveness. Needs to be demonstrated at ORNL. Development costs: medium Capital costs: low Operating costs: low
	H Slurry Wall with High-Density Polyethylene Insert (Installation of a HPDE interlocked screen within a slurry wall.) REMA-83-OL <i>Ranking:*</i> H-5-1 ($\$2M$ - $\$3M$; $\sim \$40/\text{ft}^2$)	Demonstration Technology has been used on a few test projects in Europe but none in the United States. Efficacy: Technology can be used to prevent migration of contaminants. Waste: This technology would help to limit the amount of material to be treated, but the containment walls may have to be treated as waste.	Technology Improvement: Needs demonstration project to document operational characteristics and monitor performance.	Need to evaluate the effectiveness of different materials for use as barrier walls using piezometers inside and outside the wall. Development Costs: $\$2$ - $\$3$ million for evaluation over 1 year Capital Costs: $\$30$ to $\$40$ per ft^2 of cut off wall Operating Costs: low
Walls				

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Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
alls	<div>M</div> <div>Hydromill (Provides continuous excavation of soil/rock while simultaneously creating a slurry trench panel.) REMA-84-OL Ranking: * M-5-3 (≤1M; \$30-40/ft2)</div>	<div>Demonstration</div> <div>Used mainly in Europe for slurry wall excavation. It is capable of continuous excavation of soil and soft rock at rates up to 200 ft2 per hour and rates up to 10 ft2 per hour in hard rock. Efficacy: This technology can be used to limit migration of the contaminant. Waste: No increase or decrease in waste volume associated with this technology.</div>	<div>Technology Improvement:</div> <div>Need to examine operational procedures and health physics issues related to equipment maintenance.</div>	<div>Develop health physics control procedures for maintenance.</div> <div>Development Costs: low</div> <div>Capital Costs: medium</div> <div>Operating Costs: \$30-40/ft2</div>
alls/barriers	<div>L</div> <div>Cryogenic Barriers (Uses a frozen layer of native geologic materials to contain wastes.) REMA-58-OL Ranking: * L-5-3 (≤1M; ~\$100/ft2)</div>	<div>Predemonstration</div> <div>Efficacy: Has been accepted for geotechnical applications at construction sites to stabilize soil and control ground water flow. Waste: Avoids generation of waste during construction. TTP Match</div>	<div>Science Needs:</div> <div>An evaluation of site conditions and cost comparison is needed to evaluate the use of this technology.</div>	<div>Equipment and power to freeze the soil is needed. Site specific characterization is needed.</div> <div>Development costs: medium</div> <div>Capital costs: medium</div> <div>Operating costs: ~\$100/ft2</div>
	<div>E</div> <div>Soil Saw (Creates a vertical barrier wall by moving casing with an array of jet cutting nozzles back and forth like a saw to cut the soil and inject grout material.) REMA-88-OL Ranking: * L-5-2 (\$0.8M; \$70-80/ft2)</div>	<div>Predemonstration</div> <div>NUS has been awarded a contract to demonstrate this technology at SRL. Efficacy: Technology does not appear to be applicable to large areas or areas where stones or other obstructions would be encountered. Waste: Estimated volume of spoil 40-100% of injected grout.</div>	<div>Technology Improvement:</div> <div>Need to minimize the volume of spoil generated.</div>	<div>Current demonstration needs to be completed.</div> <div>Development costs: \$0.8M</div> <div>Capital costs: medium</div> <div>Operating costs: \$70-80/ft2</div>
ains	<div>H</div> <div>French Drains REMA-43-OL Ranking: * H-5-1 (≤1; \$50-\$100/ft2)</div>	<div>Accepted</div> <div>Efficacy: Have been constructed and successfully operated at SWSA 6. Waste: No change in waste.</div>	<div>Science Needs:</div> <div>Geology and ground water flow conditions needed for design. Available at X-10, Y-12, Portsmouth.</div>	<div>Installation difficult in hard rock. May require blasting. Cost-effective use usually precludes installation in hard rock.</div> <div>Development costs: low</div> <div>Capital costs: low</div> <div>Operating costs: \$50-100/ft2</div>
	<div>H</div> <div>Biopolymer Drains (French drains installed using a biodegradable slurry.) REMA-44-OL Ranking: * H-5-1 (≤1M; \$15-\$20/ft2)</div>	<div>Accepted</div> <div>Efficacy: Have been installed at Portsmouth as part of site remediation. Waste: No change in waste volume.</div>	<div>Science Needs:</div> <div>Geology and ground water flow conditions needed for design. Available at Portsmouth.</div>	<div>Need to use a biodegradable slurry.</div> <div>Development costs: medium</div> <div>Capital costs: low</div> <div>Operating costs: \$15-20/ft2</div>
	<div>H</div> <div>Horizontal Wells (Cased well install horizontally.) REMA-45-OL Ranking: * H-5-1 (≤1M; \$150/ft)</div>	<div>Demonstration</div> <div>Efficacy: Have been used in highway construction and oil field exploration. Waste: No change in waste volume. TTP Match</div>	<div>Technology Needs:</div> <div>Need to test technical feasibility of drilling long distances in bedded shales, limestone, and interbedded shales. Also, need to determine the effective distance between wells.</div>	<div>Need a contractor experienced in directional drilling. Need disposal for potentially large amounts of cuttings.</div> <div>Development costs: low</div> <div>Capital costs: medium</div> <div>Operating costs: \$150/ft2</div>

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Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Bottom Seals (floor)	<p>L</p> <p>Vibrated Plastic Tube Bottom Seal (Installation of a bottom seal via a vibrating drive/grout injection pipe.) REMA-87-OL</p> <p><i>Ranking:*</i> L-5-4 (\$0.5M;\$200-\$300/ft²)</p>	<p>Demonstration Technology has been demonstrated in Germany, but the concept is limited to about 50-foot depths. Efficacy: The concept is useful where there are not many large objects that would deflect the pipe and cause untreated windows in the bottom seal. Waste: Limits the additional contamination of soils and water.</p>	<p>Technology Improvement: Improve capability to determine exact location of grout injection in order to ensure continuity of bottom seal.</p>	<p>Need demonstration at ORNL with cold trench about 10 feet wide x 50 feet long x 20 feet deep; then excavate and examine bottom seal for continuity. Development costs: \$500K Capital costs: medium Operating costs: \$200-300/ft²</p>
	<p>L</p> <p>Microtunneled High Density Polyethylene Liner (Provides tailored seal beneath waste to meet leach requirements of waste and surrounding soil.) REMA-86-OL</p> <p><i>Ranking:*</i> L-5-5 (\$3M;>\$500/ft²)</p>	<p>Demonstration HDPE installed via microtunnels is conceptual. The microtunnelling procedure is a well-established construction method in Europe and Asia that can be used for long lengths and depths to more than 100 feet. Efficacy: Provides a continuous bottom seal using plastic liner material designed to meet waste leach requirements. Waste: Limits the additional contamination of soils and water.</p>	<p>Technology Improvement: Need improved guidance system so that micro-tunnelling can be conducted from the surface or from more shallow shafts.</p>	<p>Need a cold-test facility and a shallow demonstration to evaluate operational problems and guidance systems. Development costs: \$2 to \$3 million over 2 years Capital costs: high Operating costs: >\$500/ft²</p>
	<p>L</p> <p>Jet Grouting (High pressure grout injection to fill cracks and form a bottom seal.) REMA-85-OL</p> <p><i>Ranking:*</i> L-5-1 (\$0.8M;\$150-\$300/ft²)</p>	<p>Demonstration Technology is well established in Europe for this application and was successfully used to form a bottom seal beneath waste at WOCE at ORNL. Efficacy: High-pressure (6000psi) pumps have been used successfully to drill vertically and to inject grouts beneath wastes to seal and prevent wastes from migrating to the water table. Waste: This technology limits the additional contamination of soils and water. TTP Match</p>	<p>Technology Improvement: Grout formulations need to be developed to allow larger percent mixing of injected grout with in situ material and minimize generation of additional wastes.</p>	<p>Need laboratory and field testing of candidate grout formulations to form soil-cement bottom seals. Development costs: \$800K Capital costs: medium Operating costs: \$150-300/ft²</p>
Destruction	<p>L</p> <p>In Situ Biodegradation (Use of microbes to biologically degrade wastes in situ) REMA-110-OL</p> <p><i>Ranking:*</i> L-5-5 (≤1M;<\$50/ton)</p>	<p>Predemonstration Efficacy: Some work has been done with low concentrations of organic contaminants in soils. TTP Match</p>	<p>Technology Improvement: Additional work is needed to determine maximum concentration of contamination that is feasible to treat by this process. Additional work is needed on delivery/injection systems.</p>	<p>Need to demonstrate the process on buried wastes with different concentrations of organic contaminants. Development costs: medium Capital costs: low Operating costs: low</p>
	<p>L</p> <p>In Situ Heating (Addition of heat to destroy hazardous organic constituents in situ.) REMA-99-OL</p> <p><i>Ranking:*</i> L-5-8 (>\$1M;<\$50/ton)</p>	<p>Conceptual Efficacy: Techniques for this process have been established for ex situ waste but have never been tried on buried waste.</p>	<p>Technology Improvement: Technology needs to be demonstrated on both laboratory-, pilot-, and field-scale applications on buried waste. In addition, the product quality of the waste after treatment needs to be established.</p>	<p>Safety, product quality, and field process operations all need to be established. Also, secondary waste streams need to be quantified. Development costs: high Capital costs: medium Operating costs: low</p>

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EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements
<ul style="list-style-type: none"> Clean Up Legacy Waste Prevent Future Insult Develop Environmental Stewardship 	Buried Waste WAG 1, WAG 3, WAG 4, WAG 5, WAG 6, WAG 7	Organics	Refer to Vol. 1, Pt. B, Chap. 6, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Treatment
EM Problems <ul style="list-style-type: none"> Facility Decontamination and Decommissioning (D&D) Remedial Action (RA)—Soils, Ground Water and Surface Water Waste Management (WM) 		Low Level Waste (LLW), metals, organics, mixed	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		Organics	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		Low Level Waste (LLW), metals, organics, mixed	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		Low Level Waste (LLW), metals, organics, mixed	Refer to Vol. 1B, Chapter 6	

Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
struction	<p>H</p> <p>Incineration (Thermal destruction of hazardous wastes in the presence of adequate oxygen for combustion.) REMA-95-OL</p> <p><i>Ranking:*</i> H-5-1 (<\$1M;>\$100/ton)</p>	<p>Demonstrated Efficacy: The technology has been accepted, and incinerators have been licensed and are in operation. Destruction of volatile organics have been measured with efficiencies up to 99.99999%. Destruction of semivolatile and nonvolatile organics have also been measured and typically exceed 99.99%. Waste: Amount of volume reduction achieved dependent on waste.</p>	<p>Technology Improvement: Waste characteristics at each of the sites are needed to determine the potential effectiveness of this technology.</p>	<p>Significant permitting and trial bum efforts are needed to - implement this technology. Development costs: medium Capital costs: high Operating costs: high</p>
struction	<p>L</p> <p>Calcining/Sintering This process heats the materials to high temperatures without fusing or melting, presumably to decrease the leachability of metals and drive off organics.) REMA-98-OL</p> <p><i>Ranking:*</i> L-5-10 (>\$1M;<\$50/ton)</p>	<p>Conceptual Efficacy: Techniques for this process have been established for ex situ waste but have never been tried on buried waste. TTP Match</p>	<p>Technology Improvement: Technology needs to be demonstrated on both laboratory-, pilot-, and field-scale applications on buried waste. In addition, the product quality of the waste after treatment needs to be established.</p>	<p>Safety, product quality, and field process operations all need to be established. Also, secondary waste streams need to be quantified. Development costs: high Capital costs: medium Operating costs: low</p>
struction	<p>H</p> <p>Low-Temperature Ashing (Heating, at 400-600 °C, of waste to destroy organics and to reduce waste volume.) REMA-7-OL</p> <p><i>Ranking:*</i> H-5-6 (>\$1M;<\$50/ton)</p>	<p>Predemonstration Efficacy: A predemonstration of this technology for the U.S. Air Force on plastic media blasting wastes proved the feasibility of this concept. This concept is not a final treatment, however, because the ash and off-gas must be treated. Waste: Greater than 90% volume reduction.</p>	<p>Science Needs: Need to demonstrate that this concept will work for other wastes such as paper, plastics, and other combustible materials; and need to develop methods for removing contaminants from the off-gas.</p>	<p>This concept has only been tested in the laboratory. The U.S. Air Force is proceeding with a pilot-scale demonstration. A final treatment of the bottom ash and the residue from off-gas cleaning must be developed. Development costs: high Capital costs: medium Operating costs: low</p>
struction	<p>M</p> <p>In Situ Particulate Grouting (Use of particulate grout to immobilize waste insitu.) REMA-3-OL</p> <p><i>Ranking:*</i> M-5-2 (>\$1M;\$40-60/yd3)</p>	<p>Demonstration Efficacy: Mixed results from limited testing at WAG 6. Penetration resistance increased but no change in hydraulic conductivity of waste. TTP Match</p>	<p>Technology Need: New chemicals and methods for delivering the grout so that it ruptures containers and effectively mixes with the waste need to be developed.</p>	<p>Needs further laboratory studies to examine grout/waste compatibility issues and develop a suitable grout delivery system. Cost for laboratory study is estimated to be \$0.1 million. Development costs: medium Capital costs: high Operating costs: \$40-60/yd3</p>

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Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Fixation				
M	<p>In Situ Chemical Grouting (Use of chemical grouts to immobilize wastes insitu.) REMA-2-OL</p> <p><i>Ranking:*</i> M-5-2 ($\leq$\$1M;\$60-\$100/yd3)</p>	<p>Demonstration Efficacy: Tests at WAG 6 with polyacrylamide were inconclusive. TTP Match</p>	<p>Technology Needs: New chemicals and methods of applying technology need to be further developed. Grout/waste compatibility studies should continue to develop grout formulations that will cure in an environment of widely varying waste chemistry. Also need to develop a robust grout delivery system.</p>	<p>Needs further laboratory studies to examine grout/waste compatibility issues and develop a good grout delivery system.</p> <p>Development costs: Cost for laboratory study is estimated to be \$0.1 million. Capital costs: medium Operation costs: \$60-100/yd³</p>
H	<p>Cementitious Solidification (Use of cementitious material to immobilize wastes.) REMA-9-OL</p> <p><i>Ranking:*</i> H-5-3 ($\leq$\$.5M;\$200-\$360/yd3)</p>	<p>In Use: Efficacy: Cementitious materials are the materials of choice because of their low processing costs, compatibility with many disposal scenarios, and ability to meet processing and performance requirements. Waste: Volume of waste increases by typically 30-60% TTP Match</p>	<p>Science Need: Better understanding of the immobilization mechanisms and the chemistry of the waste forms can lead to improved performance.</p>	<p>Formulations need to be developed and tested for the specific wastes intended for treatment. Development costs: low Capital costs: low Operating costs: \$200-360/yd³</p>
H	<p>Thermoplastic Encapsulation (Use of thermoplastics to encapsulate and immobilize wastes.) REMA-112-OL</p> <p><i>Ranking:*</i> H-5-3 ($\leq$.5M;\$25/ft3)</p>	<p>Accepted Efficacy: The waste must be dried and mixed with the molten thermoplastic so that volatiles may be driven off during the process. The waste is not chemically immobilized, but the thermoplastic is non-porous and less leachable. It is questionable whether physical encapsulation will pass the TCLP. TTP Match</p>	<p>Science Need: Passing the TCLP test and drying of the waste needs to be demonstrated. Resistance to biological degradation also needs to be demonstrated.</p>	<p>Laboratory development of the entire process followed by pilot-scale and final-site demonstration is needed. Development costs: medium Capital costs: medium Operating costs: ~\$25/ft³</p>
H	<p>Thermoset Encapsulation (Use of thermoset materials to encapsulate and immobilize wastes.) REMA-113-OL</p> <p><i>Ranking:*</i> H-5-3 ($\leq$\$1M;\$30/ft3)</p>	<p>Accepted (for ion exchange resins) Efficacy: This technology, which uses vinyl ester styrene (VES), is accepted for ion exchange resins; in the predemonstration stage for ashes and fine solids; and conceptual for liquid wastes. The process does not require dry wastes or elevated temperatures for encapsulation. TTP Match</p>	<p>Science Need: Need to demonstrate that it will pass the TCLP test and need to identify materials that will interfere with polymerization of VES.</p>	<p>Already demonstrated for ion exchange resins. Needs laboratory- and pilot-scale development and demonstration for ash and fine particles. Liquid waste will probably need evaporation of solids. Development costs: medium Capital costs: medium Operating costs: ~\$30/ft³</p>
H	<p>Sulfur Polymer Cement Encapsulation (Use of sulfur polymers to encapsulate and immobilize wastes.) REMA-114-OL</p> <p><i>Ranking:*</i> H-5-10 ($\leq$\$1M;\$25/yd3)</p>	<p>Predemonstration Efficacy: This technology requires dry solid wastes that are encapsulated in molten sulfur. It cannot be used in high-alkaline environments and it is questionable that it can pass the TCLP test. TTP Match</p>	<p>Science Need: Need to demonstrate that it will pass TCLP tests. Also need to develop technologies for drying the waste and demonstrate scale up of the technology.</p>	<p>Future laboratory- and pilot-scale development and a demonstration is needed. Development costs: high Capital costs: medium Operating costs: \$25/yd³</p>

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Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
ation	M Polymer-impregnated Concrete/Polymer-Modified Concrete (Use of polymers to achieve waterproofing and immobilization of wastes.) REMA-115-OL <i>Ranking:*</i> M-5-8 (>\$1M;<\$50/ton)	Evolving Efficacy: Although polymer-modified concretes are well established in the construction industry, application to waste forms is only conceptual and polymer impregnation is an evolving technology. The product has the advantages of the cementitious waste with the added protection of a waterproofing layer throughout the waste form.	Science Need: Needs further laboratory development, pilot-scale development, and demonstration as a waste form.	Needs further laboratory development, pilot-scale development, and demonstration. Development costs: high Capital costs: medium Operating costs: low
	L Ceramic Encapsulation (Generation of ceramic phases of wastes for immobilization.) REMA-116-OL <i>Ranking:*</i> L-5-10 (N;N)	Evolving: Conceptual Efficacy: Ceramics are dense mineral phases, thermodynamically stable. Unknown if mineral phase can be identified for each waste specie.	Technology Improvement: Pilot scale testing when laboratory tested. Science Development: Proof of concept needed. Identify which specie incorporate into ceramic phase. Performance testing/verification.	Development costs: N Capital costs: N Operating costs: N
ation, Destruction	H In Situ Vitrification (Buried Waste) (Destruction of organics and encapsulation of off metals/radionuclides in a glass-like matrix.) REMA-100-OL <i>Ranking:*</i> H-5-5 (\$3M;\$60-100/yd ³)	Predemonstration Efficacy: Equipment for in situ vitrification of buried wastes is available, but demonstrations at ORNL have not been conducted. Waste: Product is final waste form with some off-gas processing TTP Match	Technology Improvement: Need to determine if compaction or other methods can be used to prevent flashing and pressurization caused by molten glass coming in contact with combustibles and liquids in containers.	Need to demonstrate that flashing and pressurization caused by molten glass coming in contact with combustible and materials in sealed containers do not result in eruptions and spattering of glass. Development costs: \$3 million over 2 years Capital costs: \$6 million over 2 years Operating costs: \$60-100/yd ³
	M Vitrification (Encapsulation of wastes in a glass-like matrix.) REMA-117-OL <i>Ranking:*</i> M-5-6 (>\$1M;\$400-\$500/ton)	Predemonstration Efficacy: There is a good data base for high-level waste but not for low-level, radioactive or hazardous waste. The waste form is nonporous and leach resistant, but there is some question about its ability to pass the TCLP test. Waste: Product is final waste form.	Technology Improvement: Need to demonstrate destruction of semi-volatile wastes that are commonly found in low-level wastes.	Some laboratory testing has been done, but more is needed on specific waste forms. Also, pilot-plant testing and demonstrations are needed. Development costs: high Capital costs: high Operating costs: \$400-500/ton
onversion	M Transmutation (Transmute long half-life radionuclides to either short-lived or stable isotopes.) REMA-127-OL <i>Ranking:*</i> M-5-4 (<\$1M;<\$50-\$100/ton)	Conceptual Efficacy: the individual steps in the concept are either well understood or the required developments identified. The transmutation step would employ a neutron capture reaction analogous to that used in production of radionuclides Wastes: Waste volume will be significantly reduced.	Technology Need: A partitioning/transmutation demonstration is needed. the europium contained in the HFIR control cylinders is suggested.	The primary need is funding. Hot cell facilities required for the program, as well as the source of transmuting neutrons, exist at ORNL at the High Flux Isotope Reactor. Development costs: Medium. The transmutation segment of the development may not have high costs, but the radiochemical processing portion will have high unit costs. Capital costs: medium Operating costs: medium

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EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements
<ul style="list-style-type: none"> • Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship 	Buried Waste WAG 1, WAG 3, WAG 4, WAG 5, WAG 6, WAG 7	Metals	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		Organics	Refer to Vol. 1, Pt. B, Chap. 6, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Treatment
		Low Level Waste (LLW), metals, organics	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		Low Level Waste (LLW), organics, metals, mixed wastes	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		Organics	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
<ul style="list-style-type: none"> • Facility Decontamination and Decommissioning (D&D) 				
<ul style="list-style-type: none"> • Remedial Action (RA)—Soils, Ground Water and Surface Water 				
<ul style="list-style-type: none"> • Waste Management (WM) 				

al Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Recovery	Smelting, <i>see Waste Management Vol. 2, Pt. C.</i> WPRO-111-OG			
Physical Separation	<p>M</p> <p>Fracted Air Stripping (Uses a spraying well and a vacuum extraction well to force a gas through soil to remove organics.) REMA-89-OL</p> <p><i>Ranking:*</i> M-5-5 (\$2M;>\$50-75/ton)</p>	<p>Demonstration An integrated demonstration is currently being performed at Savannah River Laboratory. Difficulties were encountered with horizontal drilling in aligning spraying well and upper vacuum extraction well. Efficacy: This technology appears to be only partly effective. The normal sedimentary geologic process tends to deposit soils in horizontal layers, which promotes horizontal movement of gases through the soil instead of vertical movement. Waste: Gas or condensed organic liquid.</p>	<p>Technology Improvement: Stimulating the soil to promote conductivity vertically. Also, there needs to be a technique for establishing well-defined boundaries at the edges of the well.</p>	<p>Need manufacturing facility capable of designing and manufacturing reverse circulation down the hole motor. Drill string will have capability of directional water cutting to create cutoff wall structure at end of drill string and cut the soil to destroy the soil's original fabric. Development costs: \$2M Capital costs: medium Operating costs: \$50-75/ton</p>
Physical Separation	<p>L</p> <p>Shredding and Magnetic Separation (Separation of materials by using a magnetic field.) REMA-93-OL</p> <p><i>Ranking:*</i> L-5-1 (\$1M;\$0.2M/yr/system)</p>	<p>Demonstration Efficacy: The technology is readily available but not applied in this application. The wastes at ORNL must be identified and evaluated to see if this technology is applicable. Waste: Contaminated or hazardous waste fraction and uncontaminated or non-hazardous waste fraction. TTP Match</p>	<p>Technology Improvement: No technology or science improvements are needed.</p>	<p>Need to identify size distribution, shredability, and magnetic properties of wastes at ORNL waste sites. Development costs: \$0.5 to \$1 million Capital costs: \$75K to \$150K Operating costs: \$200K per year per system</p>
Physical/Chemical Separation	<p>L</p> <p>Soil Washing (Separation of contaminant by solvent washing. Water or other solvents may be used) REMA-6-OL</p> <p><i>Ranking:*</i> L-5-3 (<\$0.5M;\$70-150/ton)</p> <p>M</p> <p>Physical Sorting (Waste is sorted into categories determined by planned treatment.) REMA-121-OL</p> <p><i>Ranking:*</i> M-5-1 (N;N)</p>	<p>In Use Efficacy: Effective for contaminated soils in which the contaminant is soluble in the washing/leaching agent. It may also be useful for waste buried in containers if the containers can be opened. Waste: Loaded soil washing solution and cleaned material. TTP Match</p> <p>Predemonstration. Efficacy: Although routinely performed by the private sector for characterized radioactive waste, it is not available in the private sector for uncharacterized or mixed waste. Wastes: Should result in significant reduction in waste volume and allow recovery of resources.</p>	<p>Technology Improvement: Need to develop methods for removing wastes from containers, confirmatory tests to prove that the contaminant was completely removed, and procedures for removing the contaminant from the washing/leaching agent.</p>	<p>Soil washing/leaching equipment already exists. Development costs: low Capital costs: low Operating costs: \$70-150/ton</p>
Physical separation	<p>L</p> <p>Thermal Desorption (Thermal desorption is a relatively low temperature, 300 to 800 degrees F, thermal separation process.) REMA-92-OL</p> <p><i>Ranking:*</i> L-5-3 (≈\$1M;\$35-\$120/ton)</p>	<p>Demonstrated Efficacy: This technology is accepted by industry mainly for applications where the material being treated has a high surface-to-volume ratio. It is greater than 99% efficient for removing VOCs from soil. There has been limited use on buried wastes.</p>	<p>Technology Improvement: Need to establish working parameter and materials on which this process can be used with respect to buried wastes.</p>	<p>Need continued demonstrations to establish working parameters and conditions where this technology will be acceptable. Development costs: medium Capital costs: medium Operating costs: \$35-150/ton</p>

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Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Physical Separation	<p>L</p> <p>Gravity Sorting (Separation of wastes by specific gravity.) REMA-8-OL</p> <p><i>Ranking:*</i> L-5-3 ($\leq \\$1M$; $\\$0.35$-$\\$1/lb$)</p>	<p>Demonstration Efficacy: This technology is currently used in industry and mining to separate materials by both size and density. To date, there have been no applications of this technology to the segregation of wastes. The technology should be applicable for separation of wastes into different streams where other treatment technologies can be used more effectively.</p>	<p>Need to demonstrate the limits or capabilities of this technology to separate items commonly found in buried wastes for pre-treatment of wastes.</p>	<p>Development costs: medium Capital costs: medium Operating costs: low</p>
Physical Separation	<p>L</p> <p>Freeze purification (Aqueous solutions containing dissolved contaminants is slowly frozen, which produces pure water ice crystals on the surface and leaves contaminants in the mother liquor.) REMA-91-OL</p> <p><i>Ranking:*</i> L-5-5 ($\leq \\$5M$; $\leq \\$50/ton$)</p>	<p>Predemonstration Efficacy: Two basic techniques have been tried: (1) Vacuum flash/vapor compression (VFVC), which evaporates some water and forms ice simultaneously, and (2) secondary refrigerant freezing (SRF), which produces an ice-liquor slurry that is washed with fresh water to yield contaminant-free ice.</p>	<p>Technology Improvement: Additional tests are needed to establish efficiencies and to determine additives and other means of improving the technology.</p>	<p>Need continued studies as noted under technology improvement. Development costs: low Capital costs: low Operating costs: low</p>
Excavation	<p>H</p> <p>Precision Excavation (Used for excavating small areas and for recovering containers of hazardous wastes.) REMA-90-OL</p> <p><i>Ranking:*</i> H-5-1 ($\leq \\$5M$; $\leq \\$50/ton$)</p>	<p>Accepted This technology is generally accepted by industry. Drum grapplers in conjunction with fork lifts or back hoes are in general use. Precision excavation by robots is in the demonstration phase.</p>	<p>Technology Improvement: Need to continue development and demonstration of robotic technology. Available at X-10.</p>	<p>Need continued improvements in safety and preciseness of excavating and container-handling techniques. Development costs: low Capital costs: low Operating costs: low</p>
	<p>L</p> <p>Borehole Mining (Super Soil Stabilization Management) REMA-4-OL</p> <p><i>Ranking:*</i> L-5-3 ($\leq \\$1M$; $\\$50$-$\\$100/yd^3$)</p>	<p>Efficacy: This technology was developed in Japan in the early 1980s and was recently used to successfully decontaminate phenol-contaminated soil under a large warehouse in Germany. Estimated excavation rates vary from 25 to 50 yd³ of soil per hour. The process has created cavities 6.5 ft. in diameter by 10 ft. high at depths of 15 to 25 feet.</p>	<p>The technology uses off-the-shelf equipment but needs a full-scale cold demonstration to qualify operational techniques at ORNL.</p>	<p>Demonstration (cold tests) of the effectiveness of the SSS Management System on ORNL soils is needed. Development costs: medium Capital costs: medium Operating costs: $\\$50$-$100/yd^3$</p>
	<p>H</p> <p>Remote Excavation, see also Pits & Trenches REMA-38-OL</p> <p><i>Ranking:*</i> H-5-2 ($\leq \\$5M$; $\\$203$-$\\$244/ft^3$)</p>	<p>Demonstration to Accepted Efficacy: Control of air-borne releases and shielding from radioactivity are needed. Also need to control releases to water. Waste: No change in waste volume or characteristics. TTP Match</p>	<p>Science Needs: The characteristics of the waste to be removed need to be identified (primarily for health and safety issues).</p>	<p>Costs for remote excavation may vary from $\\$203/cf$ to $\\$244/cf$. (Does not include disposal costs). There are a lack of redispal options that need to be resolved before considering retrieval. Sophisticated retrieval equipment would have to be made available and possibly dedicated. Development costs: low Capital costs: high Operating costs: $\\$200$-$244/ft^3$</p>

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al Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Excavation	<p>M</p> <p>Modular Excavation (in situ retrieval and treatment system for buried wastes containing multiple modules designed to excavate, shred, and process wastes.) REMA-122-OL</p> <p><i>Ranking:*</i> M-5-8 (>\$1M;<\$50-\$100/ton)</p>	<p>Conceptual</p> <p>Efficacy: No specific development work has been done, but many of the components are similar to existing technologies.</p> <p>Wastes: Waste volume changes will be dependent on the individual processes used for treatment.</p>	<p>Science: real-time monitoring instruments.</p> <p>Technology: Mechanical design of the equipment, including adaptation of existing technologies.</p>	<p>Primarily mechanical and process engineering development support.</p> <p>Development costs: TBD (N)</p> <p>Capital costs: TBD (N)</p> <p>Operating costs: TBD (N)</p>
Excavation	<p>H</p> <p>Overshot drilling (This technology involves over coring of the bore hole lines and removal of the entire liner with its contents for retrieval of HFIR control plates.) REMA-123-OL</p> <p><i>Ranking:*</i> H-5-4 (\$5M/6 HFIR holes)</p> <p>H</p> <p>Wireline Basket Recovery (HFIR control plates which are highly radioactive have been segmentally placed in wire baskets with long handling cables and then placed in 6 auger holes in WAG 6. This technology will involve recovery using the wirelines to lift the baskets after first removing sand backfill by remote means.) REMA-125-OL</p> <p><i>Ranking:*</i> H-5-4 (\$8M/6 HFIR holes)</p>	<p>Predemonstration</p> <p>Efficacy: Over shot drilling is based on established cation drilling methods. It has been considered and equipment has been designed for retrieval of repository waste packages.</p> <p>Waste: There should be no additional waste generated unless the bore hole liner has deteriorated.</p> <p>Conceptual: The condition of the wire baskets and handling bails are unknown.</p> <p>Efficacy: Removal of the sand backfill or the concrete shielding blocks will be done remotely because of the high radiation levels of the control plates. A bore hole camera will be used to determine the condition of all components before trying to remove the baskets with the wirelines.</p> <p>Waste: Should be little additional waste unless the system has deteriorated.</p>	<p>Technology Needs: All components of this technology have been tested in heavy civil construction and the mining industry. The combination of the components needed for this operation need to be demonstrated.</p> <p>Technology Needs: Need an evaluation of industrial vacuum units to suck moist sand over a height of 20 feet and evaluation of nondestructive techniques for determining the condition of the bore hole liners, the basket, and the lifting bales.</p>	<p>Need a detailed evaluation of the existing conditions and the location of each auger hole.</p> <p>Development costs: \$0.8M</p> <p>Capital costs: medium</p> <p>Operating costs: \$5M per 6 HFIR holes</p> <p>Need to demonstrate that the condition of the components can be determined before removal attempts are made.</p> <p>Development costs: high</p> <p>Capital costs: medium</p> <p>Operating costs: \$8M per 6 HFIR holes</p>
Excavation	<p>H</p> <p>Bulk Item Exhumation (The mechanical removal of bulk equipment and large items.) REMA-126-OL</p> <p><i>Ranking:*</i> H-5-2 (<\$1M;<\$50/ton)</p>	<p>Accepted</p> <p>This technology is currently in use. Efficacy: Effective in retrieving equipment when it is identified by site characterization.</p> <p>Waste: Volume dependent on actual method/size of equipment recovered.</p>	<p>Science Needs:</p> <p>Development of remote site characterization techniques to produce sharp imaging of buried objects. Development of remote control system on attachments.</p>	<p>Need access to larger scale equipment than currently in use at ORNL. May need equipment modification and for containment.</p> <p>Development costs: medium</p> <p>Capital costs: medium</p> <p>Operating costs: medium</p>
Excavation	<p>L</p> <p>Solidify and Mine (Freeze and Mine) REMA-10-OL</p> <p><i>Ranking:*</i> L-5-8 (<\$1M;<\$50/ton)</p>	<p>Predemonstration</p> <p>Efficacy: This is a patented process known as "ISOCELL" and a demonstration is currently underway at INEL on buried wastes. Use of this technology may allow selective retrieval of buried waste by mining or tunneling and immobilization of the waste during retrieval.</p> <p>TTP Match</p>	<p>An evaluation of the technical benefits and costs needs to be done.</p>	<p>In situ cryogenic freezing technology exists, but the technology needs to be demonstrated at a site with a troublesome mobile contaminant.</p> <p>Development costs: medium</p> <p>Capital costs: medium</p> <p>Operating costs: low</p>

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EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements
<ul style="list-style-type: none"> • Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship 	Buried Waste WAG 1, WAG 3, WAG 4, WAG 5, WAG 6, WAG 7	Low Level Waste (LLW), metals, organics, mixed	Refer to Vol. 1, Pt. B, Chap. 6, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste- specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Retrieval
	Soils/Sediments	Low Level Waste (LLW), metals, organics, mixed	Refer to Vol. 1, Pt. B, Chap. 6.	Containment/isolation
		Radionuclides, metals, organics	Refer to Vol. 1, Pt. B, Chap. 6.	Containment/isolation
		Volatile Organic Hydrocarbons	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		Polychlorinated Bi- Phenols(PCB)	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
EM Problems <ul style="list-style-type: none"> • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM) 				

Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Excavation	<p>Vacuum Loader (Buried Waste) [Vacuum system to pneumatically load waste into tanker that meets DOE standards for transportation.] REMA-101-OL</p> <p>Ranking:* Not Ranked</p>	<p>Accepted Efficacy: Vacuum loader technology is available for use on solid, semi-solid, sludge, and liquid materials that will pass through an eight-inch hose. This technology was used at a Y-12 Impoundment.</p>	<p>Technology Improvement: Waste materials will need to be screened to segregate materials that will not pass through the hose, and the segregated materials will have to be shredded or handled by different methods. Integration of these operations need to be developed and demonstrated to eliminate or minimize the spread of contamination.</p>	<p>Need to demonstrate and field test these procedures at one or more of the ORNL sites. Development costs: medium Capital costs: medium Operating costs: low</p>
Capping	<p>M Capping (Use of caps and barriers to limit direct and hydrologic waste contact.) REMA-46-OL</p> <p>Ranking:* M-4-1 (L, \$0.5-7M/acre)</p>	<p>Accepted Efficacy: Commonly Used, However, the issues of potential subsidence and long-term maintenance push the typical application of a cap. Waste: All wastes remain in place. TTP Match</p>	<p>Science Needs: Geology and ground water flow conditions needed for design.</p>	<p>Costs can vary from \$500,000 to \$7 M per acre. In some cases, control of subsidence or ground water may be needed prior to capping. Development costs: low Capital costs: \$0.5-7M/acre Operating costs: low</p>
Cells/barriers	<p>M Cryogenic Barriers (Uses a frozen layer of native geologic materials to contain wastes.) REMA-58-OL</p> <p>Ranking:* M-4-3 ($\leq 1M$; ~\$200-300/ft²)</p>	<p>Predemonstration Efficacy: Has been accepted for geotechnical applications at construction sites to stabilize soil and control ground water flow. Waste: Avoids generation of waste during construction. TTP Match</p>	<p>Science Needs: An evaluation of site conditions and cost comparison is needed to evaluate the use of this technology.</p>	<p>Equipment and power to freeze the soil is needed. Site specific characterization is needed. Development costs: medium Capital costs: medium Operating costs: medium</p>
Physical/Chemical Separation	<p>H Soil Washing (Separation of contaminants from waste by solvent washing with water or other solvents) REMA-55-OL</p> <p>Ranking:* H-4-2 ($\leq \\$5M$; \$70-\$150/ton)</p>	<p>Accepted in Europe for organics Efficacy: Demonstration for metals and radionuclides has been performed at the Y-12 plant and at Fernald as part of EPA's site program. Waste: Elutriate and residual soil contamination TTP Match</p>	<p>Science Needs: Effectiveness depends on contaminant and soil characteristics. Pilot-scale studies are needed to determine design parameters and to determine if solvents other than water are necessary.</p>	<p>Applies to low-silt soils and therefore has limited application at X-10. Need a means to treat the elutriate. Development costs: low Capital costs: low Operating costs: \$70-150/ton</p>
Physical Separation	<p>H Soil Vapor Extraction (Insitu removal of volatile organic compounds by forcing air through the soil via injection/extraction wells.) REMA-78-OL</p> <p>Ranking:* H-2-3 ($\leq \\$1M$;))</p>	<p>Demonstrated Efficacy: Commercially available and demonstrated at numerous sites. Waste: Provides significant waste volume reductions.</p>	<p>Technology Needs: A method for injecting air in sufficient quantities to promote stripping in saturated zones.</p>	<p>Commercial vendors are available for design/implementation. Development costs: medium Capital costs: low Operating costs: low</p>
Physical Separation	<p>M Low Temperature Thermal Treatment (Removal of PCB's from contaminated soil by low temperature, 300-600°F, heating.) REMA-13-OL</p> <p>Ranking:* M-4-2 (\$1M; \$100-\$800/ton)</p>	<p>Demonstration Efficacy: Development needed for PCB application has been successfully applied for SVOCs. Waste: Residual contaminated soil and residues from off gas. TTP Match</p>	<p>Technology Needs: Large-scale testing on PCBs with various soil types is needed. Costs could be significant. Science Needs: Need to demonstrate if cleanup levels can be met.</p>	<p>Waste consists of treated soil (if contaminants remain) and residues from off-gas treatment. The large waste volume and energy input makes this technology similar in cost to incineration. Development costs: \$1M Capital costs: medium Operating costs: \$100-800/ton</p>

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<ul style="list-style-type: none"> • Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship 	Soils/Sediments WAG 1, WAG 2, WAG 3, WAG 4, WAG 5, WAG 6, WAG 7, WAG 11, WAG 13	Poly chlorinated Bi-phenols (PCBs)	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		Volatile Organic Hydrocarbons (VOCs)	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		VOCs, PCBs	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		PCBs, Organics	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		Organics, nitrates, PCBs	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
Remedial Action (RA)—Soils, Ground Water and Surface Water		Refractory organics, radionuclides, metals	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
Waste Management (WM)				

al Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Physical Separation	H Thermally Enhanced Soil Vapor Extraction (Co-injection of steam or hot air to provide local heat to enhance removal rates.) REMA-80-OL <i>Ranking:*</i> H-2-3 (≤\$1M;)	Demonstration Efficacy: This technology has been used commercially. It has also been demonstrated at the Portsmouth Gaseous Diffusion Plant. Wastes: If it is proven to be effective on ORNL sites, it will result in significant reductions in waste volumes. TTP Match	Technology Improvement: The effectiveness of soil vapor extraction decreases with soil moisture increase. ORNL sites must be evaluated and field demonstrations performed to determine the usefulness of this technology.	Commercial designs of equipment for this technology are available. Development costs: medium Capital costs: medium Operating costs: medium
Physical Separation	H Vapor Extraction with Radio Frequency (RF) REMA-11-OL <i>Ranking:*</i> H-2-4 (≤\$1M; <\$100/ton)	Predemonstration Efficacy: Soil vapor extraction is accepted. The use of RF to heat the soil has been successfully piloted. However, RF heating is limited to high clay or deep soils. Waste: Residue from off gas treatment. TTP Match	Science Needs: Soil characterization to predict vapor flow paths is needed. Potential for toxic off-gases needs to be assessed. Development costs could be several million dollars.	Extensive testing of hardware/structures. Development cost: Medium Capital cost: low Operating cost: <\$100/ton
Physical Separation	H Thermal Desorption REMA-16-OL <i>Ranking:*</i> H-2-2 (≤\$1M; \$35-\$120/ton)	Accepted Efficacy: Used at various remediation sites. Has been shown to be more than 99% efficient in VOC removal. Waste: Off gas treatment and residual soil contamination. TTP Match	Technology Needs: Limitations exist on the types of waste and contaminants that can be treated. The potential for toxics in the off-gases needs to be assessed.	Process equipment and significant power needed. Development cost: medium Capital costs: low Operating cost: \$35-120/ton
Destruction	M Incineration REMA-12-OL <i>Ranking:*</i> M-4-2 (\$1M-\$2M; \$100-\$800/ton)	Demonstration Efficacy: Testing at EPA's Incineration Research Facility achieved 99.9999% destruction. The K-25 incinerator (although now only treating liquids) should be able to meet requirements. Waste: Volume reduction limited when applied to soils or low combustible materials. TTP Match	Science Needs: Soil characteristics determine efficiency and waste reduction. Trial burns and other testing of any new incinerator could require millions of dollars.	Costs vary from \$100 to \$800/ton. Radioactivity and metals in ash would raise disposal costs. Waste reduction limited when applied to soils or low combustible material. Equipment and monitoring needs are substantial. Development costs: \$1-2M Capital costs: high Operating costs: \$100-800/ton
Destruction	M Molten Glass Combustor (Reacts wastes in a glass forming pool to oxidize organics and bind metals.) REMA-15-OL <i>Ranking:*</i> M-2-3 (≤\$1M; >\$200/ton)	Accepted Efficacy: Units are in use, but not at X-10 >99% removal Waste: solidified glass, significant volume reduction.	Science Needs: Identify soil characteristics, including the presence of certain organics and metals. Basically a vitrification process. The effectiveness of additives should be assessed.	Energy and equipment intensive. Solidified glass is the waste product. Development costs: medium Capital costs: high Operating costs: \$->\$200/ton
Destruction	L Chem Char Process (Destroys waste by reverse burn gasification. Can be operated to bind metals, radionuclides in a slag.) <i>see also WPRO-114-OL in Vol. 2, Pt. C.</i> REMA-20-OL <i>Ranking:*</i> L-2-4 (\$1M; <\$50-\$100/ton)	Predemonstration Efficacy: Testing conducted by the holder of the patent - Chem Char Research, Inc. Waste: Significant volume reduction.	Science Needs: Experiments to collect data such as gasifier temp. profile, product gas composition particle size, flow rate, residence time, and treatment quality need to be conducted.	Too early to assess costs. There will be significant power and equipment requirements. Development costs: \$0.75-1.5M Capital costs: M,M Operating costs:

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EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements
<ul style="list-style-type: none"> • Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship 	Soils/Sediments WAG 1, WAG 2, WAG 3, WAG 4; WAG 5, WAG 6, WAG 7, WAG 11, WAG 13	PCBs, organics, radionuclides, metals	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		Hydrocarbons	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		Organics	Refer to Vol. 1, Pt. B, Chap. 6, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Treatment
		Organics, metals	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
EM Problems <ul style="list-style-type: none"> • Facility Decontamination and Decommissioning (D&D) 				
<ul style="list-style-type: none"> • Remedial Action (RA)—Soils, Ground Water and Surface Water 				
<ul style="list-style-type: none"> • Waste Management (WM) 				

Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
struction	<div>M</div> <div>Plasma Arc Furnace (Use electrically heated plasma gas to destroy organics and bind radionuclides and heavy metal into a glass slag.) REMA-17-OL Ranking:* M-2-3 (\$10M;<\$50-\$100/ton)</div>	<div>Demonstration</div> <div>Efficacy: Some pilot-scale systems have been installed. Waste: Off gas and residuals. TTP Match</div>	<div>Science Needs:</div> <div>Information assessing metals carryover, metals stabilization, variations in input, radionuclide partitioning, and off-gas content is needed. More data on destruction efficiency for different wastes is also needed.</div>	<div>Considerable power and equipment needs. Demonstration required. Development costs: \$10M Capital costs: high Operating costs: high</div>
struction	<div>M</div> <div>Incineration, Cement Kiln REMA-14-OL Ranking:* M-2-3 (<\$1M;<\$50/ton)</div>	<div>Demonstration</div> <div>for liquids, not solids. Efficacy: Waste: Limited capacity to introduce solids into cement kiln fuels.</div>	<div>Technology Needs:</div> <div>Develop a handling method for introducing solids into the kiln and eventually into the cement.</div>	<div>Limited capacity available. Need to evaluate acceptability of radioactive wastes. Relatively inexpensive (dollars/ton) primarily due to transportation and materials handling. Little waste produced as solids are left in cement. Development costs: medium Capital costs: low Operating costs: low</div>
struction	<div>M</div> <div>Soils Treatment Using Bioremediation REMA-118-OL Ranking:* M-2-3 (\$3M-\$5M;\$100-\$200/ton)</div>	<div>Predemonstration</div> <div>Laboratory-, bench-, and pilot-scale testing are being performed on various properties. Some bacterial cultures are commercially available; others are in varying stages of development. Efficacy: A particular culture is generally most effective in degrading a single compound or a group of closely related compounds. Highly chlorinated compounds, such as TCE at ORNL, are not easily degraded. Waste: Volume is large if treated soil is not returned to site of origin. TTP Match</div>	<div>Science Needs:</div> <div>Principal data needs are ORNL soil characteristics and viability of naturally occurring and exogenous organisms in the soil. Development of innovative bioreactors should be encouraged.</div>	<div>Large-scale testing or site demonstrations are needed to establish feasibility of bioremediation. These efforts should be part of an integrated treatment approach that will accommodate mixed wastes. In situ treatment is generally less expensive than exsitu treatment. Development costs: \$3-5M Capital costs: \$100-200/ton Operating costs: TBD</div>
struction	<div>M</div> <div>Soils Treatment Using Oxidation or Reduction REMA-120-OL Ranking:* M-2-3 (\$3M-\$5M;\$100-\$200/ton)</div>	<div>Limited Demonstration</div> <div>The Portsmouth X-231B Technology Demonstration demonstrated that hydrogen peroxide was effective for remediating TCE-contaminated soils and ground water. Efficacy: Some success has been achieved using potassium permanganate and ozone as oxidizers on aqueous matrices and waste sludges; sodium reduction of PCBs and dioxins has also had some success. Waste: Residuals will require disposal. The treated soil may also require separate storage or disposal.</div>	<div>Science Needs:</div> <div>Principal data needs are ORNL soil and waste characteristics. Chemical interactions need to be assessed to determine reagent dose and oxidation-reduction impact.</div>	<div>Field trials are necessary to discover the severity of technical constraints and to optimize treatment design. An integrated treatment approach may be needed to accommodate mixed wastes. Development costs: \$3-5M Capital costs: \$100-200/ton Operating costs: TBD</div>

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EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements
<ul style="list-style-type: none"> • Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship 	Soils/Sediments WAG 1, WAG 2, WAG 3, WAG 4, WAG 5, WAG 6, WAG 7, WAG 11, WAG 13	Radionuclides, metals	Refer to Vol. 1, Pt. B, Chap. 6, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Treatment
EM Problems <ul style="list-style-type: none"> • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM) 		Radionuclides, metals, organics	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		Radionuclides, metals, organics	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment
		Radionuclides, metals, organics	Refer to Vol. 1, Pt. B, Chap. 6.	Retrieval

Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Chemical Separation	<p>L</p> <p>Electrokinetic Removal (Passing electric current through soil to separate contaminants.) REMA-19-OL</p> <p><i>Ranking:*</i> L-2-4 (\$1M-10M;>\$100/ton)</p>	<p>Predemonstration Efficacy: Exploratory studies have moved metals through soil under electrostatic potential. Waste: Residual contaminated soil.</p>	<p>Science Needs: The electronic state and chemical form of the contaminant needs to be understood. Technology Needs: Demonstrations illustrating area of influence and potential for recovery need to be performed.</p>	<p>Too early to assess costs or understand implementation needs. Development costs: Expected to exceed \$1 M and may be as high as \$10 M. Capital costs: N Operating costs: N</p>
Chemical Separation	<p>M</p> <p>Soils Treatment Using Solvent Extraction REMA-119-OL</p> <p><i>Ranking:*</i> M-2-3 (\$3M-\$5M;\$200-\$300/ton)</p>	<p>Predemonstration EPA has completed several pilot tests for application of solvent extraction to organics-contaminated soils. *Efficacy: Removal efficiencies vary significantly, approximately 50 to 95% for petroleum and other hydrocarbons. Waste: Liquid residuals will require disposal. The treated soil may also require separate storage or disposal. TTP Match</p>	<p>Science Needs: Principal data needs are the type, concentration, and solubility of the contaminants. Careful treatability studies are encouraged.</p>	<p>In addition to the extraction, soil pretreatment and post-treatment processing will be needed. Field trials are necessary to discover the severity of technical constraints. An integrated treatment approach may be needed to accommodate mixed wastes. Development costs: \$3-5M Capital costs: \$200-300/ton Operating costs: TBD</p>
Fixation	<p>M</p> <p>Stabilization/Fixation by Grouting (Use of additives to immobilize contaminants in soil.) REMA-54-OL</p> <p><i>Ranking:*</i> M-4-3 (≤\$1M;\$75/ft³)</p>	<p>Accepted. Efficacy: Has been demonstrated in a number of EPA site tests. Significant testing has been done at ORNL. Tests showed large reductions in permeability (10-6) cm/s vs. 10-3 of surrounding soil. Waste: Although waste mobility is decreased, waste volume increases. TTP Match</p>	<p>Science Needs: Effectiveness depends on the contaminant speciation and the reaction products formed. Sufficient mixing also conditions effectiveness. Ex situ application is easier to monitor than in situ. The overall claims of effectiveness need to be validated. The greatest development need is methods to inject grout in situ.</p>	<p>Mixing methods are critical to the success of grouting. Costs are generally expected to be low. Soil mixing/grout injection techniques need to be demonstrated. Development costs: medium Capital costs: medium Operating costs: \$75/ft³</p>
	<p>M</p> <p>In Situ Vitrification REMA-18-OL</p> <p><i>Ranking:*</i> M-4-3 (≤\$.5M;\$390/ton)</p>	<p>Demonstration Efficacy: Has been piloted at X-10. Ambient earth and backfill materials have been shown to be treatable. Currently demonstrated to depths less than 20 ft. and in areas with limited ground water recharge. Waste: Solidified glass and off gas. TTP Match</p>	<p>Technology Needs: Need to demonstrate technology at target depths to show that overlaps can be achieved and that off-gas radionuclides can be controlled. Field scale demonstration for Pit 1 scheduled for FY 95.</p>	<p>Significant power requirements. Field scale demonstration needed to identify needs. Development costs: low Capital costs: medium Operating costs: \$390/ton</p>
Excavation	<p>H</p> <p>Entombed clamshell. (This is a modified clamshell used to recover contaminated sediments when the jaws of the clamshell are closed. The contents inside the bucket are totally entombed.) REMA-124-OL</p> <p><i>Ranking:*</i> H-4-0 (≤\$.5M; \$25-50/yd³)</p>	<p>Demonstrated Efficacy: A 4-yd³ clamshell was fabricated at a cost of \$90,000 (1990 dollars) and used to dredge approximately 20,000 yd³ of sediments at a harbor docking facility. Waste: Some additional material (soil) will accompany the contaminated soils.</p>	<p>Technology Needs: Need to develop methods for eliminating entrapped air and water as the clamshell is closed.</p>	<p>Need to demonstrate the operational efficiency of a modified clamshell at an uncontaminated site. Development costs: \$0.2-4M Capital costs: \$100-200K Operating costs: \$25-50/yd³</p>

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Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Capping	H Capping (Pits/Trenches) (Use of caps and barriers to limit direct and hydrologic waste contact.) REMA-36-OL <i>Ranking:*</i> H-3-1 (<\$0.5M, \$0.5-7M/acre)	Accepted Efficacy: However, the issues of potential subsidence and long-term maintenance push the typical application of a cap. Waste: All wastes remain in place. TTP Match	Technology Needs: Designs more resistant to subsidence are needed.	In some cases, control of subsidence or ground water may be needed prior to capping. Development costs: low Capital costs: \$0.5-7M/acre Operating costs: low
Excavation	M In Situ Grouting (Pits/Trenches) REMA-37-OL <i>Ranking:*</i> M-3-2 (≤\$1M; \$75/ft ³)	Demonstration Efficacy: Has been demonstrated in a number of EPA site tests. Significant testing has been done at ORNL. Tests showed large reduction in permeability (10-6 cm/s vs. 10-3 of surrounding soil). Waste: Waste volume increases, although waste permeability decreases. TTP Match	Technology Needs: The greatest development need is methods to inject grout in situ. Need to assess grout-waste compatibility.	Need field tests to establish grout type and mixing techniques. Development costs: high Capital costs: medium Operating costs: ~\$75/ft ³
	H In Situ Vitrification (Pits/Trenches) REMA-35-OL <i>Ranking:*</i> H-3-1 (>\$1M; \$25/ft ³)	Demonstration Efficacy: Has been piloted at X-10. Ambient earth and backfill materials have been shown to be treatable. Currently demonstrated to depths less than 20 ft. and in areas with limited ground water recharge. Waste: Solidified glass and off gas. TTP Match	Technology Needs: Need to demonstrate technology at target depths to show that overlaps can be achieved and that off-gas radionuclides can be controlled. Field-scale demonstration for Pit 1 scheduled for FY 95.	Significant power requirements. Field scale test results needed to identify needs. Development costs: high Capital costs: medium Operating costs: \$25/ft ³
Physical Separation	L In Situ Extraction (Injection of a fluid or gas to selectively extract contaminants insitu.) REMA-39-OL <i>Ranking:*</i> L-3-10 (>\$1M; \$244/ft ³)	Conceptual Efficacy: One or even a limited series of injection fluids unlikely to be effective on wide range of contaminants. Also, the mobility of contaminants is enhanced and thereby requires greater subsurface control.	Science Needs: Considering the stage of development, considerable time and money are needed to investigate potential fluids, mixing, and contaminant control. Soil and contaminant characteristics must also be evaluated.	Implementation needs are not known at this time. Costs are speculative at this time. Development costs: high Capital costs: low Operating costs: \$200-244/ft ³
Excavation	M Remote Excavation (Use of robotics to remotely excavate wastes.) REMA-38-OL <i>Ranking:*</i> M-3-2 (≤\$0.5M; \$203-244/ft ³)	Demonstration to Accepted Efficacy: Control of air-borne releases and shielding from radioactivity are needed. Also need to control releases to water. Waste: No change in waste volume or characteristics. TTP Match	Science Needs: The characteristics of the waste to be removed need to be identified (primarily for health and safety issues).	There are a lack of redispal options that need to be resolved before considering retrieval. Sophisticated retrieval equipment would have to be made available and possibly dedicated. Development costs: low Capital costs: high Operating costs: \$200-244/ft ³

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Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Contents retrieval	<p>H</p> <p>Tank Contents Removal Using Mechanical Mining (e.g., Mechanical Arms or Self-propelled Vehicles) REMA-27-OL</p> <p>Ranking: * H-5-3 (\$4M;N)</p>	<p>Demonstration</p> <p>The technology is available (used regularly by the commercial nuclear industry and DOE) but must be designed and field demonstrated for use in tanks with a radiation environment.</p> <p>Efficacy: Complete retrieval possible.</p> <p>Waste: Retrieval produces a waste requiring storage and eventual treatment/disposal. Original waste volume may be increased.</p>	<p>Technology Needs:</p> <p>DOE's Office of Technology Development is currently developing integrated demonstrations of remotely controlled mechanical arms and multiple-end effectors. Equipment versatility is important to meet wide spectrum of needs; hence, additional development in areas of self-propelled vehicles, as well as remotely operated, materials-handling and conveyance equipment, is needed.</p>	<p>ES&H considerations may mandate that the mining equipment inside the tank be remotely operated and that above-tank equipment be mounted on tank-straddling platforms. Equipment washdown will be needed prior to relocation. Conveyance of the mined waste out of the tank to holding areas must be considered.</p> <p>Development costs: high Capital costs: medium Operating costs: N</p>
	<p>H</p> <p>Tank Contents Removal Using Pneumatic Techniques (e.g., Air Jets, Suction Systems, Air Conveyance Systems) REMA-28-OL</p> <p>Ranking: * H-5-0 (\$4M;N)</p>	<p>Demonstration</p> <p>The technology is available but would need to be engineered or optimized for a specific tank application. A demonstration of suction systems (and water jets) was performed in 1975 for some Hanford Site tanks.</p> <p>Efficacy: Pneumatic retrieval of some wastes (e.g., sticky, cohesive, crystallized wastes) will be difficult.</p> <p>Waste: Retrieval produces a waste requiring storage and eventual treatment/disposal. Original waste volume may be increased.</p>	<p>Science Needs:</p> <p>Testing will reveal whether the nature of the waste will present problems for the pneumatic system (e.g., lift capabilities of conveyance equipment).</p>	<p>ES&H considerations may mandate that the pneumatic equipment inside the tank be remotely operated and that above-tank equipment be mounted on tank-straddling platforms. Equipment washdown is minimal since most equipment is outside the tank. For problematic wastes, pneumatic techniques may need to be combined with mining or hydraulic techniques.</p> <p>Development costs: high Capital costs: medium Operating costs: N</p>
	<p>H</p> <p>Tank Contents Removal Using Hydraulic Techniques (Sluicing) REMA-29-OL</p> <p>Ranking: * H-5-0 (\$4M;N)</p>	<p>Accepted</p> <p>Sluicing and slurring pumping operations were conducted on ORNL's Gunite tanks in 1982-83.</p> <p>Efficacy: About 90% of the sludge was removed from the Gunite tanks in 36 batch operations during ORNL's sluicing tests.</p> <p>Waste: The sluiced waste and significant excess water must be stored and eventually treated for disposal.</p> <p>TTP Match</p>	<p>Technology Needs:</p> <p>Additional improvements are needed to reduce partial settling of resuspended slurry, to optimize the erosive power of the sluicing jet, and to minimize the water volume added to the sludge during sluicing.</p>	<p>ES&H considerations may mandate that the hydraulic equipment inside the tank be remotely operated, that above-tank equipment be mounted on tank-straddling platforms, and that slurry piping be doubly-contained and shielded to minimize radiation exposure.</p> <p>Development costs: high Capital costs: medium Operating costs: N</p>
Fixation	<p>M</p> <p>In Situ Solidification Using Cement-based Grouting REMA-25-OL</p> <p>Ranking: * M-5-2 (>\$5M;>\$70/m³)</p>	<p>Accepted</p> <p>Technology has been field demonstrated at ORNL WAG. 6 trenches and could be adapted to enclosed spaces with limited access using special equipment.</p> <p>Efficacy: Suitably prepared grout will pass the TCLP test. However, some wastes are incompatible with cementation.</p> <p>Waste: No secondary waste generated.</p>	<p>Science Needs:</p> <p>Detailed characterization of the waste matrix is required to determine suitability of grouting and grout/waste formulation. Additional large-scale grouting tests would help create higher confidence in long-term grouting performance.</p>	<p>Proper formulations need to be tested for the tank wastes. ES&H considerations may mandate that the feed and mixing equipment inside the tank be remotely operated and that above-tank equipment be mounted on tank-straddling platforms. Significant grouting, as an interim action, may limit the feasibility of future tank remediation.</p> <p>Development costs: high Capital costs: medium Operating costs: >\$70/m³</p>

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Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
xation	In Situ Solidification Using Silicate-based Formulations REMA-26-OL <i>Ranking:*</i> M-5-2 (>\$5M,>\$70/m ³)	Accepted Technology is in wide-scale use, although specific in situ application to tanks has not been demonstrated. Efficacy: Silicate-based formulations effect waste similar to cement. Waste: No secondary waste generated.	Science Needs: Detailed characterization of the waste matrix is required to determine mix formulations and their suitability. Additional large-scale solidification tests would help create higher confidence in long-term performance of formulations.	Proper formulations need to be (bench) tested for the tank wastes. ES&H considerations may mandate that the feed and mixing equipment inside the tank be remotely operated and that above-tank equipment be mounted on tank-straddling platforms. Significant grouting, as an interim action, may limit the feasibility of future tank remediation. Development costs: high Capital costs: medium Operating costs: >\$70/m ³
	M In Situ Treatment Using In Situ Vitrification (ISV) REMA-30-OL <i>Ranking:*</i> M-5-2 (\$3M,\$6M)	Demonstration ISV for closure and stabilization of underground storage tanks (USTs) is available, but has not been demonstrated near-scale for ORNL low-level waste tanks. Efficacy:* Treatment destroys organics and provides an excellent waste form for containing most radionuclides and inorganics. Waste: A secondary waste is generated by the ISV off-gas collection system. TTP Match	Science Needs: Techniques should be developed that eliminate residual voids in the tanks so as to avoid the risk during processing of significant subsidence of the ISV melt and its associated interruption of electrical contact, and to avoid off-gas pressurization and possible splattering of molten glass.	Field-scale tests are needed to demonstrate that residual voids can be eliminated and that ISV is applicable to USTs. Development costs: \$3 million Capital costs: \$6 million Operating costs: N
	M In Situ Solidification Using Polymer Grouting REMA-32-OL <i>Ranking:*</i> M-5-2 (>\$5M,>\$100/m ³)	Demonstration Technology has been field demonstrated at ORNL WAG 6 in the absence of radioactive contaminants. Additional demonstrations for isolating mixed waste materials in an inundated WAG 6 trench are currently proposed. Efficacy: High potential for immobilization. Waste: No secondary waste generated. However, unreacted polymer, if any, may be toxic. TTP Match	Science Needs: Detailed characterization of the waste matrix helps determine suitability of grouting and grout/waste formulation. The effects of radiation on polymer grouts need to be understood. Additional large-scale grouting tests are needed to create higher confidence in long-term grouting performance.	Proper formulations need to be tested for the tank wastes; good formulation mixing and process QA is essential. ES&H may mandate that the feed and mixing equipment inside the tank be remotely operated and that above-tank equipment be mounted on tank-straddling platforms. Significant grouting limits the feasibility of future tank remediation. Development costs: high Capital costs: medium Operating costs: >\$100/m ³
	L In Situ Solidification Using Thermoplastic Techniques REMA-33-OL <i>Ranking:*</i> L-5-3 (>\$5M,<\$70/m ³)	Accepted using bitumen for low-level radioactive waste Predemonstration: for polyethylene Efficacy: Thermoplastic matrix microencapsulates waste in a rigid form. However, waste form is deformable under some conditions, and waste is not chemically immobilized or stabilized. Waste: Off-gas collection/treatment may be needed. TTP Match	Science Needs: Detailed characterization of the waste matrix is required to determine suitability. The effects of radiation on thermoplastic materials needs to be understood. The final waste form should undergo TCLP tests. Technical feasibility of drying the waste prior to encapsulation needs to be investigated.	Drying the waste and thoroughly mixing the waste are essential. Secondary containment for some thermoplastics is needed. ES&H may mandate that the feed and mixing equipment inside the tank be remotely operated and that above-tank equipment be mounted on tank-straddling platforms. Waste encapsulation may limit the feasibility of future tank remediation. Development costs: high Capital costs: medium Operating costs: <\$70/m ³

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Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Physical separation	<p>M</p> <p>In Situ Solidification Using Sorbents REMA-31-OL</p> <p>Ranking:* M-5-1 (>\$1M;>\$50/m³)</p>	<p>Accepted for traditional sorbents Efficacy: Since sorbents cannot prevent leaching, secondary containment to prevent contact with water is required. Waste: Sorbents increase the waste volume.</p>	<p>Science Needs: Characterization of the waste matrix is required to determine suitability and preference of the sorbents as solidifying agents. Environmental Scientific, Inc., recently began marketing RADSORB, a polymer that reacts with water to form a gel that traps and retains moisture/contamination. RADSORB has yet to be field demonstrated for ORNL's inactive low-level waste tanks. Radiation degradation of polymer sorbents should also be ascertained.</p>	<p>ES&H considerations may mandate that any insertion or mixing equipment inside the tank be remotely operated. Development costs: high Capital costs: medium Operating costs: <\$50/m³</p>
Capping	<p>M</p> <p>Capping (Use of barriers to limit direct and hydrologic contact.) REMA-46-OL</p> <p>Ranking:* M-4-1 (≤\$5M;\$0.5-\$7M/acre)</p>	<p>Accepted Efficacy: Commonly used technology, however the issues of potential subsidence and long-term maintenance push the limits of the typical application of a cap. Waste: Volume unchanged. TTP Match</p>	<p>Science Needs: Long-term performance testing is needed. Available at Y-12, Portsmouth.</p>	<p>Exact determination of area of contamination, dewatering of impoundments. Development costs: low Capital costs: \$0.5-7M/acre Operating costs: \$0.5-7M/acre</p>
Drains	<p>H</p> <p>French Drains (Rock Drains) REMA-43-OL</p> <p>Ranking:* H-4-1 (≤1;\$50-\$100/ft²)</p> <p>H</p> <p>Biopolymer Drains (French drains installed using a biodegradable slurry.) REMA-44-OL</p> <p>Ranking:* H-4-2 (≤1M;\$15-\$20/ft²)</p> <p>H</p> <p>Horizontal Wells (Cased well installed horizontally.) REMA-45-OL</p> <p>Ranking:* H-4-3 (≤1M;\$150/ft)</p>	<p>Accepted Efficacy: Have been constructed and successfully operated at SWSA 6. Waste: No change in waste.</p> <p>Accepted Efficacy: Have been installed at Portsmouth as part of site remediation. Waste: No change in waste volume.</p> <p>Demonstration Efficacy: Have been used in highway construction and oil field exploration. Waste: No change in waste volume. TTP Match</p>	<p>Science Needs: Geology and ground water flow conditions needed for design. Available at X-10, Y-12, Portsmouth.</p> <p>Science Needs: Geology and ground water-flow conditions needed for design. Available at Portsmouth.</p> <p>Technology Needs: Need to test technical feasibility of drilling long distances in bedded shales, limestone, and interbedded shales. Also, need to determine the effective distance between wells.</p>	<p>Installation difficult in hard rock. May require blasting. Cost-effective use usually precludes installation in hard rock. Development costs: low Capital costs: low Operating costs: \$50-100/ft²</p> <p>Need to use a biodegradable slurry. Development costs: medium Capital costs: low Operating costs: \$15-20/ft²</p> <p>Need a contractor experienced in directional drilling. Need disposal for potentially large amounts of cuttings. Development costs: low Capital costs: medium Operating costs: \$150/ft²</p>
Barriers	<p>M</p> <p>Grout Curtains (Narrow vertical walls installed in the ground to direct laterally flowing ground water.) REMA-42-OL</p> <p>Ranking:* M-4-2 (≤1M;\$30-\$40/ft²)</p>	<p>Accepted Efficacy: Commercially available to from 30 to 40 ft. Without a confining layer (not present at ORNL), this application will not be very effective. Waste: No change in waste volume.</p>	<p>Science Needs: Characterization of soil conditions and geology. May need studies to improve effectiveness without a confining layer.</p>	<p>Significant monitoring requirements to assess effectiveness. Needs to be demonstrated at ORNL. Development costs: medium Capital costs: low Operating costs: \$30-40/ft²</p>

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Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
barriers	M Slurry Walls (Narrow vertical walls that are backfilled with slurry to direct ground water flow.) REMA-40-OL <i>Ranking:*</i> M-4-3 ($\leq 1M$; \$15-\$20/ft ²)	Accepted Efficacy: Technology is commercially available and has been used at Portsmouth. However, the lack of a confining layer at ORNL makes typical application unacceptable. Waste: No change in waste volume. TTP Match	Science Needs: Development needed so slurry walls could be used in fractured system. To apply, would need subsurface characterization. Available at Portsmouth.	There are significant construction and monitoring requirements. Development costs: medium Capital costs: low Operating costs: \$15-20/ft ²
	M Sheet Pile Walls (Interlocked sheets of steel installed in the ground to divert ground water flow.) REMA-41-OL <i>Ranking:*</i> M-4-2 ($\leq 1M$; \$30-\$40/ft ²)	Accepted Efficacy: Commercially available for depths from 30 to 40 ft. Waste: No impact on waste volume. TTP Match	Science Needs: Material compatibility testing.	Sheet piling will leak. Another barrier or monitoring to evaluate the effects of leaking may be needed. Characterization of soil and subsurface needed. Development costs: medium Capital costs: low Operating costs: \$30-40/ft ²
	L Clay/Bentonite Additives (Addition of clays including bentonite to control outleakage.) REMA-60-OL <i>Ranking:*</i> L-4-1 ($\leq .5M$; \$0.55/ft ²)	Demonstration Efficacy: The use of additives to construct a liner in an existing pond is limited (such as for landscaping). TTP Match	Technology Needs: Need to field test the technology (fairly inexpensive). Testing may be required to optimize the additive.	Identify areas contributing to outleakage. Development costs: low Capital costs: low Operating costs: \$0.55/ft ²
	L Cryogenic Barriers (Uses a frozen layer of native geologic materials to contain wastes.) REMA-58-OL <i>Ranking:*</i> L-5-3 ($\leq 1M$; ~\$200-300/ft ²)	Predemonstration Efficacy: Has been accepted for geotechnical applications at construction sites to stabilize soil and control ground water flow. Waste: Avoids generation of waste during construction. TTP Match	Science Needs: An evaluation of site conditions and cost comparison is needed to evaluate the use of this technology.	Equipment and power to freeze the soil is needed. Site specific characterization is needed. Development costs: medium Capital costs: medium Operating costs: \$200-300/ft ²
physical/chemical separation	M Soil Washing REMA-51-OL <i>Ranking:*</i> M-4-2 ($\leq .5M$; \$70-150/ton)	Demonstration Efficacy: Has been demonstrated at the Y-12 plant and Fernald. Part of EPA's Site program. The effectiveness depends on soil and sediment characteristics. Waste: Need a means to treat the elutriate. TTP Match	Pilot-scale studies are needed to determine design parameters and to determine if solvents other than water are needed.	Field screening and material handling. Development costs: low Capital costs: low Operating costs: \$70-150/ton
physical separation	M In Situ Soil Flushing (Water or aqueous solution is contacted insitu to extract contaminants.) REMA-47-OL <i>Ranking:*</i> M-4-3 ($\leq .5M$; <\$50/ton)	Demonstration Efficacy: Part of EPA's SITE Program. Effectiveness depends on the contaminant, soil characteristics, and geology. Waste: Handling (collection) and treatment of elutriate is required. TTP Match	Need to develop method to control wash flow in fractured system.	Soil and subsurface geology characterization. Development costs: low Capital costs: low Operating costs: <\$50/ton
	M Sludge Drying (Use of microwave and RF heating to dry sludge for disposal.) REMA-56-OL <i>Ranking:*</i> M-4-3 ($\leq 1M$; <\$50/ton)	Predemonstration Efficacy: The use of RF and microwaves to heat soils has been successfully piloted. Waste: Reduction in weight. Need to treat off gas.	Science Needs: Potential for toxic off-gases needs to be assessed.	Need water content of sludge, chemical, and physical characterization. Development costs: medium Capital costs: low Operating costs: <\$50/ton

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EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements
<ul style="list-style-type: none"> • Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship 	Impoundments WAG 1, WAG 5, WAG 8, WAG 9	Radionuclides, metals, organics	Refer to Vol. 1, Pt. B, Chap. 6, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste- specific characteristics are provided for each technology, specific regulatory requirements will be specified.	Treatment
EM Problems <ul style="list-style-type: none"> • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM) 				Retrieval
	Ground Water/Surface Water WAG 2, WAG 3, WAG 4, WAG 5, WAG 6, WAG 8, WAG 9, WAG 10, WAG 11	Radionuclides and inorganics	Refer to Vol. 1, Pt. B, Chap. 6.	Treatment

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Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Fixation	H In Situ Fixation (Mixing of additives, like cement, silicates, etc., to bind metals and radionuclides into a stable material.) REMA-57-OL Ranking:* H-4-1 ($\leq \$1M$; $\$50-75/yd^3$)	Demonstration Efficacy: Has been demonstrated in a number of EPA SITE tests. Significant testing has been done at ORNL showing large reductions in permeability (10-6 cm/s vs. 10-3 of surrounding soil). Waste: Significant increase in volume of waste. TTP Match	Technology Needs: The greatest development need is mixing/injection methods. Science Needs: Need to assess the additive waste compatibility.	Characterize sludge, determine optimum additive mixture. Development costs: low Capital costs: medium Operating costs: $\$50-75/yd^3$
	M In Situ Vitrification (Impoundments) REMA-59-OL Ranking:* M-4-3 ($\leq \$5M$; $\$25/yd^3$)	Demonstration Efficacy: Has been piloted at X-10. Ambient earth and backfill materials have been shown to be treatable. Currently demonstrated to depths less than 20 ft. and in areas with limited ground water recharge. Waste: Solidified glass and off gas treatment residue. TTP Match	Technology Needs: Need to demonstrate technology at target depths and show that overlaps can be achieved and that off-gas radionuclides can be controlled. Field-scale demonstration for Pit 1 is scheduled for FY 95.	Evaluation of Pit 1 demonstration to determine implementation needs. Development costs: medium Capital costs: medium Operating costs: $\$25/yd^3$
	H Mechanical Excavation REMA-50-OL Ranking:* H-4-1 ($\leq \$5M$; $\leq \$50/ton$)	Accepted Efficacy: Used extensively at ORNL. Typically, backhoes and clamshells. Waste: Volume generated depends on method. TTP Match	Technology Needs: Development of remote controls and air emission guards. Available at all sites.	Waste characteristics (especially for health and safety reasons) need to be identified. Control of airborne releases and shielding from radioactivity are needed. May need remote equipment under certain conditions. Development costs: low Capital costs: low Operating costs: $\leq \$50/ton$
	H Vacuum Loaders REMA-49-OL Ranking:* H-4-1 ($\leq \$5M$; $\leq \$50/ton$)	Accepted Efficacy: Used extensively in a variety of clean-up operations including Y-12 impoundments. Waste: Volume depends on site.	Development of remotely controlled equipment. Available at Y-12.	The soil/sediment characteristics are needed. The size particles containing most of the contamination may be useful. Remote controls may be needed. Development costs: low Capital costs: low Operating costs: $\leq \$50/ton$
Excavation	H Dredging REMA-48-OL Ranking:* H-4-1 ($\leq \$5M$; $\leq \$50/ton$)	Accepted Efficacy: Well-tested technology with fairly new application.	Modifications to accepted equipment are needed to control resuspension and/or handle high solids content. Available at K-25.	The soil/sediment characteristics are needed. The size containing most of the contamination needs to be assessed. Development costs: low Capital costs: low Operating costs: $\leq \$50/ton$
	H Ion Exchange REMA-65-OL Ranking:* H-5-1 ($\$1M$; $\$5-10/1000gal$)	Accepted Efficacy: The technology is fully developed and has been applied to several different types of waste streams, which include remove of radionuclides, metals, etc., from aqueous waste streams. Waste: This technology provides significant reduction in waste volumes. TTP Match	Technology Improvement: Laboratory scale tests need to be continued to develop new and more efficient ion exchange materials to improve the efficiency of the technology.	Laboratory scale tests should be conducted to select the best ion exchange materials for specific ORNL clean up sites. Development costs: $\$1M$ Capital costs: medium Operating costs: $\$5-10/1000$ gallons
Physical Separation				

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Action

Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Physical Separation	<div>L</div> <div>In Situ Ion Exchange (Specifically formulated materials having an "exchangeable" ion bond to the material. The materials are placed in an onsite trench and allowed to contact ground water.) REMA-64-OL <i>Ranking:*</i> L-5-3 (3M;N)</div>	<div>Predemonstration</div> <div>Efficacy: The ion exchange process has been fully developed and demonstrated for solutions containing contaminants. However, the insitu application of ion exchange has not been demonstrated. Waste: This technology should reduce waste volumes significantly, however, the exhausted ion exchange material will require disposal. TTP Match</div>	<div>Technology Improvement:</div> <div>Lab scale treatability tests are needed to provide data for ion exchange materials selection and to provide estimates of contaminant loading.</div>	<div>An ORNL site should be selected or a test site should be constructed and tests conducted to determine the capabilities of this technology to remove the contaminants. Development costs: \$3M Capital costs: medium Operating costs: TBD (N)</div>
Physical Separation	<div>H</div> <div>Activated Carbon (Combination of absorption, chemisorption, and ion exchange mechanisms to remove contaminants from aqueous solutions.) REMA-66-OL <i>Ranking:*</i> H-2-1 (1M;\$5-10/Kgal)</div>	<div>Accepted</div> <div>Efficacy: This technology is fully developed and has been used to treat organic-laden, industrial, and hazardous waste streams. Waste: This technology provides significant reductions in waste volumes.</div>	<div>Technology Improvement:</div> <div>Laboratory scale tests need to be continued to determine methods for putting additional materials into solution, and then determine the effectiveness of this technology in removal of the contaminants.</div>	<div>Characterizations of ORNL wastes need to be evaluated to determine where this technology can be implemented and design parameters in a capacity of 15 to 100 gal/min should be determined. Development costs: \$1M Capital costs: medium Operating costs: \$5-10/1000 gallons</div>
Physical Separation	<div>M</div> <div>Adsorption on Biomedia (Resins as a medium to concentrate microbes for bioaccumulation and degradation of hazardous wastes.) REMA-73-OL <i>Ranking:*</i> M-2-2 (\$2M;N)</div>	<div>Predemonstration</div> <div>Efficacy: Certain resins have been used to concentrate and or isolate certain microorganisms to enhance the treatment of hazardous wastes. Wastes: For cases where this technology is applicable, it results in significant reduction in waste volumes.</div>	<div>Technology Improvement:</div> <div>Efforts are needed to assess the microorganisms that are most likely to work with this technology. Also work is needed to determine nutrients which could enhance the effectiveness of this technology.</div>	<div>Pilot-scale treatability studies are needed to supply information for assessment of the effectiveness of this technology on specific waste streams. Development costs: \$2M Capital costs: medium Operating costs: TBD (N)</div>
	<div>L</div> <div>In Situ Biomedia Adsorption (Places resins in a trench to provide a medium to concentrate microbes for bioaccumulation and degradation of hazardous wastes.) REMA-74-OL <i>Ranking:*</i> L-2-3 (3M;N)</div>	<div>Predemonstration</div> <div>Efficacy: Bioadsorption is accepted but the use of resins to accumulate microbes and insitu application are both predemonstration. Wastes: Potentially significant reductions in waste volume.</div>	<div>Technology Improvement:</div> <div>Efforts are needed to assess the microorganisms that are most likely to work with this technology and to determine which nutrients could enhance its effectiveness. Also work is needed to control the ground water flow to provide sufficient time for bioaccumulation.</div>	<div>Pilot-scale treatability studies are needed to provide information for assessment of the effectiveness of this technology on specific waste streams. Development costs: \$3M Capital costs: medium Operating costs: TBD (N)</div>
	<div>L</div> <div>In Situ Activated Carbon (Constructs a permeable trench filled with activated carbon such that there is a gradient that will result in ground water flowing through the activated carbon to remove contaminants.) REMA-67-OL <i>Ranking:*</i> L-2-3 (3M;N)</div>	<div>Predemonstration</div> <div>Efficacy: Further development of insitu applications of activated carbon is needed. Waste: Significant waste reductions are possible for cases where this technology is applicable. However, the spent carbon must be treated or disposed.</div>	<div>Technology Improvement:</div> <div>Further development of this technology is needed to reduce the uncertainties associated with controlling flow through the bed, controlling fouling of the bed, competing contaminants and ground water constituents, and monitoring the condition and effectiveness of the carbon bed.</div>	<div>Need to demonstrate the feasibility of this technology on a selected ORNL site or construct a test facility to demonstrate its feasibility. Development costs: \$3M Capital costs: medium Operating costs: TBD (N)</div>

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Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
Physical Separation	<p>M</p> <p>Precipitation (Chemical treatment which removes soluble contaminants from water by converting them into insoluble compounds.) REMA-34-OL</p> <p><i>Ranking:*</i> M-5-1(1M;\$100-\$1000/1Kgal)</p>	<p>Accepted Efficacy: Facilities exist at ORNL with the capability to precipitate heavy metals from water. Cobalt-60 and technetium-99 can also be precipitated after special treatment. Other radioactive species may also require special treatment. Wastes: Successful use of this technology will result in significant reductions in waste volumes, and result in a concentrated sludge for disposal. TTP Match</p>	<p>Technology Improvement: The waste streams must be properly characterized and the flow rates estimated in order to size the equipment. Available at all sites.</p>	<p>Treatability testing is needed to determine additives and dosage. Development costs: \$1M Capital costs: medium Operating costs: \$100-1000/1000 gallons</p>
	<p>L</p> <p>In Situ Precipitation (Injects various chemicals such as lime, iron sulfide, iron filings, etc., to form precipitates of the contaminants to make physical separation easier.) REMA-62-OL</p> <p><i>Ranking:*</i> L-5-3 (3M;N)</p>	<p>Predemonstration Efficacy: This technology can be useful for contaminants which are in solution or can be put into solution which will act with the injected chemicals to form a precipitate. Because of the innovativeness of the delivery system and uncertainties of insitu reactors the technology needs further development. Waste: Will greatly reduce the volume of waste for disposal, although precipitates must be recovered. TTP Match</p>	<p>Technology Improvement: Need to determine the chemicals needed for various contaminants, determine the stability of the precipitates, determine the kinetics and develop delivery systems.</p>	<p>Need to characterize precipitates, flow paths, and effectiveness of the concept. Development costs: \$3M Capital costs: low Less than \$1 million TBD (N)</p>
Physical Separation	<p>H</p> <p>Air Stripping (Involves the transfer of solute from a liquid phase to a gas phase for further treatment if necessary.) REMA-76-OL</p> <p><i>Ranking:*</i> H-2-0 (\$0M;\$0.6-4.10/1000 gal)</p>	<p>Accepted Efficacy: Air stripping is a proven technique for voc removal and is used extensively in water remediation systems. It is considered by EPA as a best available technology. Wastes: Provides significant reduction of waste volumes. Residual from off gas treatment must be disposed. TTP Match</p>	<p>Technology Improvement: Science Needs: Testing to determine release and treatment need for radionuclides.</p>	<p>Need to conduct thorough characterization of contaminated water, including identification of chemical species present in order to design an air stripping system. Development costs: \$0M Capital costs: low Operating costs: \$0.6-4.10/1000 gallons</p>
	<p>H</p> <p>Steam Stripping (Technology which operates at 100°C and atmospheric pressure can effectively strip many organic compounds which cannot be stripped at ambient conditions.) REMA-77-OL</p> <p><i>Ranking:*</i> H-2-0 (\$0M;8/1000 gal)</p>	<p>Accepted Efficacy: Steam strippers have been used in industry for many years. Wastes: This system reduces waste volumes significantly when the condensed vapor phase will separate into separate organic and aqueous phases.</p>	<p>Technology Improvement: Need a pilot-scale demonstration to confirm that this system will work well on ORNL ground water and surface water contaminated with VOC's.</p>	<p>Need to characterize contaminated water in order to design system. Development costs: \$0M Capital costs: low Operating costs: \$8/1000 gallons</p>
Destruction	<p>M</p> <p>Biological Denitrification (Converting organic nitrogen to nitrates followed by denitrification by use of appropriate bacteria.) REMA-75-OL</p> <p><i>Ranking:*</i> M-2-1 (\$1M,\$200/1000gal)</p>	<p>Accepted Efficacy: The Oak Ridge Y-12 Plant has a full-scale system to denitrify high concentration nitrate wastewater. Also denitrification of low concentration nitrate waste water is commonly done at Sewage Treatment Plants. Wastes: Provides significant reductions in waste volumes. TTP Match</p>	<p>Technology Improvement: It may be possible to use the Y-12 system to determine treatment rates and other parameters which are needed to determine the effectiveness of this technology for treating ORNL wastes.</p>	<p>Studies are needed to establish processes that would be effective in denitrification of ORNL wastes. Development costs: \$1M Capital costs: low Operating costs: \$200/1000 gallons</p>

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Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
destruction	<p>M</p> <p>In Situ Biological Denitrification (Uses bacteria for the insitu conversion of organic nitrogen to nitrates and denitrification of nitrates.) REMA-111-OL</p> <p><i>Ranking:*</i> M-2-3 (\$3M;N)</p>	<p>Predemonstration Efficacy: Insitu biological denitrification was used to treat the S-3 ponds at Y-12, but it has never been used for insitu treatment of ground water. Wastes: Biological denitrification of waste waters is effective in reducing wastes. TTP Match</p>	<p>Technology Improvement: Methods are needed to inoculate the ground water with appropriate bacteria and to supply needed nutrients. Development work is also needed on how to initiate and control the process.</p>	<p>Need to demonstrate that this technology can be useful for denitrification of contaminated ground water. Development costs: \$3M Capital costs: low Operating costs: TBD (N)</p>
destruction	<p>M</p> <p>Chemical Oxidation (Used to remove a variety of waste water constituents by converting the constituents to an insoluble form conversion to a form that can be removed by further treatment or complete degradation through oxidation.) REMA-72-OL</p> <p><i>Ranking:*</i> M-2-2 (\$2M;\$100/1000gal)</p>	<p>Demonstration Efficacy: Chlorine and other chlorine-containing compounds along with ozone and hydrogen peroxide are the most commonly used reagents for treatment of waste water by this technology. Waste: For selective contaminants, this technology is very effective and reduces waste volumes significantly.</p>	<p>Technology Improvement: Needs further research to determine reaction rates and reaction products for contaminants in ORNL waste waters. Depending on the reagents used, some of the reaction products could also be hazardous materials.</p>	<p>Need to develop information which will allow selection of reagents which will not produce hazardous reaction products and will still be effective in removing contaminants from waste waters. Development costs: \$2M Capital costs: medium Operating costs: \$100/1000 gallons</p>
	<p>H</p> <p>Biological Oxidation (Uses microorganisms, principally bacteria to react with or destroy the contaminants.) REMA-68-OL</p> <p><i>Ranking:*</i> H-2-1 (\$1M;\$10/1000gal)</p>	<p>Accepted Efficacy: This technology is used routinely for the treatment of sewage and to degrade water soluble organics. Specially designed systems may be required to treat refractory contaminants such as chlorinated solvents. Wastes: Successful use of this technology will provide significant waste volume reduction. TTP Match</p>	<p>Technology Improvement: Additional work is needed to assess the effectiveness of biological oxidation for treatment of refractory organic compounds. Available at all sites.</p>	<p>Need to determine if there is sufficient need at ORNL for this technology to warrant the construction of a plant for biological oxidation of wastes. Development costs: \$1M Capital costs: medium Operating costs: \$10/1000 gallons</p>
	<p>M</p> <p>In Situ Biological Oxidation (Water amended with an electron acceptor, nutrients, and optional microorganisms is introduced into the contaminated ground water zone through injection wells and is pulled horizontally through the contaminated zone by extraction wells.) REMA-70-OL</p> <p><i>Ranking:*</i> M-2-3 (\$2M;N)</p>	<p>Demonstration Efficacy: This technology is being used extensively at SuperFund Sites and under controlled conditions can be very effective in destroying many organic compounds. Waste: This technology will eliminate or reduce the waste caused by certain organic compounds. TTP Match</p>	<p>Need to develop better methods for injecting oxygen and nutrient laden water into the area and methods for controlling the flow rates through the contaminated soil. Need to develop better controls over the dissolved oxygen content and the flow rates through the contaminated soil.</p>	<p>Need to determine if there is a sufficient need for this technology at ORNL to warrant demonstration. Development costs: \$2M Capital costs: medium Operating costs: TBD (N)</p>
	<p>M</p> <p>In Situ Chemical Oxidation (Oxidation with potassium permanganate, ozone, or hydrogen peroxide.) REMA-61-OL</p> <p><i>Ranking:*</i> M-2-2 (2M; \$2-3/1000 gal)</p>	<p>Predemonstration Efficacy: Chemical oxidation of organics with potassium permanganate and ozone has been demonstrated in aqueous matrices and on a limited basis with waste sludges. Also insitu chemical oxidation with hydrogen peroxide was demonstrated at Portsmouth to remediate soils and ground water contaminated with TCE. Waste: Greatly reduces the volume of waste involved. TTP Match</p>	<p>Technology Improvement: Need to determine which contaminants and under what conditions that this technology will be effective. Also need to determine any effects on the remaining soil. Improved delivery systems are also needed.</p>	<p>Need to characterize water/site and perform treatability tests to determine chemicals, dosages and delivery system. Development costs: \$2M Capital costs: low Operating costs: \$2-3/1000 gallons</p>

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Alternatives	Technologies	Status	Science/Technology Needs	Implementation Needs
— Destruction	<p>M</p> <p>Artificial Wetlands (Provides a controlled way of treatment through physical, chemical, and biological treatment.) REMA-63-OL</p> <p><i>Ranking:*</i> M-2-3 (3M;N)</p>	<p>Predemonstration for inorganics and laboratory demonstration for some organics. Efficacy: For situations where sedimentation, precipitation, absorption, plant uptake, and biodegradation is effective, this technology could be useful.</p>	<p>Technology Improvement: This technology needs further laboratory studies to determine the effectiveness on contaminants under conditions at ORNL sites and then a demonstration at one of more selected ORNL sites.</p>	<p>Need to characterize the soils and conditions at ORNL sites to determine if use of this technology is feasible. Development costs: \$3M Capital costs: low Operating costs: TBD (N)</p>
— Fixation	<p>H</p> <p>Cryogenic Immobilization (Intended to immobilize tritium contaminated ground water, preventing further migration and will fix it in place until natural radioactive decay reduces its toxicity to acceptable levels.) REMA-79-OL</p> <p><i>Ranking:*</i> H-5-2 (\$2M;N)</p>	<p>Demonstrated Efficacy: Ground freezing has been employed in civil engineering, practice for relatively short time periods for many years. For this application, however, it will need to be used for much longer periods of time. Waste: Waste volume will be reduced at the tritium decays.</p>	<p>Science Needs: The impact of this technology on soil integrity over long periods of time need to be evaluated. Also, possible amendments to soil to improve the effectiveness need to be pursued. Technology Needs: Automated temperature monitoring instruments are needed.</p>	<p>Site characterization and pilot scale testing are required. Development costs: \$2M Capital costs: high Operating costs: TBD (N)</p>
— Destruction	<p>H</p> <p>Anaerobic Dechlorination (Organic chemical dechlorination uses chemical reagents or catalysts to remove chlorine atoms from a chlorinated hydrocarbon which may reduce the toxicity and/or make it amenable to other forms of treatment.) REMA-69-OL</p> <p><i>Ranking:*</i> H-2-5 (\$5M;N)</p> <p>M</p> <p>In Situ Anaerobic Degradation (Uses chemical reagents or catalysts for insitu removal of remove chlorine atoms from a chlorinated hydrocarbon to reduce the toxicity or make it amenable to other forms of treatment.) REMA-71-OL</p> <p><i>Ranking:*</i> M-2-5 (\$5M;N)</p>	<p>Predemonstration Efficacy: Several reagents have been developed for dechlorinating dioxins and PCB's which include alkalimetal polyethylene glycolate salts (APEG) and potassium polyethylene glycol (KPEG). Waste: If proven to be effective, this technology would greatly reduce or eliminate the waste volume. TTP Match</p> <p>Predemonstration Efficacy: Laboratory scale tests have shown that high chlorination PCB's can be dechlorinated anaerobically. Also there are several reagents that can be used to dechlorinate dioxins and PCB's. This technology has yet to be applied insitu. Waste: This technology can effectively eliminate or reduce certain wastes. TTP Match</p>	<p>Technology Improvement: Better fundamental understanding of the biological and chemical processes involved in dechlorination are needed.</p> <p>Technology Improvement: Need to develop methods for injecting reagent-laden water and methods for controlling the flow through contaminated soil and ground water.</p>	<p>Need to evaluate the amount of waste and the effectiveness of this technology for treatment of ORNL wastes. Development costs: \$5M Capital costs: medium Operating costs: TBD (N)</p> <p>Need to assess the physical and chemical conditions of the ground water soil at ORNL sites to determine the potential for mixing reagents with the contaminated ground water. Also need to determine the effectiveness of this technology at ORNL sites. Development costs: \$5M Capital costs: low Operating costs: TBD (N)</p>
— Drainage	<p>M</p> <p>Deep Rock Drainage Curtain (Using a circular array of drill holes for a drainage gallery.) REMA-24-OL</p> <p><i>Ranking:*</i> M-1-4 (\$3M,\$30-40M)</p>	<p>Demonstration Efficacy: Well-established technique for control of seepage beneath high head dams on rock formations. Waste: Extracted leachate will need treatment.</p>	<p>Science Needs. Geologic and hydrogeologic characteristics of rock formation are needed. Ground water flow analysis will optimize design.</p>	<p>Extracted leachate requires treatment system. Need deep, rock drilling. Development costs: high Capital costs: \$30-40M</p>
— Barrier	<p>M</p> <p>Water Proofing Cave with Hydraulic Cage (Establishment of a deep rock hydraulic curtain at the periphery of the contamination zone.) REMA-21-OL</p> <p><i>Ranking:*</i> M-1-5 (\$3M,\$30-40M)</p>	<p>Conceptual Efficacy: It is planned for use in Sweden for high-level radioactive waste containment. Waste: Limited to drilling waste, no need to handle leachate. TTP Match</p>	<p>Geologic and hydrogeologic characteristics needed. Mass transport modeling of the waste-rock system needed to evaluate the sensitivity of waste movement to minor pore pressure differences.</p>	<p>A 1000-ft. (in diameter) cage requires about 350 6-in. (in diameter) boreholes. Directional drilling in deep rock formations is needed. Development costs: high Capital costs: \$30-40M</p>

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Action

Alternatives		Technologies	Status	Science/Technology Needs	Implementation Needs
ation	<div>L</div>	<div>Hydrofracture Grouting (Injection of polymers to fill cracks in host rock at the edge of the contaminant plane.) REMA-23-OL</div> <div>Ranking: * L-1-2 (\$3M,\$30-40M)</div>	<div>Demonstration</div> <div>Efficacy: Well accepted in coal mining industry for water control.</div> <div>Waste: Excess grout.</div>	<div>Science Needs:</div> <div>Evaluate long-term impact of radioactivity on cured polyurethane along with other compatibility issues. Better control of grout injection under 1000 ft. of pressure is needed.</div>	<div>Need deep, rock drilling.</div> <div>Development costs: low</div> <div>Capital costs: \$30-40M</div>
ug and abandon	<div>H</div>	<div>Well Plugging and Abandonment (Use of rig mounted drilling units to plug well bores.) REMA-22-OL</div> <div>Ranking: * H-1-2 (\$1M,\$10-20M)</div>	<div>Accepted</div> <div>Efficacy: Standard for industry. Several techniques exist. Actual techniques selected based on the geology of the formation and the physical condition of the casing.</div> <div>Waste drilling fluids must be treated/disposed.</div>	<div>Technology Needs:</div> <div>Alternatives for the safe handling of drilling fluids are needed.</div>	<div>Remotely operated equipment may be needed to protect workers.</div> <div>Development costs: low</div> <div>Capital costs: \$10-20M</div>
xcavation	<div>H</div>	<div>Pipeline Excavation (Mechanical excavation of pipeline and contaminated soil if present.) REMA-53-OL</div> <div>Ranking: * H-1-0 (\$0M,<25/yr³)</div>	<div>Accepted</div> <div>Efficacy: One of the most commonly used technologies for remediating pipelines.</div> <div>Waste: Dependant on extent of contamination in surrounding soil.</div>	<div>Science Needs: Improved methods for locating subsurface pipes and contamination.</div>	<div>Conventional equipment with worker protection from radioactivity. Location of pipes and adjacent contamination.</div> <div>Type of contamination.</div> <div>Development costs: low</div> <div>Capital costs: low</div> <div>Operating costs: <\$25/yr³</div>
ixation	<div>M</div>	<div>In Situ Grouting (Pipelines) REMA-52-OL</div> <div>Ranking: * H-1-1 (\$0M, \$25-70/yr³)</div>	<div>Accepted</div> <div>Efficacy: Grouting and abandonment of pipelines is a common remediation practice.</div>	<div>Special design to grout beneath permanent structures may be needed. Method to locate pipelines.</div>	<div>Location and condition of pipes to be grouted.</div> <div>Development costs: low</div> <div>Capital costs: medium</div> <div>Operating costs: \$25-70/yr³</div>

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Robotics and Automati

The identification of the technologies required to remedial action, and waste management at ORNL with these technologies is to provide support for other nation, and dismantlement. Hence, in this section of "other" decommissioning activities and no attempt to ple a robotic platform used to deploy a sensor was a ment tools.

The robotics/ automation technologies were group Control, and (3) Sensors; with various sub-groups id were selected for this section on the basis of the follo deployment of tools and sensors, adaptability of auto waste by reduction or elimination of clothing exchange dling redundant tasks.

on for Remedial Action

the robotics/ automation in the decommissioning, is based upon the premise that the primary purpose of necessary activities such as characterization, decontamination diagram the problem areas are identified as these differentiate between activities was made. For example, assumed to be equally applicable to deploy dismantle ed into three main categories: (1) Mechanical, (2) identified under each of the categories. Technologies involving considerations: speed and economy in the rated equipment to repetitive tasks, ability to minimize requirements, and reliability and efficiency in han-

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<p>EM Problems</p> <ul style="list-style-type: none"> • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM) 				

n for Remedial Action

Alternatives	Technologies	Status	Science Technology Needs	Implementation Needs
Mechanical—Mobility	E Wheeled/Tracked Vehicle ROBA-I-OL <i>Ranking:*</i> E-5-2 (\$3M;N)	Accepted Efficacy: An essential technology. High probability of being useful for reactors, support buildings, and storage areas. Waste: Possible emissions. Decontamination of system after use. TTP Match	Development: -Improved controls to allow more autonomy of operation. -Improved design for decontamination after use.	-Training of operators in advanced control stations. -Development Costs: \$3.0M
	M Specialized Robotic Deployment Platforms ROBA-7-OL <i>Ranking:*</i> M-4-3 (\$5M;N)	Demonstration Efficacy: Low for most applications in RA. Unique applications may require extensive development. Waste: Frequent decontamination with resulting waste fluids may be necessary. TTP Match	Development: -Specialized controls and sensors -Improved vision systems	- Cold test beds and operator training. -Development Costs: \$5.0M
	M Long-Arm Deployed Robotic Platforms ROBA-9-OL <i>Ranking:*</i> M-5-3 (\$5M;N)	Accepted Efficacy: Medium. Accurate positioning may be a problem. Limited applications in RA. Waste: Hydraulic fluid during operation. Decontamination fluids after use.	Development: -Flexible body control. -End-point sensing. -Collision avoidance. -Weight-to-payload ratio reduction.	-Cold test beds -Extensive operator training -Development Costs: \$5.0M
	E Power Sources for Mobile Platforms ROBA-10-OL <i>Ranking:*</i> E-5-1 (\$0.5M;N)	Accepted Efficacy: An essential technology. Accepted status means high efficacy. Waste: Batteries, and exhaust emissions.	Technology Improvement: - Energy storage capacity - Duty cycle availability - Current capacity/discharge rate - Emission control	- No unusual needs - Development Costs: \$1 to 4M
	E Failure Recovery Systems for Mobile Platforms ROBA-11-OL <i>Ranking:*</i> E-5-1 (\$0.5M;N)	Accepted. Efficacy: High. This is an essential technology that is well established. Waste: Little or no waste.	None	-No unusual needs -Development Costs: \$0.5M
	M Transportation Methods for Mobile Platforms ROBA-12-OL <i>Ranking:*</i> M-3-1 (\$0.5M;N)	Accepted for small robotic platforms Predemonstration for large platforms or unique devices Efficacy: Low. Waste: No waste. The purpose of the technology is to minimize decontamination waste. TTP Match	Development: -Light-weight containers for medium and heavy duty mobile platform. -Containers that can be easily decontaminated.	-No unusual needs -Development Costs: \$0.5M
	E Data/Signal Transmission ROBA-13-OL <i>Ranking:*</i> E-5-1 (\$0.5M;N)	Accepted Efficacy: High. An essential technology. Specific application may determine type of system required. Waste: None. TTP Match	None	-Testing in representative environments. -Development Costs: \$1.0M
Mechanical—Manipulation	E Dexterous Manipulators ROBA-16-OL <i>Ranking:*</i> E-5-1 (\$1M;N)	Demonstration Efficacy: High. An essential technology. Waste: Possible hydraulic fluid during use and decon fluid after use. TTP Match	Development: -Redundant manipulator planning and control. -Modular design. -Nonreplica master/slave operation. -Cooperating and coordinated dual arm control.	-Operator Training on non-replica master controllers. -Development Costs: \$1.0M

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ion for Remedial Action

Alternatives	Technologies	Status	Science Technology Needs	Implementation Needs
- Mechanical—Manipulation	<p>H Compact, High-Capacity Manipulators ROBA-19-OL</p> <p>Ranking:* H-5-1 (\$1M;N)</p>	<p>Evolving Efficacy: High. Constrained access may require this technology.</p>	<p>Development: -Compact, high-output, electrical motors. -Design/fabrication/testing of compact arms.</p>	<p>-No unusual needs -Development Costs: \$1.0M</p>
- Mechanical—Mechanisms	<p>H Tool Caddies ROBA-21-OL</p> <p>Ranking:* H-4-1 (\$0.5M;N)</p> <p>M Stabilization/Support Mechanisms or Booms ROBA-22-OL</p> <p>Ranking:* M-3-1 (\$0.5M;N)</p>	<p>Demonstration Efficacy: High. Will increase efficiency of operations and minimize waste. Waste: Decontamination after use.</p> <p>Demonstration Efficacy: Medium. Some applications may require secondary support due to deteriorating condition of facility. Waste: Minimal. Some decon waste.</p>	<p>None</p> <p>Improvement: -Use of high-strength advanced materials.</p>	<p>-No unusual needs -Development Costs: \$0.5M</p> <p>-No unusual needs -Development Costs: \$0.5M</p>
- Mechanical—End-of-Arm-Tooling	<p>E End Effectors/Alternatives ROBA-23-OL</p> <p>Ranking:* E-5-2 (\$1M;N)</p> <p>M End-Effector Changeout Mechanisms ROBA-24-OL</p> <p>Ranking:* M-3-1 (\$0.5M;N)</p> <p>H General Gripper/Tool Interface ROBA-25-OL</p> <p>Ranking:* H-4-1 (\$0.5M;N)</p> <p>M Force Limiting/Compliant Mechanisms ROBA-26-OL</p> <p>Ranking:* M-3-1 (\$0.5M;N)</p>	<p>Demonstration (Predemonstration for multi-fingered grippers) Efficacy: High. An essential technology. Primary interface with tools. Waste: Minimal. TTP Match</p> <p>Demonstration Efficacy: Medium. Applications may be limited. Waste: Minimal decon waste. TTP Match</p> <p>Accepted Efficacy: High. Many potential applications for tool/sensor gripping. Waste: Minimal decon waste.</p> <p>Demonstration Efficacy: Medium. Limited applications in RA. Waste: Minimal</p>	<p>Improvement: -Robotic compatibility of tooling.</p> <p>None</p> <p>None</p> <p>None</p>	<p>- Extensive operator training. -Development Costs: \$1.0M</p> <p>-Integration and testing with specific robotic systems. -Development Costs: \$0.5M</p> <p>-No unusual needs. -Development Costs: \$0.5M</p> <p>-No unusual needs. -Development Costs: \$0.5M</p>
Controls—Algorithms	<p>E Control Modes ROBA-27-OL</p> <p>Ranking:* E-5-N (\$N;N)</p> <p>E Vehicle/Mobility-Driving ROBA-28-OL</p> <p>Ranking:* E-5-1 (\$0.5M;N)</p>	<p>Accepted for Teleoperation Demonstration for Preprogramming. Predemonstration for other modes Efficacy: High. An essential technology. Type of control mode will depend on application. Waste: None.</p> <p>Accepted Efficacy: High. An essential technology. Many potential applications. Waste: None.</p>	<p>Development: -Operator assistance technologies. -Sensor interpretation. -Task planning. Improvement: -Better human-machine interfaces.</p> <p>Development: -Integration of driving algorithms with human-machine interface. -Fuzzy logic driving algorithms.</p>	<p>-University level research. -Development Costs: \$N</p> <p>-Operator training. - Development Costs: \$0.5M</p>

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n for Remedial Action

Alternatives	Technologies	Status	Science Technology Needs	Implementation Needs
Controls—Algorithms				
H	Vehicle/Mobility-Navigation ROBA-29-OL Ranking:* H-4-1 (\$0.5M;N)	Demonstration Efficacy: Medium. Few applications in RA. Waste: None. TTP Match	Development: -Path planning with nonholonomic constraints. -Real-time sensor feedback.	-Operator training in Global Positioning Systems. -Development Costs: \$0.5M
H	Manipulation (Joint Control) ROBA-30-OL Ranking:* H-4-1 (\$0.5M;N)	Demonstration Efficacy: Medium. Applications may be limited. Usage assumes desired trajectory is known. Waste: None. TTP Match	Development: -Special purpose control algorithms.	-University level research. -Development Costs: \$0.5M
H	Manipulation (Cartesian Control) ROBA-31-OL Ranking:* H-4-1 (\$1M;N)	Demonstration Efficacy: Medium. Applications limited for RA. Operator interaction is more intuitive than other control schemes. Waste: None	None	-No unusual needs. -Development Costs: \$1.0M
H	Manipulation (Special Purpose Control) ROBA-32-OL Ranking:* H-4-2 (\$1.5M;N)	Predemonstration Efficacy: Medium. Will lead to higher efficiency and safety. Waste: None. TTP Match	Development: -Advanced testbeds for testing and evaluating candidate algorithms.	-Software development. -Development Costs: \$1.5M
M	Manipulation (Redundancy Control) ROBA-33-OL Ranking:* M-3-2 (\$2M;N)	Predemonstration Efficacy: Medium. Arms with greater than 6 D.O.F. may be required for constrained areas. Waste: None. TTP Match	Development: -Advanced testbeds for testing and evaluating candidate algorithms.	-Software development. -Development Costs: \$2.0M
M	Combined Mobility/Manipulation ROBA-34-OL Ranking:* M-2-2 (\$1M;N)	Evolving Efficacy: Low. Minimal improvements in efficiency could be realized. Waste: None.	Development: -Redundancy resolution. -real-time task planning.	-Software development. -Development costs: \$1.0M
H	Safety (Collision Avoidance) ROBA-35-OL Ranking:* H-4-1 (\$1M;N)	Accepted Efficacy: Medium. An increase in efficiency would be realized and potential damage to equipment minimized. Waste: None. TTP Match	None	-Use of customized sensor sites. -Development Costs: \$1.0M
H	Safety (Load/Rate Limiting) ROBA-36-OL Ranking:* H-3-1 (\$0.5M;N)	Accepted: Efficacy: Medium. An increase in efficiency would be realized and potential damage to equipment minimized. Waste: None.	Improvement: -Testing of load- and rate-limiting algorithms.	-Software development. -Development Costs: \$0.5M
E	Emergency Shutdown ROBA-37 Ranking:* E-4-1 (\$0.5M;N)	Accepted for Teleoperation Predemonstration for automated shutdown: Efficacy: High. An essential technology to prevent catastrophic damage to equipment. Waste: None.	None	-Software Development. -Development Costs: \$0.5M

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ion for Remedial Action

Alternatives	Technologies	Status	Science Technology Needs	Implementation Needs
Controls—Human/Machine Interface	E Console (Fixed/Mobile/Suitcase) ROBA-38-OL <i>Ranking:*</i> E-5-1 (\$0.5M;N)	Demonstrated for fixed or mobile stations. Evolving for suitcase control stations. Efficacy: High. An essential technology for use of robotics/automation. Waste: None.	Improvement: -Reliability and capacity of data links requires improvements.	-Improved human-machine interfaces. -Development costs: \$0.5M
	M Console (Data Handling Methods) ROBA-39-OL <i>Ranking:*</i> M-3-1 (\$1M;N)	Evolving Efficacy: Medium for RA activities. The need to process, store, and retrieve data is limited. Waste: None. TTP Match	Development: -Design of heterogeneous data base management systems. -Integration of heterogeneous data sources. -Data fusion.	-Development Costs: \$1.0M
	H Operator Interface (Command Input) ROBA-40-OL <i>Ranking:*</i> H-3-1 (\$0.5M;N)	Evolving Efficacy: High. Minimizes human error and increases operational efficiency. Waste: None. TTP Match	Development: -Language expansion. -Validation of eye-gaze measures/parameters. -Head tracking	-Specialized operator training. -Development Costs: \$0.5M
	H Operator Interface (Operator Assistance) ROBA-41-OL <i>Ranking:*</i> H-3-2 (\$1.5M;N)	Demonstration for most functions Evolving for other functions Efficacy: High. Will allow most efficient operation of "teleoperated" equipment. Waste: None. TTP Match	Development: -Establish validity and completeness of knowledge bases. -Conflict resolution. -Hybrid artificial intelligence architectures. -Dynamic allocation of functions. -Machine learning.	-Extensive operator training. -Development Costs: \$1.5M
	E Operator Interface (Status/Alert System) ROBA-42-OL <i>Ranking:*</i> E-5-1 (\$0.5M;N)	Demonstration for most functions Evolving for other functions Efficacy: High. An essential technology to prevent damage to equipment/tools/sensors. Waste: None. TTP Match	Development: -Display navigation. -Sensor/data fusion.	-Extensive operator training. -Development Costs: \$0.5M
Sensors—Perception	E Vision/Aural Systems ROBA-43-OL <i>Ranking:*</i> E-5-1 (\$1M;N)	Demonstration for 3-D and HDTV. Predemonstration for directional aural. Efficacy: High. An essential technology for Robotics/Automation. Waste: None.	Development: -Sensor fusion. -Increased processing speed. -Advanced visualization.	-No unusual needs -Development Costs: \$1.0M
	M Range Finders ROBA-44-OL <i>Ranking:*</i> M-3-2 (\$1.5M;N)	Accepted. Efficacy: Medium. Applications are limited. Waste: None. TTP Match	Improvement: -Speed/accuracy improvement.	-No unusual needs -Development Costs: \$1.5M
	M Proximity Probes ROBA-45-OL <i>Ranking:*</i> M-2-2 (\$1M;N)	Predemonstration Efficacy: Medium. Alternatives to probes may be more cost effective. Waste: None. TTP Match	Improvement: -Increased range and improved presentation to operator.	-No unusual needs -Development Costs: \$1.0M

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EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements
<ul style="list-style-type: none"> • Clean Up Legacy Waste • Prevent Future Insult • Develop Environmental Stewardship 	<p>Buried Waste WAG 1, WAG 3, WAG 4, WAG 5, WAG 6, WAG 7</p> <p>Ground Water/Surface Water WAG 2, WAG 3, WAG 4, WAG 5, WAG 6, WAG 8, WAG 9, WAG 10, WAG 11</p> <p>Hydrofracture WAG 10</p> <p>Impoundments WAG 1, WAG 5, WAG 8, WAG 9</p> <p>Pipelines WAG 1, WAG 4, WAG 5, WAG 7, WAG 8</p> <p>Pits and Trenches WAG 7</p> <p>Soils/Sediments WAG 1, WAG 2, WAG 3, WAG 4, WAG 5, WAG 6, WAG 7, WAG 11, WAG 13</p> <p>Tanks WAG 1, WAG 5, WAG 8, WAG 9</p>	<p>Robotics/automation (R/A) is a cross-cutting technology that provides support to characterization, decontamination, and dismantlement activities. Specifically support is provided for the following tasks.</p> <p>I. Characterization R/A provides methods of deploying sensors and instruments required for in-situ characterization, monitoring, and surveying as described by the Characterization Data Sheets contained in Vol. 3. R/A provides methods for deploying tools to collect and prepare samples for subsequent analysis in analytical laboratories. These technologies are described in ROBA-57 and -59-OL. R/A provides the technologies required for the automation of analytical laboratories as described in ROBA-55 and -56-OL.</p> <p>II. Waste Retrieval R/A provides the vehicles, mobile platforms, or excavation systems necessary to retrieve radiologically or chemically hazard wastes or soils from waste fields or impoundments. Mobile platforms suitable for these tasks are described in ROBA-1-OL.</p> <p>III. Waste Sorting and Packaging R/A provides the bridge-mounted robotic systems (ROBA-8-OL), the manipulation systems, (ROBA-16-OL), and the End-of-Arm Tooling (ROBA-23 through -26-OL) required for the sorting and repackaging of RH-TRU waste.</p> <p>IV. Surveillance and Inspection R/A provides the vehicles or mobile platforms (ROBA-1-OL) and sensors (ROBA-43 through -46-OL) required for the periodic surveillance and inspection of waste containers in above-ground storage areas.</p>	<p>Refer to Vol. 1, Pt. A, Chap. 6, for potentially applicable proposed and promulgated environmental laws, signed and pending agreements for ORR, radiation protection standards, DOE Orders, and nonregulatory guidance. As site- and waste-specific characteristics are provided for each technology, specific regulatory requirements will be specified.</p>	<p>Robotics/Automation</p>
<p>EM Problems</p> <ul style="list-style-type: none"> • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM) 				

n for Remedial Action

Alternatives	Technologies	Status	Science Technology Needs	Implementation Needs
Sensors—Perception	M Force/Torque Sensors ROBA-46-OL <i>Ranking:*</i> M-2-1 (\$0.5M;N)	Demonstration Efficacy: Medium. Applications for RA are very limited. Waste: None TTP Match	Improvement: -Testing of force sensing systems.	-No unusual needs -Development Costs: \$0.5M
	E Position/Velocity Sensors ROBA-48-OL <i>Ranking:*</i> E-5-1 (\$0.5M;N)	Accepted Efficacy: High for analytical laboratory applications or sensor sweeps. Waste: None.	None	-No unusual needs -Development Costs: \$0.5M
	H Force/Torque ROBA-50-OL <i>Ranking:*</i> H-3-1 (\$0.5M;N)	Demonstration Efficacy: Medium. Few applications in RA activities. The need for force or torque control to prevent damage is limited. Waste: None. TTP Match	Improvement: -Impulse force resolution. -Stability.	-No unusual needs -Development Costs: \$0.5M
	H Proximity Probes as Control Sensors ROBA-51-OL <i>Ranking:*</i> H-3-1 (\$1M;N)	Accepted for small volumes. Predemonstration for large volumes. Efficacy: Medium. Alternatives to sensors may be more cost effective. Waste: None.	Improvement: -Increased range and better signal quality.	-No unusual needs -Development Costs: \$1.0M
Sensors—Control	H Tooling Sensors ROBA-52-OL <i>Ranking:*</i> H-3-1 (\$0.5M;N)	Predemonstration Efficacy: High. This technology is required to prevent damage to tools or sensors. Waste: None. TTP Match	Development: -Development/testing of tactile sensing sensors, force sensors, and proximity sensors.	-Operator training -Development Costs: \$0.5M
	E Field Hardening ROBA-53-OL <i>Ranking:*</i> E-5-1 (\$0.5M;N)	Demonstration Efficacy: Medium. The primary environmental concern in RA is high radiation fields as described in ROBA-54-OL. <i>Ranking:*</i> The ability to be decontaminated is essential for mechanical devices. Waste: None TTP Match	None	-Testing of hardened systems. -Development Costs: \$0.5M
	M Radiation Hardening ROBA-54-OL <i>Ranking:*</i> M-3-2 (\$2M;N)	Demonstration Efficacy: High. An essential technology for many RA activities, particularly reactors and hot cells. Waste: None. TTP Match	None	-Extensive radiation testing of existing electronic chips. -Development Cost: \$2.0M
	E Integrated Automated Analytical Laboratory ROBA-55-OL <i>Ranking:*</i> E-5-2 (\$3M;N)	Predemonstration for hardware systems. Evolving for data interpretation. Efficacy: High. High sample loading in analytical laboratories require maximum use of automation Waste: None. TTP Match	Development: -Development of Standard Laboratory Modules (SLM) for Sample Preparation, Analytical Instruments, and Data Interpretation.	-Extensive testing of SLM's. -EPA approval of SLM -Development Costs: \$3.0M
Other Technologies				

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EM Goals	ORNL Problems	Problem Areas/Constituents	Reference Requirements	Subelements
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<p>EM Problems</p> <ul style="list-style-type: none"> • Facility Decontamination and Decommissioning (D&D) • Remedial Action (RA)—Soils, Ground Water and Surface Water • Waste Management (WM) 				

ion for Remedial Action

Alternatives	Technologies	Status	Science Technology Needs	Implementation Needs
Other Technologies	E Information Management for Sample Handling ROBA-56-OL <i>Ranking:*</i> <i>E-5-1 (\$1M;N)</i>	Demonstration Efficacy: High. Waste: None. TTP Match	Development: -Automatic data entry systems. -Improved reliability and auditability.	-No unusual needs -Development Costs: \$1.0M
	E Sample Collection ROBA-57-OL <i>Ranking:*</i> <i>E-5-1 (\$1.5M;N)</i>	Evolving Efficacy: Medium. Alternative, but slower methods of sample collection are available and may be more cost effective. Waste: None. TTP Match	Development: -Mobile platforms to deploy and manipulate sample collection tools. -Suitable robotic end-effectors.	-No unusual needs -Development Costs: \$1.5M
	M Characterization Sensor Integration ROBA-58-OL <i>Ranking:*</i> <i>M-5-2 (\$1M;N)</i>	Demonstration Efficacy: Low. May not be cost effective. Waste: None. TTP Match	Development: -Signal conditioning. -Data/Signal transmission.	-No unusual needs. -Development Costs: \$1.0M
	E Sample Preparation ROBA-59-OL <i>Ranking:*</i> <i>E-5-1 (\$1M;N)</i>	Evolving Efficacy: Medium. Will minimize work to be performed in analytical laboratory. Waste: Usual amount of waste normally generated in sample preparation operations. TTP Match	None	-Adaptation of current sample preparation tools to robotic devices. -Development Costs: \$1.0M

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